UNIVERSITY OF CALICUT
SCHOOL OF DISTANCE EDUCATION
Study Material
CORE COURSE
B.Sc. in Counselling Psychology
I Semester

BASIC PSYCHOLOGICAL PROCESS
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Layout: Computer Section, SDE

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Module 1
INTRODUCTION

The Definition of "Psychology"
The word "psychology" is the combination of two terms - study (ology) and soul (psyche), or mind. The derivation of the word from Latin gives it this clear and obvious meaning.

"Psyche" is defined as:
1. The spirit or soul.
2. The human mind.
3. In psychoanalysis, the mind functioning as the center of thought, emotion, and behavior.

And defining "soul":

Basic Psychological Processes
1. the spiritual or immortal elements in a person.
2. a person's mental or moral or emotional nature.

Most of us would agree we have a "psyche" per the above definitions in the sense of mind, thought, and emotions. Most would also agree they have a "soul" per the second definition above relating to man's mental, moral or emotional nature. We might all have different notions about what these ultimately are, but few could sanely disagree they exist.

According to American Psychological Association (APA), *Psychology is the scientific study of the behavior of individuals and their mental processes.*

### Areas of Psychology

The American Psychological Association (APA) is devoted to the study and promotion of psychology. Because psychology is such a diverse subject, a number of different specialty areas and perspectives have emerged. The APA currently contains 53 separate divisions, each devoted to a specific area within psychology. Main divisions of them are explained below:

- **General Psychology**

  General psychology offers an introduction and overview of the field of psychology. General psychology usually covers the history of psychology, basic psychology research methods, development, emotions, motivations, personality, perception, and much more. The topics covered in an introduction to psychology course encompass the subject matter of general psychology.

- **Teaching of Psychology**

  This division of the APA strives to help teachers and students of psychology access the best resources and information needed for the teaching of psychology. The division offers free access to a number of teaching materials and promotes excellence in teaching through awards for excellence, educational lectures, and teaching programs.

- **Experimental Psychology**

  Experimental psychology, also known as scientific psychology, looks at the human mind and behavior using scientific method, research, experimentation, and statistics. Subfields of experimental psychology include:

    - **Social Psychology**: Social psychology seeks to explain and understand social behavior. Learn more about group behavior, how individuals interact with others, and social influences on decision making.

    - **Research Methods**: To learn more about research methods, experimental design, and statistical analysis

    - **Sensation and Perception**: To learn more about sensation and perception. Find information on the visual, auditory, cutaneous, and chemical sensory systems

    - **Biopsychology**: While our mind plays a role in our physical well-being, our biological processes also influence our mental health. Area of Biopsychology is to learn more about how the brain and nervous system impact our behavior, thoughts, and feelings.
• **Evaluation, Measurement, and Statistics**

Evaluation, Measurement, and Statistics is concerned with promoting high standards in both research and practical application of psychological assessment, evaluation, measurement, and statistics.

• **Behavioral Neuroscience and Comparative Psychology**

Behavioral Neuroscience and Comparative Psychology members are devoted to studying the biology of behavior. Their focus is on behavior and its relation to perception, learning, memory, cognition, motivation, and emotion. Behavioral neuroscientists study the brain in relation to behavior, its evolution, functions, abnormalities, and repair, as well as its interactions with the immune system, cardiovascular system, and energy regulation systems. Comparative psychologists study the behavior of humans and other animals, with a special eye on similarities and differences that may shed light on evolutionary and developmental processes.

• **Developmental Psychology**

Developmental Psychology promotes research in the field of developmental psychology and high standards in the application of scientific knowledge to educational, child care, policy, and related settings.

• **Society for Personality and Social Psychology**

Society for Personality and Social Psychology seeks to advance the progress of theory, basic and applied research, and practice in the field of personality and social psychology. Members are employed in academia and private industry or government, and all are concerned with how individuals affect and are affected by other people and by their social and physical environments.

• **Clinical psychology**

This is an area of integration of science, theory and clinical knowledge for the purpose of understanding, preventing, and relieving psychologically based distress or dysfunction and to promote subjective well-being and personal development. Central to its practice are psychological assessment and psychotherapy.

• **Industrial and organizational psychology**

This area applies psychology to organizations and the workplace. Industrial-organizational psychologists contribute to an organization's success by improving the performance and well-being of its people. An I-O psychologist researches and identifies how behaviors and attitudes can be improved through hiring practices, training programs, and feedback systems.

• **Educational psychology**

It is the area of study of how humans learn in educational settings, the effectiveness of educational interventions, the psychology of teaching, and the social psychology of schools as organizations.
Educational psychology is concerned with how students learn and develop, often focusing on subgroups such as gifted children and those subject to specific disabilities.

- **Military psychology**

  It is the research, design and application of psychological theories and experimentation data towards understanding, predicting and countering behaviours either in own, friendly or enemy forces or civilian population that may be undesirable, threatening or potentially dangerous to the conduct of military operations.

- **Consumer psychology**

  It is the study of when, why, how, and where people do or do not buy product. It blends elements from psychology, sociology, social anthropology and economics. It attempts to understand the buyer decision making process, both individually and in groups. It studies characteristics of individual consumers such as demographics and behavioural variables in an attempt to understand people's wants. It also tries to assess influences on the consumer from groups such as family, friends, reference groups, and society in general. Customer psychology is based on consumer buying behaviour, with the customer playing the three distinct roles of user, payer and buyer. Relationship marketing is an influential asset for customer behaviour analysis as it has a keen interest in the re-discovery of the true meaning of marketing through the re-affirmation of the importance of the customer or buyer.

- **Community psychology**

  This area deals with the relationships of the individual to communities and the wider society. Community psychologists seek to understand the quality of life of individuals, communities, and society. Their aim is to enhance quality of life through collaborative research and action. Community psychology makes use of various perspectives within and outside of psychology to address issues of communities, the relationships within them, and people's attitudes about them. Through collaborative research and action, community psychologists seek to understand and to enhance quality of life for individuals, communities, and society.

- **Humanistic psychology**

  It is a psychological perspective which rose to prominence in 1960s drawing on existentialist thought coupled with phenomenology and an emphasis on the importance of personal responsibility, free will, and self-actualization.

- **Environmental psychology**

  It is an interdisciplinary field focused on the interplay between humans and their surroundings. The field defines the term environment broadly, encompassing natural environments, social settings, built environments, learning environments, and informational environments. Since its conception, the field has been committed to the development of a discipline that is both value oriented and problem oriented, prioritizing research aiming at solving complex environmental problems in the
pursuit of individual well-being within a larger society. When solving problems involving human-environment interactions, whether global or local, one must have a model of human nature that predicts the environmental conditions under which humans will behave in a decent and creative manner. With such a model one can design, manage, protect and/or restore environments that enhance reasonable behavior, predict what the likely outcome will be when these conditions are not met, and diagnose problem situations.

- **Health psychology**

  It is the field concerned with understanding how biology, behavior, and social context influence health and illness. Health psychologists work alongside other medical professionals in clinical settings, work on behaviour change in public health promotion, teach at universities, and conduct research. Although its early beginnings can be traced to the kindred field of clinical psychology, four different divisions within health psychology and one allied field have developed over time. The four divisions include clinical health psychology, public health psychology, community health psychology, and critical health psychology.

- **Feminist psychology**

  It is a form of psychology centered on societal structures, and gender. Feminist psychology critiques the fact that historically psychological research has been done from a male perspective with the view that males are the norm. Feminist psychology is oriented on the values and principles of feminism. It incorporates gender and the ways women are affected by issues resulting from it. Gender issues can include the way people identify their gender how they have been affected by societal structures related to gender, the role of gender in the individual’s life, and any other gender related issues. The objective behind this field of study is to understand the individual within the larger social and political aspects of society. Feminist Psychology puts a strong emphasis on gender equality and women's rights.

- **Rehabilitation Psychology**

  Rehabilitation Psychology seeks to bring together all APA members interested in the psychological aspects of disability and rehabilitation, to educate the public on issues related to disability and rehabilitation, and to develop high standards and practices for professional psychologists who work in this field. Members may be involved in clinical service, research, teaching, or administration.

- **Consulting Psychology**

  Societies of Consulting Psychology members share an interest in the consultative process including applied activities, research and evaluation, and education and training. The Division serves as a forum for consultation skill, theory and knowledge development, and dissemination. It provides a professional home for those who have an identity as consulting psychologists.

- **Sports psychology**
The psychological and mental factors that effect and are affected by participation and performance in sport, exercise, and physical activity. It is also a specialization within the brain psychology and kinesiology that seeks to understand psychological/mental factors that affect performance in sports, physical activity, and exercise and apply these to enhance individual and team performance. It deals with increasing performance by managing emotions and minimizing the psychological effects of injury and poor performance. Some of the most important skills taught are goal setting, relaxation, visualization, self-talk, awareness and control, concentration, confidence, using rituals, attribution training, and periodization.

- Clinical Neuropsychology

Clinical Neuropsychology provides a scientific and professional forum for individuals interested in the study of the relationships between the brain and human behavior. It promotes interdisciplinary interaction among various interest areas including physiological cognitive, developmental, clinical rehabilitation, school, forensic, and health psychology.

- Family Psychology

The Society for Family Psychology provides a home for psychologists interested in families in their many forms. Clinical, scientific, educational, and public policy perspectives are well represented in the wide range of divisional activities.

- Media Psychology

Media Psychology focuses on the roles psychologists play in various aspects of the media, including, but not limited to, radio, television, film, video, newsprint, magazines, and newer technologies. It seeks to promote research into the impact of media on human behavior; to facilitate interaction between psychology and media representatives; to enrich the teaching, training, and practice of media psychology; and to prepare psychologists to interpret psychological research to the lay public and to other professionals.

- Peace Psychology
Society for the Study of Peace, Conflict, and Violence: Peace Psychology Division works to promote peace in the world at large and within nations, communities, and families. It encourages psychological and multidisciplinary research, education, and training on issues concerning peace, nonviolent conflict resolution, reconciliation and the causes, consequences and prevention of violence and destructive conflict. The Division fosters communication among researchers, teachers, and practitioners who are working on these issues and are applying the knowledge and methods of psychology in the advancement of peace and prevention of violence and destructive conflict. The Division seeks to make connections between all areas of psychological work and peace and welcomes participation from all areas of the discipline.

- **International Psychology**

International Psychology seeks to develop a psychological science and practice that is contextually informed, culturally inclusive, serves the public interest, and promotes global perspectives within and outside of APA. The Division of International Psychology represents the interest of all psychologists who foster international connections among psychologists, engage in multicultural research or practice, apply psychological principles to the development of public policy, or are otherwise concerned with individual and group consequences of global events.

- **Pediatric Psychology**

Society of Pediatric Psychology members are part of an integrated field of science and practice in which the principles of psychology are applied within the context of pediatric health. The field aims to promote the health and development of children, adolescents, and their families through use of evidence-based methods. Areas of expertise within the field include, but are not limited to: psychosocial, developmental and contextual factors contributing to the etiology, course and outcome of pediatric medical conditions; assessment and treatment of behavioral and emotional concomitants of illness, injury, and developmental disorders; prevention of illness and injury; promotion of health and health-related behaviors; education, training and mentoring of psychologists and providers of medical care; improvement of health care delivery systems and advocacy for public policy that serves the needs of children, adolescents, and their families.

- **Pharmacotherapy**
American Society for the Advancement of Pharmacotheraphy (ASAP) was created to enhance psychological treatments combined with psychopharmacological medications. It promotes the public interest by working for the establishment of high quality statutory and regulatory standards for psychological care. The Division encourages the collaborative practice of psychological and pharmacological treatments with other health professions. It seeks funding for training in psychopharmacology and pharmacotherapy from private and public sources, e.g., federal Graduate Medical Education programs. It facilitates increased access to improved mental health services in federal and state demonstration projects using psychologists trained in psychopharmacology.

**Branches of Psychology**

There are a number of unique and distinctive branches of psychology. Each branch looks at questions and problems from a different perspective. While each branch has its own focus on psychological problems or concerns, all areas share a common goal of studying and explaining human thought and behavior. The following are some of the major branches of psychology within the field today.

**Abnormal Psychology**

Abnormal psychology is the area that looks at psychopathology and abnormal behavior. The term covers a broad range of disorders, from depression to obsession-compulsion to sexual deviation and many more. Counselors, clinical psychologists and psychotherapists often work directly in this field.

**Behavioral Psychology**

Behavioral psychology, also known as behaviorism, is a theory of learning based upon the idea that all behaviors are acquired through conditioning. While this branch of psychology dominated the field during the first part of the twentieth century, it became less prominent during the 1950s. However, behavioral techniques remain a mainstay in therapy, education and many other areas.

**Biopsychology**

The branch of psychology focused on the study of how the brain influences behavior is often known as biopsychology, although it has also been called physiological psychology, behavioral neuroscience and psychobiology.

**Cognitive Psychology**

Cognitive psychology is the branch of psychology that focuses on internal states, such as motivation, problem solving, decision-making, thinking and attention. This area of psychology has continued to grow since it emerged in the 1960s.

**Comparative Psychology**

Basic Psychological Processes
Comparative psychology is the branch of psychology concerned with the study of animal behavior. The study of animal behavior can lead to a deeper and broader understanding of human psychology.

**Developmental Psychology**

This branch of psychology looks at development throughout the lifespan, from childhood to adulthood. The scientific study of human development seeks to understand and explain how and why people change throughout life. This includes all aspects of human growth, including physical, emotional, intellectual, social, perceptual and personality development. Topics studied in this field include everything from prenatal development to Alzheimer's disease.

**Educational Psychology**

Educational psychology is the branch of psychology concerned with schools, teaching psychology, educational issues and student concerns. Educational psychologists often study how students learn or work directly with students, parents, teachers and administrators to improve student outcomes.

**Experimental Psychology**

Experimental psychology is the branch of psychology that utilizes scientific methods to research the brain and behavior. Many of these techniques are also used by other areas in psychology to conduct research on everything from childhood development to social issues.

**Forensic Psychology**

Forensic psychology is a specialty area that deals with issues related to psychology and the law. Forensic psychologists perform a wide variety of duties, including providing testimony in court cases, assessing children in suspected child abuse cases, preparing children to give testimony and evaluating the mental competence of criminal suspects.

**Personality Psychology**

This branch of psychology is focused on the patterns of thoughts, feelings, and behavior that make a person unique. Some of the best-known theories in psychology have arisen from this field, including Freud's psychoanalytic theory of personality and Erikson's theory of psychosocial development.

**Social Psychology**

Social psychology seeks to explain and understand social behavior and looks at diverse topics including group behavior, social interactions, leadership, nonverbal communication and social influences on decision-making.

**Approaches to study Psychological process**

The study of psychology in philosophical context dates back to the ancient civilizations of Egypt, Greece, China, India, and Persia. Historians point to the writings of ancient Greek philosophers, such Thales, Plato, and Aristotle (esp. De Anima), as the first significant work to be rich in psychology-related thought. In 1802, French physiologist Pierre Cabanis sketched out the beginnings of physiological psychology with his essay, he interpreted the mind in light of his previous studies of biology, arguing that sensibility and soul are properties of the nervous system.
German physician Wilhelm Wundt is known as the "father of experimental psychology," because he founded the first psychological laboratory, at Leipzig University in 1879. Wundt focused on breaking down mental processes into the most basic components, starting a school of psychology that is called structuralism. Edward Titchener was another major structuralist thinker. Functionalism formed as a reaction to the theories of the structuralist school of thought and was heavily influenced by the work of the American philosopher and psychologist William James. In his seminal book, Principles of Psychology, published in 1890, he laid the foundations for many of the questions that psychologists would explore for years to come. Other major functionalist thinkers included John Dewey and Harvey Carr. Other 19th-century contributors to the field include the German psychologist Hermann Ebbinghaus, a pioneer in the experimental study of memory who discovered the learning and forgetting curve at the University of Berlin; and the Russian-Soviet physiologist Ivan Pavlov, who discovered classical conditioning theory of learning whilst investigating the digestive system of dogs.

Starting in the 1950s, the experimental techniques set forth by Wundt, James, Ebbinghaus, and others would be reiterated as experimental psychology became increasingly cognitive concerned with information and its processing and, eventually, constituted a part of the wider cognitive science. In its early years, this development had been seen as a "revolution", as it both responded to and reacted against strains of thought including psychodynamics and behaviorism that had developed in the meantime.

The Biological Approach

The study of physiology played a major role in the development of psychology as a separate science. Today, this perspective is known as biological psychology. Sometimes referred to as biopsychology or physiological psychology, this perspective emphasizes the physical and biological bases of behavior. This perspective has grown significantly over the last few decades, especially with advances in our ability to explore and understand the human brain and nervous system. Tools such as MRI scans and PET scans allow researchers to look at the brain under a variety of conditions. Scientists can now look at the effects of brain damage, drugs, and disease in ways that were simply not possible in the past.

The Psychodynamic Approach

The psychodynamic approach originated with the work of Sigmund Freud. This perspective emphasizes the role of the unconscious mind, early childhood experiences, and interpersonal relationships to explain human behavior and to treat people suffering from mental illnesses. There are many different ways to think about human thought and behavior. The many perspectives in modern psychology provide researchers and students a way to approach different problems and find new ways to explain and predict human behavior as well as develop new treatment approaches for problem behaviors.

Freud's understanding of the mind was largely based on interpretive methods, introspection and clinical observations, and was focused in particular on resolving unconscious conflict, mental distress and psychopathology. Freud's theories became very well-known, largely because they tackled subjects such as sexuality, repression, and the unconscious mind as general aspects of
psychological development. These were largely considered taboo topics at the time, and Freud provided a catalyst for the ideas to be openly discussed in polite society. Clinically, Freud helped to pioneer the method of free association and a therapeutic interest in dreams.

Freud had a significant influence on Swiss psychiatrist Carl Jung, whose analytical psychology became an alternative form of depth psychology. Other well-known psychoanalytic thinkers of the mid-twentieth century included German-American psychologist Erik Erickson, Austrian-British psychoanalyst Melanie Klein, English psychoanalyst and physician D. W. Winnicott, German psychologist Karen Homey, German-born psychologist and philosopher Erich Fromm, English psychiatrist John Bowlby and Sigmund Freud's daughter, psychoanalyst Anna Freud. Throughout the 20th century, psychoanalysis evolved into diverse schools of thought, most of which may be classed as Neo-Freudians.

Behaviorist Approach

Behaviorism became the dominant school of thought during the 1950s. American behaviorism was founded in the early 20th century by John B. Watson, and embraced and extended by Edward Thorndike, Clark L. Hull, Edward C. Tolman, and later B. F. Skinner. Behaviorism is focused on observable behavior. It theorizes that all behavior can be explained by environmental causes, rather than by internal forces. Theories of learning including classical conditioning and operant conditioning were the focus of a great deal of research. Much research was done with laboratory-based animal experimentation, which was increasing in popularity as physiology grew more sophisticated.

Skinner's behaviorism shared with its predecessors a philosophical inclination toward positivism and determinism. Skinner maintained that his view of science could be traced back to Ernst Mach, who held that the research methods most faithful to their scientific orientation would yield "the pursuit of tools for the control of life problems rather than a search for timeless truths". He believed that the contents of the mind were not open to scientific scrutiny and that scientific psychology should emphasize the study of observable behavior. He focused on behavior–environment relations and analyzed overt and covert (i.e., private) behavior as a function of the organism interacting with its environment. Therefore, they often rejected or deemphasized dualistic explanations such as "mind" or "consciousness"; and, in lieu of probing an "unconscious mind" that underlies unawareness, they spoke of the "contingency-shaped behaviors" in which unawareness becomes outwardly manifest.

Among the American behaviorists' most famous creations are John B. Watson's Little Albert experiment, which applied classical conditioning to the developing human child, and Skinner's notion of operant conditioning, which acknowledged that human agency could affect patterns and cycles of environmental stimuli and behavioral responses. American linguist Noam Chomsky's critique of the behaviorist model of language acquisition is regarded by many as a key factor in the decline of behaviorism's prominence. But Skinner's behaviorism has not died, perhaps in part because it has generated successful practical applications. The fall of behaviorism as an overarching model in psychology, however, gave way to a new dominant paradigm: cognitive approaches.

Cognitive Approach
Cognitive psychology is the branch of psychology that studies mental processes including how people think, perceive, remember, and learn. As part of the larger field of cognitive science, this branch of psychology is related to other disciplines including neuroscience, philosophy, and linguistics.

Noam Chomsky helped to ignite a "cognitive revolution" in psychology when he criticized the behaviorists' notions of "stimulus", "response", and "reinforcement", arguing that such ideas—which Skinner had borrowed from animal experiments in the laboratory—could be applied to complex human behavior, most notably language acquisition, in only a vague and superficial manner. The postulation that humans are born with the instinct or "innate facility" for acquiring language posed a challenge to the behaviorist position that all behavior (including language) is contingent upon learning and reinforcement. Social learning theorists such as Albert Bandura argued that the child's environment could make contributions of its own to the behaviors of an observant subject.

Meanwhile, accumulating technology helped to renew interest and belief in the mental states and representations i.e., the cognition that had fallen out of favor with behaviorists. English neuroscientist Charles Sherrington and Canadian psychologist Donald O. Hebb used experimental methods to link psychological phenomena with the structure and function of the brain. With the rise of computer science and artificial intelligence, analogies were drawn between the processing of information by humans and information processing by machines. Research in cognition had proven practical since World War II, when it aided in the understanding of weapons operation. By the late 20th century, though, cognitivism had become the dominant paradigm of mainstream psychology, and cognitive psychology emerged as a popular branch.

Assuming both that the covert mind should be studied and that the scientific method should be used to study it, cognitive psychologists set such concepts as "subliminal processing" and "implicit memory" in place of the psychoanalytic "unconscious mind" or the behavioristic "contingency-shaped behaviors". Elements of behaviorism and cognitive psychology were synthesized to form the basis of cognitive behavioral therapy, a form of psychotherapy modified from techniques developed by American psychologist Albert Ellis and American psychiatrist Aaron T. Beck. Cognitive psychology was subsumed along with other disciplines, such as philosophy of mind, computer science, and neuroscience, under the umbrella discipline of science. Another of the most influential theories from this school of thought was the stages of cognitive development theory proposed by Jean Piaget.

Humanistic Approach

Humanistic psychology was developed in the 1950s in reaction to both behaviorism and psychoanalysis. By using phenomenology, inter subjectivity and first-person categories, the humanistic approach sought to glimpse the whole person not just the fragmented parts of the personality or cognitive functioning. Humanism focused on fundamentally and uniquely human issues, such as individual free will, personal growth, self-actualization, self-identity, death, aloneness, freedom, and meaning. The humanistic approach was distinguished by its emphasis on subjective meaning, rejection of determinism, and concern for positive growth rather than pathology. Some of the founders of the humanistic school of thought were American...
psychologists Abraham Maslow, who formulated a hierarchy of human needs, and Carl Rogers, who created and developed client-centered therapy. Later, positive psychology opened up humanistic themes to scientific modes of exploration.

Methods to study Psychology

Experimental method

Experiment is the step in the scientific method that arbitrates between competing models or hypotheses. Experimentation is also used to test existing theories or new hypotheses in order to support them or disprove them. An experiment or test can be carried out using the scientific method to answer a question or investigate a problem. First an observation is made. Then a question is asked, or a problem arises. Next, a hypothesis is formed. Then experiment is used to test that hypothesis. The results are analyzed, a conclusion is drawn, sometimes a theory is formed, and results are communicated through research papers. A good experiment usually tests a hypothesis. However, an experiment may also test a question or test previous results.

It is important that one knows all factors in an experiment. It is also important that the results are as accurate as possible. If an experiment is carefully conducted, the results usually either support or disprove the hypothesis. An experiment can never "prove" a hypothesis, it can only add support. However, one repeatable experiment that provides a counterexample can disprove a theory or hypothesis. An experiment must also control the possible confounding factors -- any factors that would mar the accuracy or repeatability of the experiment or the ability to interpret the results.

Types of experiments

Controlled experiments

An experiment or test or show can be carried out by using the scientific method. The steps are making an observation, ask a question, form a hypothesis, test the hypothesis, analyze the results, draw a conclusion, and communicate results. The reason a hypothesis is tested is so that it can be confirmed, denied, or refined, with the knowledge currently available. The test has one variable. The control is the regular group and experimental is the group with the variable added to it. To demonstrate a cause and effect hypothesis, an experiment must often show that, for example, a phenomenon occurs after a certain treatment is given to a subject, and that the phenomenon does not occur in the absence of the treatment.

A controlled experiment generally compares the results obtained from an experimental sample against a control sample, which is practically identical to the experimental sample except for the one aspect whose effect is being tested (the independent variable). A good example would be a drug trial. The sample or group receiving the drug would be the experimental one; and the one receiving the placebo would be the control one. In many laboratory experiments it is good practice to have several replicate samples for the test being performed and have both a positive control and a negative control. The results from replicate samples can often be averaged, or if one of the
replicates is obviously inconsistent with the results from the other samples, it can be discarded as being the result of an experimental error (some step of the test procedure may have been mistakenly omitted for that sample). Most often, tests are done in duplicate or triplicate. A positive control is a procedure that is very similar to the actual experimental test but which is known from previous experience to give a positive result. A negative control is known to give a negative result. The positive control confirms that the basic conditions of the experiment were able to produce a positive result, even if none of the actual experimental samples produce a positive result. The negative control demonstrates the base-line result obtained when a test does not produce a measurable positive result; often the value of the negative control is treated as a "background" value to be subtracted from the test sample results. Sometimes the positive control takes the quadrant of a standard curve.

An example that is often used in teaching laboratories is a controlled protein assay. Students might be given a fluid sample containing an unknown (to the student) amount of protein. It is their job to correctly perform a controlled experiment in which they determine the concentration of protein in fluid sample (usually called the "unknown sample"). The teaching lab would be equipped with a protein standard solution with a known protein concentration. Students could make several positive control samples containing various dilutions of the protein standard. Negative control samples would contain all of the reagents for the protein assay but no protein. In this example, all samples are performed in duplicate. The assay is a colorimetric assay in which a spectrophotometer can measure the amount of protein in samples by detecting a colored complex formed by the interaction of protein molecules and molecules of an added dye. In the illustration, the results for the diluted test samples can be compared to the results of the standard curve (the blue line in the illustration) in order to determine an estimate of the amount of protein in the unknown sample.

Controlled experiments can be performed when it is difficult to exactly control all the conditions in an experiment. In this case, the experiment begins by creating two or more sample groups that are probabilistically equivalent, which means that measurements of traits should be similar among the groups and that the groups should respond in the same manner if given the same treatment. This equivalency is determined by statistical methods that take into account the amount of variation between individuals and the number of individuals in each group. In fields such as microbiology and chemistry, where there is very little variation between individuals and the group size is easily in the millions, these statistical methods are often bypassed and simply splitting a solution into equal parts is assumed to produce identical sample groups.

Once equivalent groups have been formed, the experimenter tries to treat them identically except for the one variable that he or she wishes to isolate. Human experimentation requires special safeguards against outside variables such as the placebo effect. Such experiments are generally double blind, meaning that neither the volunteer nor the researcher knows which individuals are in the control group or the experimental group until after all of the data have been collected. This ensures that any effects on the volunteer are due to the treatment itself and are not a response to the knowledge that he is being treated.

In human experiments, a subject (person) may be given a stimulus to which he or she should respond. The goal of the experiment is to measure the response to a given stimulus by a test method.

Natural experiments

A natural experiment is an observational study in which the assignment of treatments to subjects has been haphazard: That is, the assignment of treatments to subjects has not been made by experimenters (and certainly not by randomization). Natural experiments are most useful when there has been a clearly defined and large change in the treatment (or exposure) to a clearly defined
subpopulation, so that changes in responses may be plausibly attributed to the change in treatments (or exposure). Natural experiments are considered for study designs whenever controlled experimentation is difficult, such as in epidemiology and economics. One of the most famous natural experiments was the 1854 Broad Street cholera outbreak in London, England. On 31 August 1854, a major outbreak of cholera struck Soho. Over the next three days 127 people near Broad Street died. By the end of the outbreak 616 people died. The physician John Snow identified the source of the outbreak as the nearest public water pump, which he identified using a map of deaths and illness. In this example, Snow discovered a strong association between the use of the water and deaths and illnesses due to cholera. Snow found that the water company (the Southwark and Vauxhall Company) that supplied water to districts with high attack rates obtained the water from the Thames downstream from where raw sewage was discharged into the river. By contrast, districts that were supplied water by the Lambeth Company, which obtained water upstream from the points of sewage discharge, had low attack rates. The water supply in mid-Nineteenth Century London was not developed by scientists studying cholera, and so exposure to this well may be considered a haphazard event. Therefore, this exposure has been recognized as being a natural experiment.

Field experiment
Field experiments are so named in order to draw a contrast with laboratory experiments. Often used in the social sciences, and especially in economic analyses of education and health interventions, field experiments have the advantage that outcomes are observed in a natural setting rather than in a contrived laboratory environment. However, like natural experiments, field experiments suffer from the possibility of contamination: experimental conditions can be controlled with more precision and certainty in the lab.

Observation

Observation is either an activity of a living being consisting of receiving knowledge of the outside world through the senses, or the recording of data using scientific instruments. The term may also refer to any data collected during this activity. Human sense impressions are subjective and qualitative making them difficult to record or compare. The idea of measurement evolved to allow recording and comparison of observations made at different times and places by different people. Measurement consists of using observation to compare the thing being measured to a standard; an artifact, process or definition which can be duplicated or shared by all observers, and counting how many of the standard units are comparable to the object. Measurement reduces an observation to a number which can be recorded, and two observations which result in the same number are equal within the resolution of the process. One problem encountered throughout scientific fields is that the observation may affect the process being observed, resulting in a different outcome than if the process was unobserved. This is called the observer effect. For example, it is not normally possible to check the air pressure in an automobile tire without letting out some of the air, thereby changing the pressure. However, in most fields of science it is possible to reduce the effects of observation to insignificance by using better instruments.

Naturalistic observation
It is a method of observation, commonly used by psychologists, behavioral scientists, and social scientists, that involves observing subjects in their natural habitats. Researchers take great care in avoiding making interferences with the behaviour they are observing by using unobtrusive methods. Objectively, studying events as they occur naturally, without intervention. They can be overt (the participants are aware they are being observed) or covert (the participants do not know they are being observed). There are obviously more ethical guidelines to take into consideration when a covert observation is being carried out.

**Participant observation**

It is a type of research strategy. It is a widely used methodology in many disciplines, particularly, cultural anthropology, but also sociology, communication studies, and social psychology. Its aim is to gain a close and intimate familiarity with a given group of individuals (such as a religious, occupational, or sub cultural group, or a particular community) and their practices through an intensive involvement with people in their natural environment, usually over an extended period of time.

**Field study**

A field study is a term used by naturalists for the scientific study of free-living wild animals in which the subjects are observed in their natural habitat, without changing, harming, or materially altering the setting or behavior of the animals under study. It helps to reveal the behaviour of various organisms present in their natural surroundings.

**Questionnaire**

A questionnaire is a research instrument consisting of a series of questions and other prompts for the purpose of gathering information from respondents. Although they are often designed for statistical analysis of the responses, this is not always the case. The questionnaire was invented by Sir Francis Galton.

Questionnaires have advantages over some other types of surveys in that they are cheap, do not require as much effort from the questioner as verbal or telephone surveys, and often have standardized answers that make it simple to compile data. However, such standardized answers may frustrate users. Questionnaires are also sharply limited by the fact that respondents must be able to read the questions and respond to them. Thus, for some demographic groups conducting a survey by questionnaire may not be practical.

**Case study**

A case study is a research methodology common in social science. It is based on an in-depth investigation of a single individual, group, or event to explore causation in order to find underlying principles.

Rather than using samples and following a rigid protocol to examine limited number of variables, case study methods involve an in-depth, longitudinal examination of a single instance or event: a
case. They provide a systematic way of looking at events, collecting data, analyzing information, and reporting the results. As a result the researcher may gain a sharpened understanding of why the instance happened as it did, and what might become important to look at more extensively in future research. Case studies lend themselves to both generating and testing hypotheses.

Another suggestion is that case study should be defined as a research strategy, an empirical inquiry that investigates a phenomenon within its real-life context. Case study research means single and multiple case studies, can include quantitative evidence, relies on multiple sources of evidence and benefits from the prior development of theoretical propositions. Case studies should not be confused with qualitative research and they can be based on any mix of quantitative and qualitative evidence. Single-subject research provides the statistical framework for making inferences from quantitative case-study data. This is also supported and well-formulated in (Lamnek, 2005): "The case study is a research approach, situated between concrete data taking techniques and methodological paradigms."

**Psychology and Social issues**

Social issues are matters which directly or indirectly affect many or all members of a society and are considered to be problems, controversies related to moral values, or both. Social issues are related to the fabric of the community, including conflicts among the interests of community members, and lie beyond the control of any one individual.

Some of the major social issues include: Abortion, Ageism, Civil rights, Crime, Disability rights, Discrimination, Divorce, Family values, Feminism, HIV/AIDS, Immigration, Incest, Social exclusion, female infanticide, poverty, child labour, etc.

**Abortion** is the termination of a pregnancy by the removal or expulsion from the uterus of a fetus or embryo, resulting in or caused by its death. An abortion can occur spontaneously due to complications during pregnancy or can be induced, in humans and other species. Worldwide 42 million abortions are estimated to take place annually with 22 million of these occurring safely and 20 million unsafely. While very few deaths result from safe abortions, unsafe abortions result in 70,000 deaths and 5 million disabilities a year. One of the main determinates of the availability of safe abortions is the legality of the procedure. Only 40% of the world's population is able to access therapeutic and elective abortions within gestational limits. The frequency of abortions is, however, similar whether or not access is restricted. Abortion has a long history and has been induced by various methods including herbal abortifacients, the use of sharpened tools, physical trauma, and other traditional methods. Contemporary medicine utilizes medications and surgical procedures to induce abortion. The legality, prevalence, and cultural views on abortion vary substantially around the world. In many parts of the world there is prominent and divisive public controversy over the ethical and legal issues of abortion. Abortion and abortion-related issues feature prominently in the national politics in many nations, often involving the opposing pro-life and pro-choice worldwide social movements. Incidence of abortion has declined worldwide, as access to family planning education and contraceptive services has increased.

**Ageism**, also called age discrimination is stereotyping of and discrimination against individuals or groups because of their age. It is a set of beliefs, attitudes, norms, and values used to justify age based prejudice and discrimination. This may be casual or systematic. The term was coined in 1987 by US gerontologist Robert N. Butler to describe discrimination against seniors, and patterned on sexism and racism. Butler defined ageism as a combination of three connected elements. Among them were prejudicial attitudes towards older people, old age, and the aging process; discriminatory practices against older people; and institutional practices and policies that perpetuate stereotypes about older people. The term has also been used to describe prejudice and discrimination against
adolescence and children, including ignoring their ideas because they are too young, or assuming that they should behave in certain ways because of their age.

Ageism commonly refers to positive discriminatory practices, regardless of the age towards which it is applied. There are several subsidiary forms of ageism. Adultism is a predisposition towards adults, which is seen as biased against children, youth, and all young people who are not addressed or viewed as adults. Jeunism is the discrimination against older people in favor of younger ones. This includes political candidacies, commercial functions, and cultural settings where the supposed greater vitality and/or physical beauty of youth is more appreciated than the supposed greater moral and/or intellectual rigor of adulthood. Adultcentrism is the "exaggerated egocentrism of adults." Adultocracy is the social convention which defines "maturity" and "immaturity," placing adults in a dominant position over young people, both theoretically and practically. Gerontocracy is a form of oligarchical rule in which an entity is ruled by leaders who are significantly older than most of the adult population. Chronocentrism is primarily the belief that a certain state of humanity is superior to all previous and/or future times.

Ageism may also lead to the development of fears towards certain age groups, particularly: Pedophobia, the fear of infants and children; Ephebophobia, the fear of youth, sometimes also referred as an irrational fear of adolescents or a prejudice against teenagers; and Gerontophobia, the fear of elderly people.

Civil and political rights are a class of rights and freedoms that protect individuals from unwarranted action by government and private organizations and individuals and ensure one's ability to participate in the civil and political life of the state without discrimination or repression. Civil rights include the ensuring of peoples' physical integrity and safety; protection from discrimination on grounds such as physical or mental disability, gender, religion, race, sexual orientation, national origin, age, and individual rights such as the freedoms of thought and conscience, speech and expression, religion, the press, and movement.

Political rights include natural justice (procedural fairness) in law, such as the rights of the accused, including the right to a fair trial; due process; the right to seek redress or a legal remedy; and rights of participation in civil society and politics such as freedom of association, the right to assemble, the right to petition, and the right to vote.

Civil and political rights comprise the first portion of the Universal Declaration of Human Rights (with economic, social and cultural rights comprising the second portion). The theory of three generations of human rights considers this group of rights to be "first-generation rights" and the theory of negative and positive rights considers them to be generally negative rights.

Crime is the breach of rules or laws for which some governing authority (via mechanisms such as legal systems) can ultimately prescribe a conviction. Individual human societies may each define crime and crimes differently. While every crime violates the law, not every violation of the law counts as a crime; for example: breaches of contract and of other civil law may rank as "offences" or as "infractions". Modern societies generally regard crimes as offenses against the public or the state, distinguished from torts (offenses against private parties that can give rise to a civil cause of action).

When informal relationships and sanctions prove insufficient to establish and maintain a desired social order, a government or a sovereign state may impose more formalized or stricter systems of social control. With institutional and legal machinery at their disposal, agents of the State can compel populations to conform to codes, and can opt to punish or to attempt to reform those who do not conform.

Authorities employ various mechanisms to regulate (encouraging or discouraging) certain behaviors in general. Governing or administering agencies may for example codify rules into laws, police citizens and visitors to ensure that they comply with those laws, and implement other
policies and practices which legislators or administrators have prescribed with the aim of discouraging or preventing crime. In addition, authorities provide remedies and sanctions, and collectively these constitute a criminal justice system. Legal sanctions vary widely in their severity, they may include (for example) incarceration of temporary character aimed at reforming the convict. Some jurisdictions have penal codes written to inflict permanent harsh punishments: legal mutilation, capital punishment or life without parole.

**The Disability Rights Movement** aims to improve the quality of life of people with disabilities and to confront the disadvantages and discrimination that they face. The goals and demands of the movement are bifurcated. One major concern is achieving civil rights for the disabled. This is further broken down into issues of accessibility in transportation, architecture, and the physical environment and equal opportunities in employment, education, and housing. Effective civil rights legislation is sought in order to eliminate exclusionary practice.

For people with physical disabilities accessibility and safety are primary issues that this movement works to reform. Access to public areas such as city streets and public buildings and restrooms are some of the more visible changes brought about in recent decades. A noticeable change in some parts of the world is the installation of elevators, transit lifts, wheelchair ramps and curb cuts, allowing people in wheelchairs and with other mobility impairments to use public sidewalks and public transit more easily and more safely. These improvements have also been appreciated by parents pushing strollers or carts, bicycle users, and travelers with rolling luggage. Accesses to education and employment have also been a major focus of this movement. Adaptive technologies, enabling people to work jobs they could not have previously, help create access to jobs and economic independence. Access in the classroom has helped improve education opportunities and independence for people with disabilities.

The second concern of the movement deals with lifestyle, self-determination, and an individual’s ability to live independently. The right to have an independent life as an adult, sometimes using paid assistant care instead of being institutionalized, is another major goal of this movement, and is the main goal of the similar independent living and self-advocacy movements, which are more strongly associated with people with intellectual disabilities and mental health disorders. These movements have supported people with disabilities to live as more active participants in society.

**Discrimination** is a sociological term referring to the treatment taken toward or against a person of a certain group in consideration based solely on class or category. Discrimination is the actual behavior towards another group. It involves excluding or restricting members of one group from opportunities that are available to other groups. The United Nations explains: "Discriminatory behaviors take many forms, but they all involve some form of exclusion or rejection.” Discriminatory laws such as redlining have existed in many countries. In some countries, controversial attempts such as racial quotas have been used to redress negative effects of discrimination.

**Divorce** (or the dissolution of marriage) is the final termination of a marital union, cancelling the legal duties and responsibilities of marriage and dissolving the bonds of matrimony between the parties. In most countries divorce requires the sanction of a court or other authority in a legal process. The legal process for divorce may also involve issues of spousal support, child custody, child support, distribution of property and division of debt.

**Family values** are political and social beliefs that hold the nuclear family to be the essential ethical and moral unit of society. Familialism is the ideology that promotes the family and its values as an institution. The phrase has different meanings in different cultures. In the late 20th and early 21st Centuries, the term has been frequently used in political debate, especially by social and religious conservatives, who believe that the world has seen a decline in family values since the end of the Second World War. But the term is vague, and means different things to different people.
Feminism refers to political, cultural, and economic movements aimed at establishing greater rights, legal protection for women and/or women's liberation. Feminism includes some of the sociological theories and philosophies concerned with issues of gender difference. It is also a movement that campaigns for women's rights and interests. Nancy Cott defines feminism as the belief in the importance of gender equality, invalidating the idea of gender hierarchy as a socially constructed concept.

According to Maggie Humm and Rebecca Walker, the history of feminism can be divided into three waves. The first wave transpired in the nineteenth and early twentieth centuries, the second occurred in the 1960s and 1970s, and the third extends from the 1990s to the present. Feminist theory emerged from these feminist movements. It is manifest in a variety of disciplines such as feminist geography, feminist history, feminist theology, and feminist literary criticism.

Feminism has changed traditional perspectives on a wide range of areas in human life, from culture to law. Feminist activists have campaigned for women's legal rights—such as rights of contract, property rights, and voting rights—while also promoting women's rights to bodily integrity and autonomy, abortion rights, and reproductive rights. They have struggled to protect women and girls from domestic violence, sexual harassment, and rape. On economic matters, feminists have advocated for workplace rights, including maternity leave and equal pay, and against other forms of gender-specific discrimination against women.

Acquired immune deficiency syndrome or acquired immunodeficiency syndrome (AIDS) is a disease of the human immune system caused by the human immunodeficiency virus (HIV). This condition progressively reduces the effectiveness of the immune system and leaves individuals susceptible to opportunistic infections and tumors. HIV is transmitted through direct contact of a mucous membrane or the bloodstream with a bodily fluid containing HIV, such as blood, semen, vaginal fluid, preseminal fluid, and breast milk.

This transmission can involve anal, vaginal or oral sex, blood transfusion, contaminated hypodermic needles, exchange between mother and baby during pregnancy, childbirth, breastfeeding or other exposure to one of the above bodily fluids. Genetic research indicates that HIV originated in west-central Africa during the late nineteenth or early twentieth century. AIDS was first recognized by the U.S. Centers for Disease Control and Prevention in 1981 and its cause, HIV, identified in the early 1980s. Although treatments for AIDS and HIV can slow the course of the disease, there is currently no vaccine or cure. Antiretroviral treatment reduces both the mortality and the morbidity of HIV infection, but these drugs are expensive and routine access to antiretroviral medication is not available in all countries. Due to the difficulty in treating HIV infection, preventing infection is a key aim in controlling the AIDS pandemic, with health organizations promoting safe sex and needle-exchange programmes in attempts to slow the spread of the virus.

Incest is sexual intercourse between close relatives that is either illegal in the jurisdiction where it takes place or socially taboo. The type of sexual activity and the nature of the relationship between people that constitutes a breach of law or social taboo vary with culture and jurisdiction. Some societies consider it to include only those who live in the same household, or who belong to the same clan or lineage; other societies consider it to include "blood relatives"; other societies further include those related by adoption or marriage.

Incest between adults and those under the age of majority or age of consent is considered a form of child sexual abuse that has been shown to be one of the most extreme forms of childhood trauma, a trauma that often does serious and long-term psychological damage, especially in the case of parental incest. Prevalence is difficult to generalize, but research has estimated 10-15% of the general population as having at least one incest experience, with less than 2% involving intercourse or attempted intercourse. Among women, research has yielded estimates as high as twenty percent.
Father-daughter incest was for many years the most commonly reported and studied form of incest. More recently, studies have suggested that sibling incest, particularly older brothers abusing younger siblings, is the most common form of incest. Some studies suggest that adolescent perpetrators of sibling incest abuse younger victims, their abuse occurs over a lengthier period, and they use violence more frequently and severely than adult perpetrators; and that sibling incest has a higher rate of penetrative acts than father or stepfather incest, with father and older brother incest resulting in greater reported distress than step-father incest.

**Consensual adult** incest is equally a crime in most countries, although it is seen by some as a **victimless crime**, and thus, it is rarely reported.

Most societies have prohibitions against incest. The **incest taboo** is and has been one of the most common of all cultural **taboos**, both in current nations and many past societies, with legal penalties imposed in some jurisdictions. Most modern societies have legal or social restrictions on closely consanguineous marriages.

**Social exclusion** is a multidimensional process of progressive social rupture, detaching groups and individuals from social relations and institutions and preventing them from full participation in the normal, normatively prescribed activities of the society in which they live. Another definition of this sociological term is as follows: The outcome of multiple deprivations that prevent individuals or groups from participating fully in the economic, social, and political life of the society in which they live.

An inherent problem with the term, however, is the tendency of its use by practitioners who define it to fit their argument. It is used across disciplines including **education**, **sociology**, **psychology**, **politics** and **economics**.

Social exclusion is evident in deprived communities; it is harder for people to engage fully in society. In such communities, weak social networking limits the circulation about information about jobs, political activities, and community events. But many social workers believe that exclusion in the countryside is as great as, if not greater than, that in cities. In rural areas there is less access to goods, services and facilities, making life difficult in many respects.

**Sex-selective abortion or female infanticide** (also referred to as **son preference** or **female deselection**) are methods of sex-selection which are practiced in areas where male children are valued over female children. Sex-selective abortion refers to the targeted **abortion** of female fetuses; the fetus' sex may be identified by **ultrasound** but also rarely by **amniocentesis** or another procedure.

These practices arise in areas where cultural norms value male children over female children. Societies in which male children are valued over female children are common, especially in parts of countries like the **People's Republic of China**, **Korea**, **Taiwan**, and **India**.

In 2005, 90 million women were estimated to be "missing" in Afghanistan, Bangladesh, China, India, Pakistan, South Korea and Taiwan alone, possibly due to sex-selective abortion. The existence of the practice appears to be determined by culture, rather than by economic conditions, because such deviations in sex ratios do not exist in sub-Saharan Africa, Latin America, and the Caribbean. Some demographers, however, argue that perceived gender imbalances may arise from underreporting of female births, rather than sex-selective abortion or infanticide.

Sex-selective abortion was rare before the late 20th century, because of the difficulty of determining the sex of the fetus before birth, but ultrasound has made such selection easier. However, prior to this, parents would alter family sex compositions through **infanticide**. It is believed to be responsible for at least part of the skewed birth statistics in favor of males in **mainland China**, **India**, **Taiwan**, and **South Korea**. Even today, there are no scientifically proven and commercialized practices that allow gender detection during the first trimester, and ultrasound is fairly unreliable until approximately the 20th week of pregnancy. Consequently, sex selection...
often requires late term abortion of a fetus close to the limit of viability, making the practice frowned-upon even within the pro-choice community.

**Poverty** means being unable to afford basic human needs, such as clean water, nutrition, healthcare, education, clothing and shelter. This is also referred to as absolute poverty or destitution. **Relative poverty** is the condition of having fewer resources or less income than others within a society or country, or compared to worldwide averages. About 1.7 billion people live in absolute poverty; before the industrial revolution, poverty had mostly been the norm. **Poverty reduction** has historically been a result of economic growth as increased levels of production, such as modern industrial technology, made more wealth available for those who were otherwise too poor to afford them. Also, investments in modernizing agriculture and increasing yields is considered the core of the antipoverty effort, given three-quarters of the world's poor are rural farmers.

Today, continued economic development is constrained by the lack of economic freedoms. Economic liberalization includes extending property rights, especially to land, to the poor, and making financial services, notably savings, accessible. Inefficient institutions, corruption and political instability can also discourage investment. Aid and government support in health, education and infrastructure helps growth by increasing human and physical capital.

**Child labour** refers to the employment of children at regular and sustained labour. This practice is considered exploitative by many international organizations and is illegal in many countries. Child labour was utilized to varying extents through most of history, but entered public dispute with the advent of universal schooling, with changes in working conditions during the industrial revolution, and with the emergence of the concepts of workers' and children's rights. In many developed countries, it is considered inappropriate or exploitative if a child below a certain age works (excluding household chores or school-related work). An employer is usually not permitted to hire a child below a certain minimum age. This minimum age depends on the country and the type of work involved. States ratifying the Minimum Age Convention adopted by the International Labour Organization in 1973, have adopted minimum ages varying from 14 to 16. Child labor laws in the United States set the minimum age to work in an establishment without restrictions and without parents’ consent at age 16.

When noticing carefully, it is evident that there is no any issue which is not related to society and psychology.

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**Module 2**

**BIOLOGICAL BASIS OF BEHAVIOUR**

Nervous system
The human nervous system is an organ system containing a network of specialized cells called neurons that coordinate the actions of an animal and transmit signals between different parts of its body. In most animals, the nervous system consists of two parts, central and peripheral. The central nervous system of vertebrates (such as humans) contains the brain, spinal cord, and retina. The peripheral nervous system consists of sensory neurons, clusters of neurons called ganglia, and nerves connecting them to each other and to the central nervous system. These regions are all interconnected by means of complex neural pathways. The enteric nervous system, a subsystem of the peripheral nervous system, has the capacity, even when severed from the rest of the nervous system through its primary connection by the vagus nerve, to function independently in controlling the gastrointestinal system.

Neurons send signals to other cells as electrochemical waves travelling along thin fibres called axons, which cause chemicals called neurotransmitters to be released at junctions called synapses. A cell that receives a synaptic signal may be excited, inhibited, or otherwise modulated. Sensory neurons are activated by physical stimuli impinging on them, and send signals that inform the central nervous system of the state of the body and the external environment. Motor neurons, situated either in the central nervous system or in peripheral ganglia, connect the nervous system to muscles or other effector organs. Central neurons, which in vertebrates greatly outnumber the other types, make all of their input and output connections with other neurons. The interactions of all these types of neurons form neural circuits that generate an organism's perception of the world and determine its behavior. Along with neurons, the nervous system contains other specialized cells called glial cells (or simply glia), which provide structural and metabolic support.

Nervous systems are found in most multicellular animals, but vary greatly in complexity. Sponges have no nervous system, although they have homologs of many genes that play crucial...
roles in nervous system function, and are capable of several whole-body responses, including a primitive form of locomotion. Placozoans and mesozoans—other simple animals that are not classified as part of the subkingdom Eumetazoa—also have no nervous system. In Radiata (radially symmetric animals such as jellyfish) the nervous system consists of a simple nerve net. Bilateria, which include the great majority of vertebrates and invertebrates, all have a nervous system containing a brain, one central cord (or two running in parallel), and peripheral nerves. The size of the bilaterian nervous system ranges from a few hundred cells in the simplest worms, to on the order of 100 billion cells in humans. Neuroscience is the study of the nervous system.

Structure
The nervous system derives its name from nerves, which are cylindrical bundles of tissue that emanate from the brain and central cord, and branch repeatedly to innervate every part of the body. Nerves are large enough to have been recognized by the ancient Egyptians, Greeks, and Romans, but their internal structure was not understood until it became possible to examine them using a microscope. A microscopic examination shows that nerves consist primarily of the axons of neurons, along with a variety of membranes that wrap around them and segregate them into fascicles. The neurons that give rise to nerves do not lie within them—their cell bodies reside within the brain, central cord, or peripheral ganglia.

All animals more advanced than sponges have a nervous system. However, even sponges, unicellular animals, and non-animals such as slime molds have cell-to-cell signalling mechanisms that are precursors to those of neurons. In radially symmetric animals such as the jellyfish and hydra, the nervous system consists of a diffuse network of isolated cells. In bilateral animals, which make up the great majority of existing species, the nervous system has a common structure that originated early in the Cambrian period, over 500 million years ago.

Cells
The nervous system is primarily made up of two categories of cells: neurons and glial cells.

Neurons
The nervous system is defined by the presence of a special type of cell—the neuron (sometimes called "neurone" or "nerve cell"). Neurons can be distinguished from other cells in a number of ways, but their most fundamental property is that they communicate with other cells via synapses, which are membrane-to-membrane junctions containing molecular machinery that allows rapid transmission of signals, either electrical or chemical. Many types of neuron possess an axon, a protoplasmic protrusion that can extend to distant parts of the body and make thousands of synaptic contacts. Axons frequently travel through the body in bundles called nerves. Even in the nervous system of a single species such as humans, hundreds of different types of neurons exist, with a wide variety of morphologies and functions. These include sensory neurons that transmute physical stimuli such as light and sound into neural signals, and motor neurons that transmute neural signals into activation of muscles or glands; however in many species the great majority of neurons receive all of their input from other neurons and send their output to other neurons.

Glial cells
Glial cells are non-neuronal cells that provide support and nutrition, maintain homeostasis, form myelin, and participate in signal transmission in the nervous system. In the human brain, it is estimated that the total number of glia roughly equals the number of neurons, although the proportions vary in different brain areas. Among the most important functions of glial cells are to support neurons and hold them in place; to supply nutrients to neurons; to insulate neurons electrically; to destroy pathogens and remove dead neurons; and to provide guidance cues directing
the axons of neurons to their targets. A very important type of glial cell (oligodendrocytes in the central nervous system, and Schwann cells in the peripheral nervous system) generates layers of a fatty substance called myelin that wraps around axons and provides electrical insulation which allows them to transmit action potentials much more rapidly and efficiently.

Function
At the most basic level, the function of the nervous system is to send signals from one cell to others, or from one part of the body to others. There are multiple ways that a cell can send signals to other cells. One is by releasing chemicals called hormones into the internal circulation, so that they can diffuse to distant sites. In contrast to this "broadcast" mode of signaling, the nervous system provides "point-to-point" signals—neurons project their axons to specific target areas and make synaptic connections with specific target cells. Thus, neural signaling is capable of a much higher level of specificity than hormonal signaling. It is also much faster: the fastest nerve signals travel at speeds that exceed 100 meters per second.

At a more integrative level, the primary function of the nervous system is to control the body. It does this by extracting information from the environment using sensory receptors, sending signals that encode this information into the central nervous system, processing the information to determine an appropriate response, and sending output signals to muscles or glands to activate the response. The evolution of a complex nervous system has made it possible for various animal species to have advanced perception abilities such as vision, complex social interactions, rapid coordination of organ systems, and integrated processing of concurrent signals. In humans, the sophistication of the nervous system makes it possible to have language, abstract representation of concepts, transmission of culture, and many other features of human society that would not exist without the human brain.

Neurons and synapses
Major elements in synaptic transmission. An electrochemical wave called an action potential travels along the axon of a neuron. When the wave reaches a synapse, it provokes release of a puff of neurotransmitter molecules, which bind to chemical receptor molecules located in the membrane of the target cell.

Most neurons send signals via their axons, although some types are capable of dendrite-to-dendrite communication. (In fact, the types of neurons called amacrine cells have no axons, and communicate only via their dendrites.) Neural signals propagate along an axon in the form of electrochemical waves called action potentials, which produce cell-to-cell signals at points where axon terminals make synaptic contact with other cells.

Synapses may be electrical or chemical. Electrical synapses make direct electrical connections between neurons, but chemical synapses are much more common, and much more diverse in function. At a chemical synapse, the cell that sends signals is called presynaptic, and the cell that receives signals is called postsynaptic. Both the presynaptic and postsynaptic areas are full of molecular machinery that carries out the signalling process. The presynaptic area contains large numbers of tiny spherical vessels called synaptic vesicles, packed with neurotransmitter chemicals. When the presynaptic terminal is electrically stimulated, an array of molecules embedded in the membrane are activated, and cause the contents of the vesicles to be released into the narrow space between the presynaptic and postsynaptic membranes, called the synaptic cleft. The neurotransmitter then binds to receptors embedded in the postsynaptic membrane, causing them to enter an activated state. Depending on the type of receptor, the resulting effect on the postsynaptic
cell may be excitatory, inhibitory, or modulatory in more complex ways. For example, release of the neurotransmitter acetylcholine at a synaptic contact between a motor neuron and a muscle cell induces rapid contraction of the muscle cell. The entire synaptic transmission process takes only a fraction of a millisecond, although the effects on the postsynaptic cell may last much longer (even indefinitely, in cases where the synaptic signal leads to the formation of a memory trace).

There are literally hundreds of different types of synapses. In fact, there are over a hundred known neurotransmitters, and many of them have multiple types of receptor. Many synapses use more than one neurotransmitter—a common arrangement is for a synapse to use one fast-acting small-molecule neurotransmitter such as glutamate or GABA, along with one or more peptide neurotransmitters that play slower-acting modulatory roles. Molecular neuroscientists generally divide receptors into two broad groups: chemically gated ion channels and second messenger systems. When a chemically gated ion channel is activated, it forms a passage that allow specific types of ion to flow across the membrane. Depending on the type of ion, the effect on the target cell may be excitatory or inhibitory. When a second messenger system is activated, it starts a cascade of molecular interactions inside the target cell, which may ultimately produce a wide variety of complex effects, such as increasing or decreasing the sensitivity of the cell to stimuli, or even altering gene transcription.

According to a rule called Dale's principle, which has only a few known exceptions, a neuron releases the same neurotransmitters at all of its synapses. This does not mean, though, that a neuron exerts the same effect on all of its targets, because the effect of a synapse depends not on the neurotransmitter, but on the receptors that it activates. Because different targets can (and frequently do) use different types of receptors, it is possible for a neuron to have excitatory effects on one set of target cells, inhibitory effects on others, and complex modulatory effects on others still. Nevertheless, it happens that the two most widely used neurotransmitters, glutamate and GABA, each have largely consistent effects. Glutamate has several widely occurring types of receptors, but all of them are excitatory or modulatory. Similarly, GABA has several widely occurring receptor types, but all of them are inhibitory. Because of this consistency, glutamatergic cells are frequently referred to as "excitatory neurons", and GABAergic cells as "inhibitory neurons". Strictly speaking this is an abuse of terminology—it is the receptors that are excitatory and inhibitory, not the neurons—but it is commonly seen even in scholarly publications.

One very important subset of synapses are capable of forming memory traces by means of long-lasting activity-dependent changes in synaptic strength. The best-known form of neural memory is a process called long-term potentiation (abbreviated LTP), which operates at synapses that use the neurotransmitter glutamate acting on a special type of receptor known as the NMDA receptor. The NMDA receptor has an "associative" property: if the two cells involved in the synapse are both activated at approximately the same time, a channel opens that permits calcium to flow into the target cell. The calcium entry initiates a second messenger cascade that ultimately leads to an increase in the number of glutamate receptors in the target cell, thereby increasing the effective strength of the synapse. This change in strength can last for weeks or longer. Since the discovery of LTP in 1973, many other types of synaptic memory traces have been found, involving increases or decreases in synaptic strength that are induced by varying conditions, and last for variable periods of time. Reward learning, for example, depends on a variant form of LTP that is conditioned on an extra input coming from a reward-signalling pathway that uses dopamine as neurotransmitter. All these forms of synaptic modifiability, taken collectively, give rise to neural plasticity, that is, to a capability for the nervous system to adapt itself to variations in the environment.

A neuron is an electrically excitable cell that processes and transmits information by electrical and chemical signaling. Chemical signaling occurs via synapses, specialized connections with other
cells. Neurons connect to each other to form networks. Neurons are the core components of the nervous system, which includes the brain, spinal cord, and peripheral ganglia. A number of specialized types of neurons exist: sensory neurons respond to touch, sound, light and numerous other stimuli affecting cells of the sensory organs that then send signals to the spinal cord and brain. Motor neurons receive signals from the brain and spinal cord and cause muscle contractions and affect glands. Interneurons connect neurons to other neurons within the same region of the brain or spinal cord.

A typical neuron possesses a cell body (often called the soma), dendrites, and an axon. Dendrites are filaments that arise from the cell body, often extending for hundreds of microns and branching multiple times, giving rise to a complex "dendritic tree". An axon is a special cellular filament that arises from the cell body at a site called the axon hillock and travels for a distance, as far as 1 m in humans or even more in other species. The cell body of a neuron frequently gives rise to multiple dendrites, but never to more than one axon, although the axon may branch hundreds of times before it terminates. At the majority of synapses, signals are sent from the axon of one neuron to a dendrite of another. There are, however, many exceptions to these rules: neurons that lack dendrites, neurons that have no axon, synapses that connect an axon to another axon or a dendrite to another dendrite, etc.

All neurons are electrically excitable, maintaining voltage gradients across their membranes by means of metabolically driven ion pumps, which combine with ion channels embedded in the membrane to generate intracellular-versus-extracellular concentration differences of ions such as sodium, potassium, chloride, and calcium. Changes in the cross-membrane voltage can alter the function of voltage-dependent ion channels. If the voltage changes by a large enough amount, an all-or-none electrochemical pulse called an action potential is generated, which travels rapidly along the cell's axon, and activates synaptic connections with other cells when it arrives.

Neurons of the adult brain do not generally undergo cell division, and usually cannot be replaced after being lost, although there are a few known exceptions. In most cases they are generated by special types of stem cells, although astrocytes (a type of glial cell) have been observed to turn into neurons as they are sometimes pluripotent.

A neuron is a special type of cell that is found in the bodies of most animals (all members of the group Eumetazoa, to be precise this excludes only sponges and a few other very simple animals). The features that define a neuron are electrical excitability and the presence of synapses, which are complex membrane junctions used to transmit signals to other cells. The body's neurons, plus the glial cells that give them structural and metabolic support, together constitute the nervous system. In vertebrates, the majority of neurons belong to the central nervous system, but some reside in peripheral ganglia, and many sensory neurons are situated in sensory organs such as the retina and cochlea.

Although neurons are very diverse and there are exceptions to nearly every rule, it is convenient to begin with a schematic description of the structure and function of a "typical" neuron. A typical neuron is divided into three parts: the soma or cell body, dendrites, and axon. The soma is usually compact; the axon and dendrites are filaments that extrude from it. Dendrites typically branch profusely, getting thinner with each branching, and extending their farthest branches a few hundred microns from the soma. The axon leaves the soma at a swelling called the axon hillock, and can extend for great distances, giving rise to hundreds of branches. Unlike dendrites, an axon usually maintains the same diameter as it extends. The soma may give rise to numerous dendrites, but never to more than one axon. Synaptic signals from other neurons are received by the soma and dendrites; signals to other neurons are transmitted by the axon. A typical synapse, then, is a contact between the axon of one neuron and a dendrite or soma of another. Synaptic signals may be
excitatory or inhibitory. If the net excitation received by a neuron over a short period of time is large enough, the neuron generates a brief pulse called an action potential, which originates at the soma and propagates rapidly along the axon, activating synapses onto other neurons as it goes. Many neurons fit the foregoing schema in every respect, but there are also exceptions to most parts of it. There are no neurons that lack a soma, but there are neurons that lack dendrites, and others that lack an axon. Furthermore, in addition to the typical axodendritic and axosomatic synapses, there are axoaxonic (axon-to-axon) and dendrodendritic (dendrite-to-dendrite) synapses. The key to neural function is the synaptic signalling process, which is partly electrical and partly chemical. The electrical aspect depends on properties of the neuron's membrane. Like all animal cells, every neuron is surrounded by a plasma membrane, a bilayer of lipid molecules with many types of protein structures embedded in it. A lipid bilayer is a powerful electrical insulator, but in neurons, many of the protein structures embedded in the membrane are electrically active. These include ion channels that permit electrically charged ions to flow across the membrane, and ion pumps that actively transport ions from one side of the membrane to the other. Most ion channels are permeable only to specific types of ions. Some ion channels are voltage gated, meaning that they can be switched between open and closed states by altering the voltage difference across the membrane. Others are chemically gated, meaning that they can be switched between open and closed states by interactions with chemicals that diffuse through the extracellular fluid. The interactions between ion channels and ion pumps produce a voltage difference across the membrane, typically a bit less than 1/10 of a volt at baseline. This voltage has two functions: first, it provides a power source for an assortment of voltage-dependent protein machinery that is embedded in the membrane; second, it provides a basis for electrical signal transmission between different parts of the membrane. Neurons communicate by chemical and electrical synapses in a process known as synaptic transmission. The fundamental process that triggers synaptic transmission is the action potential, a propagating electrical signal that is generated by exploiting the electrically excitable membrane of the neuron. This is also known as a wave of depolarization.

Anatomy and histology
Neurons are highly specialized for the processing and transmission of cellular signals. Given the diversity of functions performed by neurons in different parts of the nervous system, there is, as expected, a wide variety in the shape, size, and electrochemical properties of neurons. For instance, the soma of a neuron can vary from 4 to 100 micrometers in diameter.

- The **soma** is the central part of the neuron. It contains the **nucleus** of the cell, and therefore is where most **protein synthesis** occurs. The nucleus ranges from 3 to 18 micrometers in diameter.

- The **dendrites** of a neuron are cellular extensions with many branches, and metaphorically this overall shape and structure is referred to as a dendritic tree. This is where the majority of input to the neuron occurs.

- The **axon** is a finer, cable-like projection which can extend tens, hundreds, or even tens of thousands of times the diameter of the soma in length. The axon carries **nerve signals** away from the soma (and also carries some types of information back to it). Many neurons have only one axon, but this axon may—and usually will—undergo extensive branching, enabling communication with many target cells. The part of the axon where it emerges from the soma is called the **axon hillock**. Besides being an anatomical structure, the axon hillock is also the part of the neuron that has the greatest density of **voltage-dependent sodium channels**. This makes it the most easily-excited part of the neuron and the spike initiation zone for the axon: in electrophysiological terms it has the most negative **action potential threshold**. While the axon and axon hillock are generally involved in information outflow, this region can also receive input from other neurons.
• The **axon terminal** contains **synapses**, specialized structures where **neurotransmitter** chemicals are released in order to communicate with target neurons.

Although the canonical view of the neuron attributes dedicated functions to its various anatomical components, dendrites and axons often act in ways contrary to their so-called main function. Axons and dendrites in the central nervous system are typically only about one **micrometer** thick, while some in the peripheral nervous system are much thicker. The soma is usually about 10–25 micrometers in diameter and often is not much larger than the **cell nucleus** it contains. The longest axon of a human **motoneuron** can be over a meter long, reaching from the base of the spine to the toes. Sensory neurons have axons that run from the toes to the **dorsal columns**, over 1.5 meters in adults. **Giraffes** have single axons several meters in length running along the entire length of their necks. Much of what is known about axonal function comes from studying the **squid giant axon**, an ideal experimental preparation because of its relatively immense size (0.5–1 millimeters thick, several centimeters long).

Fully differentiated neurons are permanently **amitotic**; however, recent research shows that additional neurons throughout the brain can originate from neural **stem cells** found throughout the brain but in particularly high concentrations in the **subventricular zone** and **subgranular zone** through the process of **neurogenesis**.

**Histology and internal structure**

![Golgi-stained neurons in human hippocampal tissue.](image)

Nerve cell bodies stained with basophilic dyes show numerous microscopic clumps of **Nissl substance** (named after German psychiatrist and neuropathologist **Franz Nissl**, 1860–1919), which consists of rough **endoplasmic reticulum** and associated **ribosomal RNA**. The prominence of the Nissl substance can be explained by the fact that nerve cells are metabolically very active, and hence are involved in large amounts of **protein** synthesis.

The cell body of a neuron is supported by a complex meshwork of structural proteins called **neurofilaments**, which are assembled into larger neurofibrils. Some neurons also contain pigment granules, such as neuromelanin (a brownish-black pigment, byproduct of synthesis of **catecholamines**) and **lipofuscin** (yellowish-brown pigment that accumulates with age).

There are different internal structural characteristics between axons and dendrites. Typical axons almost never contain **ribosomes**, except some in the initial segment. Dendrites contain granular **endoplasmic reticulum** or **ribosomes**, with diminishing amounts with distance from the cell body.
**Classes**

![Image of pyramidal neurons in mouse cerebral cortex expressing green fluorescent protein. The red staining indicates GABAergic interneurons.](image)

SMI32-stained pyramidal neurons in cerebral cortex.

Neurons exist in a number of different shapes and sizes and can be classified by their morphology and function. The anatomist Camillo Golgi grouped neurons into two types; type I with long axons used to move signals over long distances and type II with short axons, which can often be confused with dendrites. Type I cells can be further divided by where the cell body or soma is located. The basic morphology of type I neurons, represented by spinal motor neurons, consists of a cell body called the soma and a long thin axon which is covered by the myelin sheath. Around the cell body is a branching dendritic tree that receives signals from other neurons. The end of the axon has branching terminals (axon terminal) that release neurotransmitters into a gap called the synaptic cleft between the terminals and the dendrites of the next neuron.

**Structural classification**

**Polarity**

Most neurons can be anatomically characterized as:

- Unipolar or pseudounipolar: dendrite and axon emerging from same process.
- Bipolar: axon and single dendrite on opposite ends of the soma.
- Multipolar: more than two dendrites:
  - Golgi I: neurons with long-projecting axonal processes; examples are pyramidal cells, Purkinje cells, and anterior horn cells.
  - Golgi II: neurons whose axonal process projects locally; the best example is the granule cell.
**Other**

Furthermore, some unique neuronal types can be identified according to their location in the nervous system and distinct shape. Some examples are: 
- **Basket cells**, interneurons that form a dense plexus of terminals around the soma of target cells, found in the cortex and cerebellum.
- **Betz cells**, large motor neurons.
- **Medium spiny neurons**, most neurons in the corpus striatum.
- **Purkinje cells**, huge neurons in the cerebellum, a type of Golgi I multipolar neuron.
- **Pyramidal cells**, neurons with triangular soma, a type of Golgi I.
- **Renshaw cells**, neurons with both ends linked to alpha motor neurons.
- **Granule cells**, a type of Golgi II neuron.
- **Anterior horn** cells, motoneurons located in the spinal cord.

**Functional classification**

**Direction**

- **Afferent neurons** convey information from tissues and organs into the central nervous system and are sometimes also called sensory neurons.
- **Efferent neurons** transmit signals from the central nervous system to the effector cells and are sometimes called motor neurons.
- **Interneurons** connect neurons within specific regions of the central nervous system.

Afferent and efferent can also refer generally to neurons which, respectively, bring information to or send information from the brain region.

**Action on other neurons**

A neuron affects other neurons by releasing a neurotransmitter that binds to chemical receptors. The effect upon the target neuron is determined not by the source neuron or by the neurotransmitter, but by the type of receptor that is activated. A neurotransmitter can be thought of as a key, and a receptor as a lock: the same type of key can here be used to open many different types of locks. Receptors can be classified broadly as excitatory (causing an increase in firing rate), inhibitory (causing a decrease in firing rate), or modulatory (causing long-lasting effects not directly related to firing rate).

In fact, however, the two most common neurotransmitters in the brain, glutamate and GABA, have actions that are largely consistent. Glutamate acts on several different types of receptors, but most of them have effects that are excitatory. Similarly GABA acts on several different types of receptors, but all of them have effects (in adult animals, at least) that are inhibitory. Because of this consistency, it is common for neuroscientists to simplify the terminology by referring to cells that release glutamate as "excitatory neurons," and cells that release GABA as "inhibitory neurons."

Since well over 90% of the neurons in the brain release either glutamate or GABA, these labels encompass the great majority of neurons. There are also other types of neurons that have consistent effects on their targets, for example "excitatory" motor neurons in the spinal cord that release acetylcholine, and "inhibitory" spinal neurons that release glycine.

The distinction between excitatory and inhibitory neurotransmitters is not absolute, however. Rather, it depends on the class of chemical receptors present on the target neuron. In principle, a single neuron, releasing a single neurotransmitter, can have excitatory effects on some targets, inhibitory effects on others, and modulatory effects on others still. For example, photoreceptors in...
the retina constantly release the neurotransmitter glutamate in the absence of light. So-called OFF bipolar cells are, like most neurons, excited by the released glutamate. However, neighboring target neurons called ON bipolar cells are instead inhibited by glutamate, because they lack the typical ionotropic glutamate receptors and instead express a class of inhibitory metabotropic glutamate receptors. When light is present, the photoreceptors cease releasing glutamate, which relieves the ON bipolar cells from inhibition, activating them; this simultaneously removes the excitation from the OFF bipolar cells, silencing them.

**Discharge patterns**

Neurons can be classified according to their electrophysiological characteristics:

- **Tonic or regular spiking.** Some neurons are typically constantly (or tonically) active. Example: interneurons in neurostriatum.
- **Phasic or bursting.** Neurons that fire in bursts are called phasic.
- **Fast spiking.** Some neurons are notable for their fast firing rates, for example some types of cortical inhibitory interneurons, cells in globus pallidus, retinal ganglion cells.

**Classification by neurotransmitter production**

Neurons differ in the type of neurotransmitter they manufacture. Some examples are:

- **Cholinergic neurons - acetylcholine**
  Acetylcholine is released from presynaptic neurons into the synaptic cleft. It acts as a ligand for both ligand-gated ion channels and metabotropic (GPCRs) muscarinic receptors. Nicotinic receptors, are pentameric ligand-gated ion channels composed of alpha and beta subunits that bind nicotine. Ligand binding opens the channel causing influx of Na+ depolarization and increases the probability of presynaptic neurotransmitter release.

- **GABAergic neurons - gamma aminobutyric acid**
  GABA is one of two neuroinhibitors in the CNS, the other being Glycine. GABA has a homologous function to ACh, gating anion channels that allow Cl- ions to enter the post synaptic neuron. Cl- causes hyperpolarization within the neuron, decreasing the probability of an action potential firing as the voltage becomes more negative (recall that for an action potential to fire, a positive voltage threshold must be reached).

- **Glutamatergic neurons - glutamate**
  Glutamate is one of two primary excitatory amino acids, the other being Aspartate. Glutamate receptors are one of four categories, three of which are ligand-gated ion channels and one of which is a G-protein coupled receptor (often referred to as GPCR). 1 - AMPA and Kainate receptors both function as cation channels permeable to Na+ cation channels mediating fast excitatory synaptic transmission 2 - NMDA receptors are another cation channel that is more permeable to Ca2+. The function of NMDA receptors is dependent on Glycine receptor binding as a co-agonist within the channel pore. NMDA receptors will not function without both ligands present. 3 - Metabotropic receptors, GPCRs modulate synaptic transmission and postsynaptic excitability. Glutamate can cause excitotoxicity when blood flow to the brain is interrupted, resulting in brain damage. When blood flow is suppressed, glutamate is released from presynaptic neurons causing NMDA and AMPA receptor activation moreso than would normally be the case outside of stress conditions, leading to elevated Ca2+ and Na+ entering the post synaptic neuron and cell damage.

- **Dopaminergic neurons - dopamine**
  Dopamine is a neurotransmitter that acts on D1 type (D1 and D5) Gs coupled receptors which increase cAMP and PKA or D2 type (D2,D3 and D4) receptors which activate Gi-coupled receptors
that decrease cAMP and PKA. Dopamine is connected to mood and behavior, and modulates both pre and post synaptic neurotransmission. Loss of dopamine neurons in the substantia nigra has been linked to Parkinson's disease.

**serotonergic neurons - serotonin**

Serotonin, (5-Hydroxytryptamine, 5-HT), can act as excitatory or inhibitory. Of the four 5-HT receptor classes, 3 are GPCR and 1 is ligand gated cation channel. Serotonin is synthesized from tryptophan by tryptophan hydroxylase, and then further by aromatic acid decarboxylase. A lack of 5-HT at postsynaptic neurons has been linked to depression. Drugs that block the presynaptic serotonin transporter are used for treatment, such as Prozac and Zoloft.

**Central Nervous System**

The central nervous system (CNS) is the part of the nervous system that coordinates the activity of all parts of the bodies of bilaterian animals—that is, all multicellular animals except sponges and radially symmetric animals such as jellyfish. It contains the majority of the nervous system and consists of the brain and the spinal cord, as well as the retina. Together with the peripheral nervous system, it has a fundamental role in the control of behavior. The CNS is contained within the dorsal cavity, with the brain in the cranial cavity and the spinal cord in the spinal cavity. In vertebrates, the brain is protected by the skull, while the spinal cord is protected by the vertebrae, and both are enclosed in the meninges.

**Development**

During early development of the vertebrate embryo, a longitudinal groove on the neural plate gradually deepens as ridges on either side of the groove (the neural folds) become elevated, and ultimately meet, transforming the groove into a closed tube, the ectodermal wall of which forms the rudiment of the nervous system. This tube initially differentiates into three vesicles (pockets): the prosencephalon at the front, the mesencephalon, and, between the mesencephalon and the spinal cord, the rhombencephalon. (By six weeks in the human embryo) the prosencephalon then divides further into the telencephalon and diencephalon; and the rhombencephalon divides into the metencephalon and myelencephalon.

As the vertebrate grows, these vesicles differentiate further still. The telencephalon differentiates into, among other things, the striatum, the hippocampus and the neocortex, and its cavity becomes the first and second ventricles. Diencephalon elaborations include the subthalamus, hypothalamus, thalamus and epithalamus, and its cavity forms the third ventricle. The tectum, pretectum, cerebral peduncle and other structures develop out of the mesencephalon, and its cavity grows into the mesencephalic duct (cerebral aqueduct). The metencephalon becomes, among other things, the pons and the cerebellum, the myelencephalon forms the medulla oblongata, and their cavities develop into the fourth ventricle.

**Central nervous system**

**Brain**

Prosencephalon

Telencephalon

Rhinencephalon, Amygdala, Hippocampus, Neocortex, Basal ganglia, Lateral ventricles

Diencephalon
Brain stem
Mesencephalon
Tectum, Cerebral peduncle, Pretectum, Mesencephalic duct

Rhomencephalon
Metencephalon
Pons, Cerebellum

Myelencephalon
Medulla oblongata

Spinal cord

Evolution


Planarians, members of the phylum Platyhelminthes (flatworms), have the simplest, clearly defined delineation of a nervous system into a central nervous system (CNS) and a peripheral nervous system (PNS). Their primitive brain, consisting of two fused anterior ganglia, and longitudinal nerve cords form the CNS; the laterally projecting nerves form the PNS. A molecular study found that more than 95% of the 116 genes involved in the nervous system of planarians, which includes genes related to the CNS, also exist in humans. Like planarians, vertebrates have a distinct CNS and PNS, though more complex than those of planarians.
The basic pattern of the CNS is highly conserved throughout the different species of vertebrates and during evolution. The major trend that can be observed is towards a progressive telencephalisation: the telencephalon of reptiles is only an appendix to the large olfactory bulb, while in mammals it makes up most of the volume of the CNS. In the human brain, the telencephalon covers most of the diencephalon and the mesencephalon. Indeed, the allometric study of brain size among different species shows a striking continuity from rats to whales, and allows us to complete the knowledge about the evolution of the CNS obtained through cranial endocasts. Mammals – which appear in the fossil record after the first fishes, amphibians, and reptiles – are the only vertebrates to possess the evolutionarily recent, outermost part of the cerebral cortex known as the neocortex. The neocortex of monotremes (the duck-billed platypus and several species of spiny anteaters) and of marsupials (such as kangaroos, koalas, opossums, wombats, and Tasmanian devils) lack the convolutions - gyri and sulci - found in the neocortex of most placent mammals (eutherians). Within placental mammals, the size and complexity of the neocortex increased over time. The area of the neocortex of mice is only about 1/100 that of monkeys, and that of monkeys is only about 1/10 that of humans. In addition, rats lack convolutions in their neocortex (possibly also because rats are small mammals), whereas cats have a moderate degree of convolutions, and humans have quite extensive convolutions.

Diseases of the central nervous system
There are many central nervous system diseases, including infections of the central nervous system such as encephalitis and poliomyelitis, neurodegenerative diseases such as Alzheimer's disease and amyotrophic lateral sclerosis, autoimmune and inflammatory diseases such as multiple sclerosis or acute disseminated encephalomyelitis, and genetic disorders such as Krabbe's disease, Huntington's disease, or adreno leukodystrophy. Lastly, cancers of the central nervous system can cause severe illness and, when malignant, can have very high mortality rates.

Brain

The brain is the center of the nervous system in all vertebrate, and most invertebrate, animals. Some primitive animals such as jellyfish and starfish have a decentralized nervous system without a brain, while sponges lack any nervous system at all. In vertebrates, the brain is located in the head, protected by the skull and close to the primary sensory apparatus of vision, hearing, balance, taste, and smell.

Brains can be extremely complex. The cerebral cortex of the human brain contains roughly 15-33 billion neurons, perhaps more, depending on gender and age, linked with up to 10,000 synaptic connections each. Each cubic millimeter of cerebral cortex contains roughly one billion synapses. These neurons communicate with one another by means of long protoplasmic fibers called axons, which carry trains of signal pulses called action potentials to distant parts of the brain or body and target them to specific recipient cells.

The brain controls the other organ systems of the body, either by activating muscles or by causing secretion of chemicals such as hormones. This centralized control allows rapid and coordinated responses to changes in the environment. Some basic types of responsiveness are possible without a brain: even single-celled organisms may be capable of extracting information from the environment and acting in response to it. Sponges, which lack a central nervous system, are capable of coordinated body contractions and even locomotion. In vertebrates, the spinal cord by itself contains neural circuitry capable of generating reflex responses as well as simple motor patterns such as swimming or walking. However, sophisticated control of behavior on the basis of complex sensory input requires the information-integrating capabilities of a centralized brain.
Despite rapid scientific progress, much about how brains work remains a mystery. The operations of individual neurons and synapses are now understood in considerable detail, but the way they cooperate in ensembles of thousands or millions has been very difficult to decipher. Methods of observation such as EEG recording and functional brain imaging tell us that brain operations are highly organized, while single unit recording can resolve the activity of single neurons, but how individual cells give rise to complex operations is unknown.

Macroscopic structure
The brain is the most complex biological structure known, and comparing the brains of different species on the basis of appearance is often difficult. Nevertheless, there are common principles of brain architecture that apply across a wide range of species. These are revealed mainly by three approaches. The evolutionary approach means comparing brain structures of different species, and using the principle that features found in all branches that have descended from a given ancient form were probably present in the ancestor as well. The developmental approach means examining how the form of the brain changes during the progression from embryonic to adult stages. The genetic approach means analyzing gene expression in various parts of the brain across a range of species. Each approach complements and informs the other two.

Bilatera
With the exception of a few primitive forms such as sponges and jellyfish, all living animals are bilateria, meaning animals with a bilaterally symmetric body shape (that is, left and right sides that are approximate mirror images of each other).

All bilateria are thought to have descended from a common ancestor that appeared early in the Cambrian period, 550–600 million years ago. This ancestor had the shape of a simple tube worm with a segmented body, and at an abstract level, that worm-shape continues to be reflected in the body and nervous system plans of all modern bilateria, including humans. The fundamental bilateral body form is a tube with a hollow gut cavity running from mouth to anus, and a nerve cord with an enlargement (a "ganglion") for each body segment, with an especially large ganglion at the front, called the "brain".

Invertebrates
Drosophila

For invertebrates (e.g., insects, molluscs, worms, etc.) the components of the brain differ so greatly from the vertebrate pattern that it is hard to make meaningful comparisons except on the basis of genetics. Two groups of invertebrates have notably complex brains: arthropods (insects, crustaceans, arachnids, and others), and cephalopods (octopuses, squids, and similar molluscs). The brains of arthropods and cephalopods arise from twin parallel nerve cords that extend through the body of the animal. Arthropods have a central brain with three divisions and large optical lobes behind each eye for visual processing. Cephalopods have the largest brains of any invertebrates. The brain of the octopus in particular is highly developed, comparable in complexity to the brains of some vertebrates.

There are a few invertebrates whose brains have been studied intensively. The large sea slug Aplysia was chosen by Nobel Prize-winning neurophysiologist Eric Kandel, because of the simplicity and accessibility of its nervous system, as a model for studying the cellular basis of learning and memory, and subjected to hundreds of experiments. The most thoroughly studied invertebrate brains, however, belong to the fruit fly Drosophila and the tiny roundworm Caenorhabditis elegans (C. elegans).
Because of the large array of techniques available for studying their genetics, fruit flies have been a natural subject for studying the role of genes in brain development. Remarkably, many aspects of Drosophila neurogenetics have turned out to be relevant to humans. The first biological clock genes, for example, were identified by examining Drosophila mutants that showed disrupted daily activity cycles. A search in the genomes of vertebrates turned up a set of analogous genes, which were found to play similar roles in the mouse biological clock—and therefore almost certainly in the human biological clock as well.

Like Drosophila, the nematode worm C. elegans has been studied largely because of its importance in genetics. In the early 1970s, Sydney Brenner chose it as a model system for studying the way that genes control development. One of the advantages of working with this worm is that the body plan is very stereotyped: the nervous system of the hermaphrodite morph contains exactly 302 neurons, always in the same places, making identical synaptic connections in every worm. In a heroic project, Brenner’s team sliced worms into thousands of ultrathin sections and photographed every section under an electron microscope, then visually matched fibers from section to section, in order to map out every neuron and synapse in the entire body. Nothing approaching this level of detail is available for any other organism, and the information has been used to enable a multitude of studies that would not have been possible without it.

**Vertebrates**

The brains of vertebrates are made of very soft tissue, with a texture that has been compared to Jello. Living brain tissue is pinkish on the outside and mostly white on the inside, with subtle variations in color. Vertebrate brains are surrounded by a system of connective tissue membranes called meninges that separate the skull from the brain. This three-layered covering is composed of (from the outside in) the dura mater ("hard mother"), arachnoid mater ("spidery mother"), and pia mater ("soft mother"). The arachnoid and pia are physically connected and thus often considered as a single layer, the pia-arachnoid. Below the arachnoid is the subarachnoid space which contains cerebrospinal fluid (CSF), which circulates in the narrow spaces between cells and through cavities called ventricles, and serves to nourish, support, and protect the brain tissue. Blood vessels enter the central nervous system through the perivascular space above the pia mater. The cells in the blood vessel walls are joined tightly, forming the blood-brain barrier which protects the brain from toxins that might enter through the blood.

The first vertebrates appeared over 500 million years ago (mya), during the Cambrian period, and may have somewhat resembled the modern hagfish in form. Sharks appeared about 450 mya, amphibians about 400 mya, reptiles about 350 mya, and mammals about 200 mya. No modern species should be described as more "primitive" than others, since all have an equally long evolutionary history, but the brains of modern hagfishes, lampreys, sharks, amphibians, reptiles, and mammals show a gradient of size and complexity that roughly follows the evolutionary sequence. All of these brains contain the same set of basic anatomical components, but many are rudimentary in hagfishes, whereas in mammals the foremost parts are greatly elaborated and expanded.

All vertebrate brains share a common underlying form, which can most easily be appreciated by examining how they develop. The first appearance of the nervous system is as a thin strip of tissue running along the back of the embryo. This strip thickens and then folds up to form a hollow tube. The front end of the tube develops into the brain. In its earliest form, the brain appears as three swellings, which eventually become the forebrain, midbrain, and hindbrain. In many classes of vertebrates these three parts remain similar in size in the adult, but in mammals the forebrain becomes much larger than the other parts, and the midbrain quite small.
The relationship between brain size, body size and other variables has been studied across a wide range of vertebrate species. Brain size increases with body size but not proportionally. Averaging across all orders of mammals, it follows a power law, with an exponent of about 0.75. This formula applies to the average brain of mammals but each family departs from it, reflecting their sophistication of behavior. For example, primates have brains 5 to 10 times as large as the formula predicts. Predators tend to have larger brains. When the mammalian brain increases in size, not all parts increase at the same rate. The larger the brain of a species, the greater the fraction taken up by the cortex.

**Vertebrate brain regions**

Neuroanatomists usually consider the brain to consist of six main regions: the telencephalon (cerebral hemispheres), diencephalon (thalamus and hypothalamus), mesencephalon (midbrain), cerebellum, pons, and medulla oblongata. Each of these areas in turn has a complex internal structure. Some areas, such as the cortex and cerebellum, consist of layers, folded or convoluted to fit within the available space. Other areas consist of clusters of many small nuclei. If fine distinctions are made on the basis of neural structure, chemistry, and connectivity, thousands of distinguishable areas can be identified within the vertebrate brain.

Some branches of vertebrate evolution have led to substantial changes in brain shape, especially in the forebrain. The brain of a shark shows the basic components in a straightforward way, but in teleost fishes (the great majority of modern species), the forebrain has become "everted", like a sock turned inside out. In birds, also, there are major changes in shape. One of the main structures in the avian forebrain, the dorsal ventricular ridge, was long thought to correspond to the basal ganglia of mammals, but is now thought to be more closely related to the neocortex.

Several brain areas have maintained their identities across the whole range of vertebrates, from hagfishes to humans. Here is a list of some of the most important areas, along with a very brief description of their functions as currently understood (but note that the functions of most of them are still disputed to some degree):

- The **medulla**, along with the spinal cord, contains many small nuclei involved in a wide variety of sensory and motor functions.
- The **hypothalamus** is a small region at the base of the forebrain, whose complexity and importance belies its size. It is composed of numerous small nuclei, each with distinct connections and distinct neurochemistry. The hypothalamus is the central control station for sleep/wake cycles, control of eating and drinking, control of hormone release, and many other critical biological functions. Like the hypothalamus, the thalamus is a collection of nuclei with diverse functions. Some of them are involved in relaying information to and from the cerebral hemispheres. Others are involved in motivation. The subthalamic area (zona incerta) seems to contain action-generating systems for several types of "consummatory" behaviors, including eating, drinking, defecation, and copulation.
- The **cerebellum** modulates the outputs of other brain systems to make them more precise. Removal of the cerebellum does not prevent an animal from doing anything in particular, but it makes actions hesitant and clumsy. This precision is not built-in, but learned by trial and error. Learning how to ride a bicycle is an example of a type of neural plasticity that may take place largely within the cerebellum.
- The **tectum**, often called "optic tectum", allows actions to be directed toward points in space. In mammals it is called the "superior colliculus", and its best studied function is to direct eye movements. It also directs reaching movements, though. It gets strong visual inputs, but also inputs from other senses that are useful in directing actions, such as auditory input in owls, input from the thermosensitive pit organs in snakes, etc. In some fishes, such as lampreys, it is the largest part of the brain.
The **pallium** is a layer of gray matter that lies on the surface of the forebrain. In reptiles and mammals it is called **cortex** instead. The pallium is involved in multiple functions, including **olfaction** and **spatial memory**. In mammals, where it comes to dominate the brain, it subsumes functions from many subcortical areas.

The **hippocampus**, strictly speaking, is found only in mammals. However, the area it derives from, the medial pallium, has counterparts in all vertebrates. There is evidence that this part of the brain is involved in spatial memory and navigation in fishes, birds, reptiles, and mammals.

The **basal ganglia** are a group of interconnected structures in the forebrain, of which our understanding has increased enormously over the last few years. The primary function of the basal ganglia seems to be **action selection**. They send inhibitory signals to all parts of the brain that can generate actions, and in the right circumstances can release the inhibition, so that the action-generating systems are able to execute their actions. Rewards and punishments exert their most important neural effects within the basal ganglia.

The **olfactory bulb** is a special structure that processes olfactory sensory signals, and sends its output to the olfactory part of the pallium. It is a major brain component in many vertebrates, but much reduced in primates.

**Mammals**

The **cerebral cortex** is the part of the brain that most strongly distinguishes mammals from other vertebrates, primates from other mammals, and humans from other primates. The hindbrain and midbrain of mammals are generally similar to those of other vertebrates, but dramatic differences appear in the forebrain, which is not only greatly enlarged, but also altered in structure.[39] In non-mammalian vertebrates, the surface of the **cerebrum** is lined with a comparatively simple layered structure called the **pallium**. In mammals, the pallium evolves into a complex 6-layered structure called **neocortex** or isocortex. In primates, the neocortex is greatly enlarged, especially the part called the **frontal lobes**. In humans, this enlargement of the frontal lobes is taken to an extreme, and other parts of the cortex also become quite large and complex. Also the **hippocampus** of mammals has a distinctive structure.

Unfortunately, the evolutionary history of these mammalian features, especially the 6-layered cortex, is difficult to trace. This is largely because of a **missing link** problem. The ancestors of mammals, called **synapsids**, split off from the ancestors of modern reptiles and birds about 350 million years ago. However, the most recent branching that has left living results within the mammals was the split between **monotremes** (the platypus and echidna), **marsupials** (opossum, kangaroo, etc.) and **placentals** (most living mammals), which took place about 120 million years ago. The brains of monotremes and marsupials are distinctive from those of placentals in some ways, but they have fully mammalian cortical and hippocampal structures. Thus, these structures must have evolved between 350 and 120 million years ago, a period that has left no evidence except fossils, which do not preserve tissue as soft as brain.

**Primates, including humans**

The primate brain contains the same structures as the brains of other mammals, but is considerably larger in proportion to body size. Most of the enlargement comes from a massive expansion of the cortex, focusing especially on the parts subserving vision and forethought. The visual processing network of primates is very complex, including at least 30 distinguishable areas, with a bewildering web of interconnections. Taking all of these together, visual processing makes use of about half of the brain. The other part of the brain that is greatly enlarged is the **prefrontal cortex**, whose functions are difficult to summarize succinctly, but relate to planning, working memory, motivation, attention, and executive control.
Microscopic structure

The brain is composed of two broad classes of cells: neurons and glia. These two types are equally numerous in the brain as a whole, although glial cells outnumber neurons roughly 4 to 1 in the cerebral cortex. Glia come in several types, which perform a number of critical functions, including structural support, metabolic support, insulation, and guidance of development.

The property that makes neurons so important is that, unlike glia, they are capable of sending signals to each other over long distances. They send these signals by means of an axon, a thin protoplasmic fiber that extends from the cell body and projects, usually with numerous branches, to other areas, sometimes nearby, sometimes in distant parts of the brain or body. The extent of an axon can be extraordinary: to take an example, if a pyramidal cell of the neocortex were magnified so that its cell body became the size of a human, its axon, equally magnified, would become a cable a few centimeters in diameter, extending farther than a kilometer. These axons transmit signals in the form of electrochemical pulses called action potentials, lasting less than a thousandth of a second and traveling along the axon at speeds of 1–100 meters per second. Some neurons emit action potentials constantly, at rates of 10–100 per second, usually in irregular temporal patterns; other neurons are quiet most of the time, but occasionally emit a burst of action potentials.

Axons transmit signals to other neurons, or to non-neuronal cells, by means of specialized junctions called synapses. A single axon may make as many as several thousand synaptic connections. When an action potential, traveling along an axon, arrives at a synapse, it causes a chemical called a neurotransmitter to be released. The neurotransmitter binds to receptor molecules in the membrane of the target cell. Some types of neuronal receptors are excitatory, meaning that they increase the rate of action potentials in the target cell; other receptors are inhibitory, meaning that they decrease the rate of action potentials; others have complex modulatory effects.

Axons actually fill most of the space in the brain. Often large groups of them are bundled together in what are called nerve fiber tracts. Many axons are wrapped in thick sheaths of a fatty substance called myelin, which serves to greatly increase the speed of action potential propagation. Myelin is white, so parts of the brain filled exclusively with nerve fibers appear as white matter, in contrast to the gray matter that marks areas with high densities of neuron cell bodies. The total length of myelinated axons in an average adult human brain is well over 100,000 kilometres (62,000 mi).

Development

The brain does not simply grow; rather, it develops in an intricately orchestrated sequence of stages. Many neurons are created in special zones that contain stem cells, and then migrate through the tissue to reach their ultimate locations. In the cortex, for example, the first stage of development is the formation of a "scaffold" by a special group of glial cells, called radial glia, which send fibers vertically across the cortex. New cortical neurons are created at the bottom of the cortex, and then "climb" along the radial fibers until they reach the layers they are destined to occupy in the adult.
This diagram depicts the main subdivisions of the embryonic vertebrate brain. These regions will later differentiate into forebrain, midbrain and hindbrain structures.

In vertebrates, the early stages of neural development are similar for all species. As the embryo transforms from a round blob of cells into a wormlike structure, a narrow strip of ectoderm running along the midline of the back is induced to become the neural plate, the precursor of the nervous system. The neural plate invaginates to form the neural groove, and then the folds that line the groove merge to enclose the neural tube, a hollow cord of cells with a fluid-filled ventricle at the center. At the front end, the ventricles and cord swell to form three vesicles that are the precursors of the forebrain, midbrain, and hindbrain. At about the same time, the hindbrain splits into the metencephalon (which will contain the cerebellum and pons) and the myelencephalon (which will contain the medulla oblongata). Each of these areas contains proliferative zones at which neurons and glia cells are generated; the resulting cells then migrate, sometimes for long distances, to their final positions.

Once a neuron is in place, it begins to extend dendrites and an axon into the area around it. Axons, because they commonly extend a great distance from the cell body and need to make contact with specific targets, grow in a particularly complex way. The tip of a growing axon consists of a blob of protoplasm called a "growth cone", studded with chemical receptors. These receptors sense the local environment, causing the growth cone to be attracted or repelled by various cellular elements, and thus to be pulled in a particular direction at each point along its path. The result of this pathfinding process is that the growth cone navigates through the brain until it reaches its destination area, where other chemical cues cause it to begin generating synapses. Taking the entire brain into account, many thousands of genes give rise to proteins that influence axonal pathfinding. The synaptic network that finally emerges is only partly determined by genes, though. In many parts of the brain, axons initially "overgrow", and then are "pruned" by mechanisms that depend on neural activity. In the projection from the eye to the midbrain, for example, the structure in the adult contains a very precise mapping, connecting each point on the surface of the retina to a corresponding point in a midbrain layer. In the first stages of development, each axon from the retina is guided to the right general vicinity in the midbrain by chemical cues, but then branches very profusely and makes initial contact with a wide swath of midbrain neurons. The retina, before birth, contains special mechanisms that cause it to generate waves of activity that originate spontaneously at some point and then propagate slowly across the retinal layer. These waves are useful because they cause neighboring neurons to be active at the same time: that is, they produce a
neural activity pattern that contains information about the spatial arrangement of the neurons. This information is exploited in the midbrain by a mechanism that causes synapses to weaken, and eventually vanish, if activity in an axon is not followed by activity of the target cell. The result of this sophisticated process is a gradual tuning and tightening of the map, leaving it finally in its precise adult form.

Similar things happen in other brain areas: an initial synaptic matrix is generated as a result of genetically determined chemical guidance, but then gradually refined by activity-dependent mechanisms, partly driven by internal dynamics, partly by external sensory inputs. In some cases, as with the retina-midbrain system, activity patterns depend on mechanisms that operate only in the developing brain, and apparently exist solely for the purpose of guiding development.

In humans and many other mammals, new neurons are created mainly before birth, and the infant brain actually contains substantially more neurons than the adult brain. There are, however, a few areas where new neurons continue to be generated throughout life. The two areas for which this is well established are the olfactory bulb, which is involved in the sense of smell, and the dentate gyrus of the hippocampus, where there is evidence that the new neurons play a role in storing newly acquired memories. With these exceptions, however, the set of neurons that is present in early childhood is the set that is present for life. Glial cells are different, however; as with most types of cells in the body, these are generated throughout the lifespan.

Although the pool of neurons is largely in place by birth, the axonal connections continue to develop for a long time afterward. In humans, full myelination is not completed until adolescence. There has long been debate about whether the qualities of mind, personality, and intelligence can mainly be attributed to heredity or to upbringing; the nature versus nurture debate. This is not just a philosophical question: it has great practical relevance to parents and educators. Although many details remain to be settled, neuroscience clearly shows that both factors are essential. Genes determine the general form of the brain, and genes determine how the brain reacts to experience. Experience, however, is required to refine the matrix of synaptic connections. In some respects it is mainly a matter of presence or absence of experience during critical periods of development. In other respects, the quantity and quality of experience may be more relevant: for example, there is substantial evidence that animals raised in enriched environments have thicker cortices, indicating a higher density of synaptic connections, than animals whose levels of stimulation are restricted.

**Spinal cord**

The spinal cord is a long, thin, tubular bundle of nervous tissue and support cells that extends from the brain (the medulla specifically). The brain and spinal cord together make up the central nervous system. The spinal cord extends down to the space between the first and second lumbar vertebrae; it does not extend the entire length of the vertebral column. It is around 45 cm (18 in) in men and around 43 cm (17 in) long in women. The enclosing bony vertebral column protects the relatively shorter spinal cord. The spinal cord functions primarily in the transmission of neural signals between the brain and the rest of the body but also contains neural circuits that can independently control numerous reflexes and central pattern generators. The spinal cord has three major functions: A. Serve as a conduit for motor information, which travels down the spinal cord. B. Serve as a conduit for sensory information, which travels up the spinal cord. C. Serve as a center for coordinating certain reflexes.

**Structure**

The spinal cord is the main pathway for information connecting the brain and peripheral nervous system. The length of the spinal cord is much shorter than the length of the bony spinal column. The human spinal cord extends from the medulla oblongata and continues...
through the conus medullaris near the first or second lumbar vertebra, terminating in a fibrous extension known as the filum terminale.

It is about 45 cm (18 in) long in men and around 43 cm (17 in) in women, ovoid-shaped, and is enlarged in the cervical and lumbar regions. The cervical enlargement, located from C4 to T1, is where sensory input comes from and motor output goes to the arms. The lumbar enlargement, located between T9 and T12, handles sensory input and motor output coming from and going to the legs. You should notice that the name is somewhat misleading. However, this region of the cord does indeed have branches that extend to the lumbar region.

In cross-section, the peripheral region of the cord contains neuronal white matter tracts containing sensory and motor neurons. Internal to this peripheral region is the gray, butterfly-shaped central region made up of nerve cell bodies. This central region surrounds the central canal, which is an anatomic extension of the spaces in the brain known as the ventricles and, like the ventricles, contains cerebrospinal fluid.

The spinal cord has a shape that is compressed dorso-ventrally, giving it an elliptical shape. The cord has grooves in the dorsal and ventral sides. The posterior median sulcus is the groove in the dorsal side, and the anterior median fissure is the groove in the ventral side. Running down the center of the spinal cord is a cavity, called the central canal.

The three meninges that cover the spinal cord—the outer dura mater, the arachnoid mater, and the innermost pia mater—are continuous with that in the brainstem and cerebral hemispheres. Similarly, cerebrospinal fluid is found in the subarachnoid space. The cord is stabilized within the dura mater by the connecting denticulate ligaments, which extend from the enveloping pia mater laterally between the dorsal and ventral roots. The dural sac ends at the vertebral level of the second sacral vertebra.

The spinal cord is protected by three layers of tissue, called spinal meninges, that surround the cord. The dura mater is the outermost layer, and it forms a tough protective coating. Between the dura mater and the surrounding bone of the vertebrae is a space, called the epidural space. The epidural space is filled with adipose tissue, and it contains a network of blood vessels. The arachnoid is the middle protective layer. Its name comes from the fact that the tissue has a spiderweb-like appearance. The space between the arachnoid and the underlying pia mater is called the subarachnoid space. The subarachnoid space contains cerebrospinal fluid (CSF). The medical procedure known as a “spinal tap” involves use of a needle to withdraw CSF from the subarachnoid space, usually from the lumbar region of the spine. The pia mater is the innermost protective layer. It is very delicate and it is tightly associated with the surface of the spinal cord.

**Spinal cord segments**

The human spinal cord is divided into 31 different segments. At every segment, right and left pairs of spinal nerves (mixed; sensory and motor) form. Six to eight motor nerve rootlets branch out of right and left ventro lateral sulci in a very orderly manner. Nerve rootlets combine to form nerve roots. Likewise, sensory nerve rootlets form off right and left dorsal lateral sulci and form sensory nerve roots. The ventral (motor) and dorsal (sensory) roots combine to form spinal nerves (mixed; motor and sensory), one on each side of the spinal cord. Spinal nerves, with the exception of C1 and C2, form inside intervertebral foramen (IVF). Note that at each spinal segment, the border between the central and peripheral nervous system can be observed. Rootlets are a part of the peripheral nervous system.

In the upper part of the vertebral column, spinal nerves exit directly from the spinal cord, whereas in the lower part of the vertebral column nerves pass further down the column before exiting. The terminal portion of the spinal cord is called the conus medullaris. The pia mater continues as an
extension called the **filum terminale**, which anchors the spinal cord to the coccyx. The **cauda equina** ("horse’s tail") is the name for the collection of nerves in the vertebral column that continue to travel through the vertebral column below the **conus medullaris**. The cauda equina forms as a result of the fact that the spinal cord stops growing in length at about age four, even though the vertebral column continues to lengthen until adulthood. This results in the fact that sacral spinal nerves actually originate in the upper lumbar region. The spinal cord can be anatomically divided into 31 spinal segments based on the origins of the spinal nerves.

Each segment of the spinal cord is associated with a pair of ganglia, called dorsal root ganglia, which are situated just outside of the spinal cord. These ganglia contain cell bodies of sensory neurons. Axons of these sensory neurons travel into the spinal cord via the dorsal roots. Ventral roots consist of axons from motor neurons, which bring information to the periphery from cell bodies within the CNS. Dorsal roots and ventral roots come together and exit the intervertebral foramina as they become spinal nerves.

The gray matter, in the center of the cord, is shaped like a butterfly and consists of cell bodies of **interneurons** and motor neurons. It also consists of **neuroglia** cells and unmyelinated axons. Projections of the gray matter (the "wings") are called horns. Together, the gray horns and the gray **commissure** form the "gray H."

The white matter is located outside of the gray matter and consists almost totally of myelinated motor and sensory axons. "Columns" of white matter carry information either up or down the spinal cord. Within the CNS, nerve cell bodies are generally organized into functional clusters, called nuclei. Axons within the CNS are grouped into tracts.

There are 33 (some EMS text say 25, counting the sacral as one solid piece) spinal cord nerve segments in a human spinal cord:

- **8 cervical segments forming 8 pairs of cervical nerves** (C1 spinal nerves exit spinal column between occiput and C1 vertebra; C2 nerves exit between posterior arch of C1 vertebra and lamina of C2 vertebra; C3-C8 spinal nerves through IVF above corresponding cervical vertebra, with the exception of C8 pair which exit via IVF between C7 and T1 vertebra)
- **12 thoracic segments forming 12 pairs of thoracic nerves** (exit spinal column through IVF below corresponding vertebra T1-T12)
- **5 lumbar segments forming 5 pairs of lumbar nerves** (exit spinal column through IVF, below corresponding vertebra L1-L5)
- **5 (or 1) sacral segments forming 5 pairs of sacral nerves** (exit spinal column through IVF, below corresponding vertebra S1-S5)
- **3 coccygeal segments joined up becoming a single segment forming 1 pair of coccygeal nerves** (exit spinal column through the sacral hiatus).

Because the **vertebral column** grows longer than the spinal cord, spinal cord segments do not correspond to vertebral segments in adults, especially in the lower spinal cord. In the fetus, vertebral segments do correspond with spinal cord segments. In the adult, however, the spinal cord ends around the L1/L2 vertebral level, forming a structure known as the **conus medullaris**. For example, lumbar and sacral spinal cord segments are found between vertebral levels T9 and L2. Although the spinal cord cell bodies end around the L1/L2 vertebral level, the spinal nerves for each segment exit at the level of the corresponding vertebra. For the nerves of the lower spinal cord, this means that they exit the vertebral column much lower (more caudally) than their roots.
As these nerves travel from their respective roots to their point of exit from the vertebral column, the nerves of the lower spinal segments form a bundle called the cauda equina. There are two regions where the spinal cord enlarges:

- **Cervical enlargement** - corresponds roughly to the brachial plexus nerves, which innervate the upper limb. It includes spinal cord segments from about C4 to T1. The vertebral levels of the enlargement are roughly the same (C4 to T1).

- **Lumbosacral enlargement** - corresponds to the lumbosacral plexus nerves, which innervate the lower limb. It comprises the spinal cord segments from L2 to S3 and is found about the vertebral levels of T9 to T12.

**Spinocerebellar Tracts**

Proprioceptive information in the body travels up the spinal cord via three tracts. Below L2, the proprioceptive information travels up the spinal cord in the ventral spinocerebellar tract. Also known as the anterior spinocerebellar tract, sensory receptors take in the information and travel into the spinal cord. The cell bodies of these primary neurons are located in the dorsal root ganglia. In the spinal cord, the axons synapse and the secondary neuronal axons decussate and then travel up to the superior cerebellar peduncle where they decussate again. From here, the information is brought to deep nuclei of the cerebellum including the fastigial and interposed nuclei. From the levels of L2 to T1, proprioceptive information enters the spinal cord and ascends ipsilaterally, where it synapses in Clarke's nucleus. The secondary neuronal axons continue to ascend ipsilaterally and then pass into the cerebellum via the inferior cerebellar peduncle. This tract is known as the dorsal spinocerebellar tract. From above T1, proprioceptive primary axons enter the spinal cord and ascend ipsilaterally until reaching the accessory cuneate nucleus, where they synapse. The secondary axons pass into the cerebellum via the inferior cerebellar peduncle where again, these axons synapse on cerebellar deep nuclei. This tract is known as the cuneocerebellar tract.

Motor information travels from the brain down the spinal cord via descending spinal cord tracts. Descending tracts involve two neurons: the upper motor neuron (UMN) and lower motor neuron (LMN). A nerve signal travels down the upper motor neuron until it synapses with the lower motor neuron in the spinal cord. Then, the lower motor neuron conducts the nerve signal to the spinal root where efferent nerve fibers carry the motor signal toward the target muscle. The descending tracts are composed of white matter. There are several descending tracts serving different functions. The corticospinal tracts (lateral and anterior) are responsible for coordinated limb movements.

**Injury**

Spinal cord injuries can be caused by trauma to the spinal column (stretching, bruising, applying pressure, severing, laceration, etc.). The vertebral bones or intervertebral disks can shatter, causing the spinal cord to be punctured by a sharp fragment of bone. Usually, victims of spinal cord injuries will suffer loss of feeling in certain parts of their body. In milder cases, a victim might only suffer loss of hand or foot function. More severe injuries may result in paraplegia, tetraplegia, or full body paralysis (called Quadriplegia) below the site of injury to the spinal cord. Damage to upper motor neuron axons in the spinal cord results in a characteristic pattern of ipsilateral deficits. These include hyperreflexia, hypertonia and muscle weakness. Lower motor neuronal damage results in its own characteristic pattern of deficits. Rather than an entire side of deficits, there is a pattern relating to the myotome affected by the damage. Additionally, lower motor neurons are characterized by muscle weakness, hypotonia, hyporeflexia and muscle atrophy. Spinal shock and neurogenic shock can occur from a spinal injury. Spinal shock is usually temporary, lasting only for 24–48 hours, and is a temporary absence of sensory and motor
functions. Neurogenic shock lasts for weeks and can lead to a loss of muscle tone due to disuse of the muscles below the injured site.

The two areas of the spinal cord most commonly injured are the **cervical spine** (C1-C7) and the **lumbar spine** (L1-L5). (The notation C1, C7, L1, L5 refer to the location of a specific **vertebra** in either the cervical, thoracic, or lumbar region of the spine.)

Peripheral nervous system

The **Peripheral Nervous System** consists of the nerves and ganglia outside of the **brain** and the **spinal cord**. The main function of the PNS is to connect the CNS to the limb and organ. Unlike the central nervous system, the PNS is not protected by **bone** or by the **blood-brain barrier**, leaving it exposed to **toxins** and mechanical injuries. The peripheral nervous system is divided into the **somatic nervous system** and the **autonomic nervous system**; some textbooks also include **sensory systems**.

General classification
By direction
There are two types of neurons, carrying nerve impulses in different directions. These two groups of neurons are:

- The **sensory neurons** are **afferent** neurons which relay nerve impulses toward the central nervous system.

- The **motor neurons** are **efferent** neurons which relay nerve impulses away from the central nervous system.

By function
The peripheral nervous system is functionally as well as structurally divided into the *somatic nervous system* and *autonomic nervous system*. The *somatic nervous system* is responsible for coordinating the body movements, and also for receiving external stimuli. It is the system that regulates activities that are under conscious control. The *autonomic nervous system* is then split into the sympathetic division, parasympathetic division, and enteric division. The sympathetic nervous system responds to impending danger, and is responsible for the increase of one's heartbeat and blood pressure, among other physiological changes, along with the sense of excitement one feels due to the increase of adrenaline in the system. The parasympathetic nervous system, on the other hand, is evident when a person is resting and feels relaxed, and is responsible for such things as the constriction of the pupil, the slowing of the heart, the dilation of the blood vessels, and the stimulation of the digestive and *genitourinary* systems. The role of the enteric nervous system is to manage every aspect of digestion, from the esophagus to the stomach, small intestine and colon.

Naming of specific nerves
Ten out of the twelve *cranial nerves* originate from the brainstem, and mainly control the functions of the anatomic structures of the head with some exceptions. The nuclei of cranial nerves I and II lie in the forebrain and thalamus, respectively, and are thus not considered to be true cranial nerves. CN X (10) receives visceral sensory information from the thorax and abdomen, and CN XI (11) is responsible for innervating the sternocleidomastoid and trapezius muscles, neither of which is exclusively in the head.

*Spinal nerves* take their origins from the spinal cord. They control the functions of the rest of the body. In humans, there are 31 pairs of spinal nerves: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal. In the cervical region, the spinal nerve roots come out above the corresponding vertebrae (i.e. nerve root between the skull and 1st cervical vertebrae is called spinal nerve C1). From the thoracic region to the coccygeal region, the spinal nerve roots come out below the corresponding vertebrae. It is important to note that this method creates a problem when naming the spinal nerve root between C7 and T1 (so it is called spinal nerve root C8). In the lumbar and sacral region, the spinal nerve roots travel within the dural sac and they travel below the level of L2 as the cauda equina.

Cervical spinal nerves (C1-C4)
The first 4 cervical spinal nerves, C1 through C4, split and recombine to produce a variety of nerves that subserve the neck and back of head. Spinal nerve C1 is called the **suboccipital nerve** which provides motor innervation to muscles at the base of the skull. C2 and C3 form many of the nerves of the neck, providing both sensory and motor control. These include the **greater occipital nerve** which provides sensation to the back of the head, the **lesser occipital nerve** which provides sensation to the area behind the ears, the **greater auricular nerve** and the **lesser auricular nerve**. See occipital neuralgia. The **phrenic nerve** arises
from nerve roots C3, C4 and C5. It innervates the diaphragm, enabling breathing. If the spinal cord is transected above C3, then spontaneous breathing is not possible.

Brachial plexus (C5-T1)
The last four cervical spinal nerves, C5 through C8, and the first thoracic spinal nerve, T1, combine to form the brachial plexus, or plexus brachialis, a tangled array of nerves, splitting, combining and recombining, to form the nerves that subserve the arm and upper back. Although the brachial plexus may appear tangled, it is highly organized and predictable, with little variation between people. See brachial plexus injuries.

Before forming three cords
The first nerve off the brachial plexus, or plexus brachialis, is the dorsal scapular nerve, arising from C5 nerve root, and innervating the rhomboids and the levator scapulae muscles. The long thoracic nerve arises from C5, C6 and C7 to innervate the serratus anterior. The brachial plexus first forms three trunks, the superior trunk, composed of the C5 and C6 nerve roots, the middle trunk, made of the C7 nerve root, and the inferior trunk, made of the C8 and T1 nerve roots. The suprascapular nerve is an early branch of the superior trunk. It innervates the supraspinatus and infraspinatus muscles, part of the rotator cuff. The trunks reshuffle as they traverse towards the arm into cords. There are three of them. The lateral cord is made up of fibers from the superior and middle trunk. The posterior cord is made up of fibers from all three trunks. The medial cord is composed of fibers solely from the inferior trunk.

Lateral cord
The lateral cord gives rise to the following nerves:
- The lateral pectoral nerve, C5, C6 and C7 to the pectoralis major muscle, or musculus pectoralis major.
- The musculocutaneous nerve which innervates the biceps muscle
- The median nerve, partly. The other part comes from the medial cord. See below for

Posterior cord
- The posterior cord gives rise to the following nerves:
  - The upper subscapular nerve, C7 and C8, to the subscapularis muscle, or musculus supca of the rotator cuff.
  - The lower subscapular nerve, C5 and C6, to the teres major muscle, or the musculus teres major.
  - The thoracodorsal nerve, C6, C7 and C8, to the latissimus dorsi muscle, or musculus latissimus dorsi.
  - The axillary nerve, which supplies sensation to the shoulder and motor to the deltoid muscle or musculus deltoideus, and the teres minor muscle, or musculus teres minor, also of the rotator cuff.
  - The radial nerve, or nervus radialis, which innervates the triceps brachii muscle, the brachioradialis muscle, or musculus brachioradialis, the extensor muscles of the fingers and
wrist (extensor carpi radialis muscle), and the extensor and abductor muscles of the thumb. See radial nerve injuries.

Medial cord
The medial cord gives rise to the following nerves:

- The median pectoral nerve, C8 and T1, to the pectoralis muscle
- The medial brachial cutaneous nerve, T1
- The medial antebrachial cutaneous nerve, C8 and T1
- The median nerve, partly. The other part comes from the lateral cord. C7, C8 and T1 nerve roots. The first branch of the median nerve is to the pronator teres muscle, then the flexor carpi radialis, the palmaris longus and the flexor digitorum superficialis. The median nerve provides sensation to the anterior palm, the anterior thumb, index finger and middle finger. It is the nerve compressed in carpal tunnel syndrome.

- The ulnar nerve originates in nerve roots C7, C8 and T1. It provides sensation to the ring and pinky fingers. It innervates the flexor carpi ulnaris muscle, the flexor digitorum profundus muscle to the ring and pinky fingers, and the intrinsic muscles of the hand (the interosseous muscle, the lumbrical muscles and the flexor pollicus brevis muscle). This nerve traverses a groove on the elbow called the cubital tunnel, also known as the funny bone. Striking the nerve at this point produces an unpleasant sensation in the ring and little finger.

Neurotransmitters
The main neurotransmitters of the peripheral nervous system are acetylcholine and noradrenaline. However, there are several other neurotransmitters as well, jointly labeled Non-noradrenergic, non-cholinergic (NANC) transmitters. Examples of such transmitters include non-peptides: ATP, GABA, dopamine, NO, and peptides: neuropeptide Y, VIP, GnRH, Substance P and CGRP.

Cerebral Hemisphere
A cerebral hemisphere (hemispherium cerebrale) is one of the two regions of the eutherian brain that are delineated by the median plane, (medial longitudinal fissure). The brain can thus be described as being divided into left and right cerebral hemispheres. Each of these hemispheres has an outer layer of grey matter called the cerebral cortex that is supported by an inner layer of white matter. The hemispheres are linked by the corpus callosum, a very large bundle of nerve fibers, and also by other smaller commissures, including the anterior commissure, posterior commissure, and hippocampal commissure. These commissures transfer information between the two hemispheres to coordinate localized functions. The architecture, types of cells, types of neurotransmitters and receptor subtypes are all distributed among the two hemispheres in a markedly asymmetric fashion. However, while some of these hemispheric distribution differences are consistent across human beings, or even across some species, many observable distribution differences vary from individual to individual within a given species.

Embryological development
The cerebral hemispheres are derived from the telencephalon. They arise five weeks after conception as bilateral invaginations of the walls. The hemispheres grow round in a C-shape and then back again, pulling all structures internal to the hemispheres (such as the ventricles) with them. The interventricular foramen (sometimes called the interventricular foramena of munro) allows communication with the lateral ventricle. The choroid plexus is formed from ependymal cells and vascular mesenchyme.
Hemisphere lateralization
Hand preference (which hand someone prefers to use) has to do with hemisphere lateralization. Broad generalizations are often made in popular psychology about certain function (eg. logic, creativity) being lateralised, that is, located in the right or left side of the brain. These ideas need to be treated carefully because the popular lateralizations are often distributed across both sides.

The best evidence of lateralization for one specific ability is language. Both of the major areas involved in language skills, Broca's area and Wernicke's area, are in the left hemisphere. Perceptual information from the eyes, ears, and rest of the body is sent to the opposite hemisphere, and motor information sent out to the body also comes from the opposite hemisphere (see also primary sensory areas).

Neuropsychologists (e.g. Roger Sperry, Michael Gazzaniga) have studied split-brain patients to better understand lateralization. Sperry pioneered the use of lateralized tachistoscopes to present visual information to one hemisphere or the other. Scientists have also studied people born without a corpus callosum to determine specialization of brain hemispheres.

The magnocellular pathway of the visual system sends more information to the right hemisphere, while the parvocellular pathway sends more information to the left hemisphere. There are higher levels of the neurotransmitter norepinephrine on the right and higher levels of dopamine on the left. There is more white-matter (longer axons) on right and more grey-matter (cell bodies) on the left.

Linear reasoning functions of language such as grammar and word production are often lateralized to the left hemisphere of the brain. In contrast, holistic reasoning functions of language such as intonation and emphasis are often lateralized to the right hemisphere of the brain. Other integrative functions such as intuitive or heuristic arithmetic, binaural sound localization, emotions, etc. seem to be more bilaterally controlled.

**Left hemisphere functions**  **Right hemisphere functions**

numerical computation (exact calculation, numerical comparison, estimation)  numerical computation (approximate calculation, numerical comparison, estimation)
left hemisphere only: direct fact retrieval  language: intonation/accentuation, prosody, pragmatic, contextual
language: grammar/vocabulary, literal

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**Endocrine Gland**
Endocrine glands are glands of the endocrine system that secrete their products, hormones, directly into the blood rather than through a duct. The main endocrine glands include the pituitary gland, pancreas, ovaries, testes, thyroid gland, and adrenal glands. The hypothalamus is a neuroendocrine organ. Other organs which are not so well known for their endocrine activity include the stomach, which produces such hormones as ghrelin.

Local chemical messengers, not generally considered part of the endocrine system, include autocrines, which act on the cells that secrete them, and paracrines, which act on a different cell type nearby.

**Chemistry**
Most hormones are steroid- or amino acid-based. Hormones alter cell activity by stimulating or inhibiting characteristic cellular processes of their target cells. Cell responses to hormone stimulation may involve changes in membrane permeability; enzyme synthesis, activation, or inhibition; secretory activity; gene activation; and mitosis. Second-messenger mechanisms employing intracellular messengers and transduced by G proteins are a common means by which amino acid–based hormones interact with their target cells. In the cyclic AMP system, the hormone binds to a plasma membrane receptor that couples to a G protein.
When the G protein is activated it, in turn, couples to adenylate cyclase, which catalyzes the synthesis of cyclic AMP from ATP. Cyclic AMP initiates reactions that activate protein kinases and other enzymes, leading to cellular response. The PIP-calcium signal mechanism, involving phosphatidyl inositol, is another important second-messenger system. Other second messengers are cyclic GMP and calcium. Steroid hormones (and thyroid hormone) enter their target cells and effect responses by activating DNA, which initiates messenger RNA formation leading to protein synthesis. Target cell specificity The ability of a target cell to respond to a hormone depends on the presence of receptors, within the cell or on its plasma membrane, to which the hormone can bind. Hormone receptors are dynamic structures. Changes in number and sensitivity of hormone receptors may occur in response to high or low levels of stimulating hormones.
Blood levels of hormones reflect a balance between secretion and degradation/excretion. The liver and kidneys are the major organs that degrade hormones; breakdown products are excreted in urine and feces. Hormone half-life and duration of activity are limited and vary from hormone to hormone. Interaction of hormones at target cells Permissiveness is the situation in which a hormone cannot exert its full effects without the presence of another hormone. Synergism occurs when two or more hormones produce the same effects in a target cell and their results are amplified. Antagonism occurs when a hormone opposes or reverses the effect of another hormone.

Control of hormone release

Endocrine organs are activated to release their hormones by humoral, neural, or hormonal stimuli. Negative feedback is important in regulating hormone levels in the blood. The nervous system, acting through hypothalamic controls, can in certain cases override or modulate hormonal effects.

Major endocrine organs

**Pituitary gland**

The pituitary gland hangs from the base of the brain by a stalk and is enclosed by bone. It consists of a hormone-producing glandular portion (anterior pituitary) and a neural portion (posterior pituitary), which is an extension of the hypothalamus. The hypothalamus regulates the hormonal output of the anterior pituitary and synthesizes two hormones that it exports to the posterior pituitary of storage and later release. Four of the six adeno hypophyseal hormones are tropic hormones that regulate the function of other endocrine organs. Most anterior pituitary hormones exhibit a diurnal rhythm of release, which is subject to modification by stimuli influencing the hypothalamus.

**Somatotropic hormone** or **Growth hormone** (GH) is an anabolic hormone that stimulates growth of all body tissues but especially skeletal muscle and bone. It may act directly, or indirectly via insulin-like growth factors (IGFs). GH mobilizes fats, stimulates protein synthesis, and inhibits glucose uptake and metabolism. Secretion is regulated by growth hormone releasing hormone (GHRH) and growth hormone inhibiting hormone (GHIH), or somatostatin. Hypersecretion causes gigantism in children and acromegaly in adults; hyposecretion in children causes pituitary dwarfism.

**Thyroid-stimulating hormone** (TSH) promotes normal development and activity of the thyroid gland. Thyrotropin-releasing hormone (TRH) stimulates its release; negative feedback of thyroid hormone inhibits it.

**Adrenocorticotropic hormone** (ACTH) stimulates the adrenal cortex to release corticosteroids. ACTH release is triggered by corticotropin-releasing hormone (CRH) and inhibited by rising glucocorticoid levels.

The gonadotropins—follicle-stimulating hormone (FSH) and luteinizing hormone (LH) regulate the functions of the gonads in both sexes. FSH stimulates sex cell production; LH stimulates gonadal hormone production. Gonadotropin levels rise in response to gonadotropin-releasing hormone (GnRH). Negative feedback of gonadal hormones inhibits gonadotropin release.

**Prolactin** (PRL) promotes milk production in humans. Its secretion is prompted by prolactin-releasing hormone (PRH) and inhibited by prolactin-inhibiting hormone (PIH). The neurohypophysis stores and releases two hypothalamic hormones:
Oxytocin stimulates powerful uterine contractions, which trigger labor and delivery of an infant, and milk ejection in nursing women. Its release is mediated reflexively by the hypothalamus and represents a positive feedback mechanism. Antidiuretic hormone (ADH) stimulates the kidney tubules to reabsorb and conserve water, resulting in small volumes of highly concentrated urine and decreased plasma osmolality. ADH is released in response to high solute concentrations in the blood and inhibited by low solute concentrations in the blood. Hyposecretion results in diabetes insipidus.

**Thyroid gland**
The thyroid gland is located in the anterior throat. Thyroid follicles store colloid containing thyroglobulin, a glycoprotein from which thyroid hormone is derived. Thyroid hormone (TH) includes thyroxine (T4) and triiodothyronine (T3), which increase the rate of cellular metabolism. Consequently, oxygen use and heat production rise. Secretion of thyroid hormone, prompted by TSH, requires reuptake of the stored colloid by the follicle cells and splitting of the hormones from the colloid for release. Rising levels of thyroid hormone feed back to inhibit the pituitary and hypothalamus.

Most T4 is converted to T3 (the more active form) in the target tissues. These hormones act by turning on gene transcription and protein synthesis. Graves’ disease is the most common cause of hyperthyroidism; hyposecretion causes cretinism in infants and myxedema in adults. Calcitonin, produced by the parafollicular cells of the thyroid gland in response to rising blood calcium levels, depresses blood calcium levels by inhibiting bone matrix resorption and enhancing calcium deposit in bone.

**Parathyroid glands**
The parathyroid glands, located on the dorsal aspect of the thyroid gland, secrete parathyroid hormone (PTH), which causes an increase in blood calcium levels by targeting bone, the intestine, and the kidneys. PTH is the antagonist of calcitonin. PTH release is triggered by falling blood calcium levels and is inhibited by rising blood calcium levels. Hyperparathyroidism results in hypercalcaemia and all its effects and in extreme bone wasting. Hypoparathyroidism leads to hypocalcaemia, evidenced by tetany and respiratory paralysis.

**Pancreas**
The pancreas, located in the abdomen close to the stomach, is both an exocrine and an endocrine gland. The endocrine portion (pancreatic islets) releases insulin and glucagon and smaller amounts of other hormones to the blood. Glucagon, released by alpha (α) cells when glucose level in blood are low, stimulates the liver to release glucose to the blood. Insulin is released by beta (β) cells when blood levels of glucose (and amino acids) are rising. It increases the rate of glucose uptake and metabolism by most body cells. Hyposecretion of insulin results in diabetes mellitus; cardinal signs are polyuria, polydipsia, and polyphagia.

**Gonads**
The ovaries of the female, located in the pelvic cavity, release two main hormones. Secretion of estrogens by the ovarian follicles begins at puberty under the influence of FSH. Estrogens stimulate maturation of the female reproductive system and development of the secondary sex characteristics. Progesterone is released in response to high blood levels of LH. It works with estrogens in establishing the menstrual cycle.
The testes of the male begin to produce testosterone at puberty in response to LH. Testosterone promotes maturation of the male reproductive organs, development of secondary sex characteristics, and production of sperm by the testes.

**Pineal gland**

The pineal gland is located in the diencephalon. Its primary hormone is melatonin, which influences daily rhythms and may have an antigonadotropic effect in humans.

Other hormone-producing structures:

Many body organs not normally considered endocrine organs contain isolated cell clusters that secrete hormones. Examples include the heart (atrial natriuretic peptide); gastrointestinal tract organs (gastrin, secretin, and others); the placenta (hormones of pregnancy—estrogen, progesterone, and others); the kidneys (erythropoietin and renin); skin (cholecalciferol); and adipose tissue (leptin and resistin).

Developmental aspects of the endocrine system:

Endocrine glands derive from all three germ layers. Those derived from mesoderm produce steroidal hormones; the others produce the amino acid–based hormones.

The natural decrease in function of the female’s ovaries during late middle age results in menopause. The efficiency of all endocrine glands seems to decrease gradually as aging occurs. This leads to a generalized increase in the incidence of diabetes mellitus and a lower metabolic rate.

**Heredity and Behavior**

Many things affect the way human behavior develops, especially heredity and hormones. We are shaped by life experiences and how we react to those experiences can be traced back to hormones and our family histories. Both nature and how we were nurtured affect human behavior. Heredity, or the genes that we are handed down from our parents cannot be controlled (as of yet). We inherit certain genes from each of our parents at conception. This combination of genes creates a whole new genetic combination that is unique to the individual. The combination of genes create physical traits that can be apparent or appear later in life. Some of these traits are affected by the environment. There are "factors" that determine if the trait will be apparent. A person that has a genetic disposition to diabetes may not get the disease if they maintain a healthy diet throughout their life.

There are many traits that can be attributed to heredity. Freckles on a person's face can be attributed to a gene that one of the parents of this person was carrying. However, physical attributes are not the only traits that can be credited to our parent's genes. A person with anxiety, depression, schizophrenia, and many other mental illnesses have a tendency to also have a family history of the illness. According to Morris and Maisto (2005), "Siblings of people with schizophrenia are about eight times more likely, and the children of schizophrenic parents about ten times more likely, to develop the disorder than someone chosen randomly from the general population." As with some physical traits, the predisposition to mental illness does not always dictate whether the person will get the disease. Having a blood relative with the disease just increases the chances that the same disease will be apparent within the same family.

Identifying specific genes that cause aggression for example, are difficult to link to a specific gene. There have been many studies that have attempted to find a specific link or gene combination that creates a behavior but since behavior has a number of environmental factors, these studies have not been successful. Studies have been more successful in finding a link between missing or extra chromosomes with certain diseases and physical malformations.
Hormones are responsible for a number of human functions which include growth, development, metabolism, sexual desire and reproduction. Hormones also have a huge impact on human behavior, especially mood. Many people only become aware of hormones at the onset of puberty. At this time the body goes through physical and chemical changes. Physical attributes such as pubic hair appears and emotional fluctuations become apparent. The pituitary gland, the ovaries and gonads, the pineal gland, the thyroid gland, the parathyroid gland, and the pancreas are all responsible for releasing hormones. Each gland has a different hormone which in turn, is responsible for different functions of the body. For example, the thyroid gland releases the hormone thyroxin. Thyroxin is responsible for a person's metabolism, which determines if a person tends to gain weight or remain thin. There has been more attention paid to metabolism as people have become more health oriented. A slow metabolism is often to blame by people who have difficulty keeping extra weight at bay.

The thyroid gland that is responsible for metabolism is also responsible for a number of human behaviors. "An overactive thyroid can produce a variety of symptoms: overexcitablility, insomnia, reduced attention span, fatigue, agitation, acting out of character, and snap decisions, as well as reduced concentration and difficulty focusing on a task" (Morris and Maisto, 2005). Just as the thyroid gland is responsible for hormones that affect a number of symptoms, so too are other glands. Estrogen and testosterone are hormones that both men and women become aware of in early adulthood. Both of these hormones are responsible for sexual desire but play different roles in opposite sexes.

Testosterone has been attributed to triggering aggression. Men typically have a higher level of testosterone and are therefore more likely to be aggressive however women that are aggressive often times have higher levels of testosterone in their systems as well. Women have higher estrogen levels than men and experience different fluctuations of this hormone throughout the month. Estrogen reaches its highest level in women during ovulation. When the estrogen level drops off, it triggers the menstrual cycle. This drop in estrogen can cause females to become irritable and sometimes depressed. Hormone fluctuations of any kind can cause a shift in human behavior. Even a hormone that is responsible for regulating sugar can indirectly cause a behavior shift. A lack of sugar or too much of it, can cause many physical symptoms which in turn can cause a person to become irritable or sluggish.

As we can see, heredity can have an affect on human behavior as long as the circumstances are right. Hormones on the other hand, do have an affect on human behavior. Hormones do not need environmental influences to have an affect on behavior. Heredity and hormones together help to create personalities that are unique to each person.

Consciousness levels and Psychological basis.
An altered level of consciousness is an measure of arousal other than normal. Level of consciousness (LOC) is a measurement of a person's arousability and responsiveness to stimuli from the environment. A mildly depressed level of consciousness may be classed as lethargy; someone in this state can be aroused with little difficulty. People who are obtunded have a more depressed level of consciousness and cannot be fully aroused. Those who are not able to be aroused from a sleep-like state are said to be stuporous. Coma is the inability to make any purposeful response. Scales such as the Glasgow coma scale have been designed to measure level of consciousness.

An altered level of consciousness can result from a variety of factors, including alterations in the chemical environment of the brain (e.g. exposure to poisons), insufficient oxygen or blood flow in
the brain, and excessive pressure within the skull. Prolonged unconsciousness is understood to be a sign of a medical emergency. A deficit in the level of consciousness suggests that both of the cerebral hemispheres or the reticular activating system have been injured. A decreased level of consciousness correlates to increased morbidity (disability) and mortality (death). Thus it is a valuable measure of a patient's medical and neurological status. In fact, some sources consider level of consciousness to be one of the vital signs.

### Definition

Scales and terms to classify the levels of consciousness differ, but in general, reduction in response to stimuli indicates an altered level of consciousness:

### Levels of consciousness

<table>
<thead>
<tr>
<th>Level</th>
<th>Summary (Kruse)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conscious</td>
<td>Normal</td>
<td>Assessment of LOC involves checking <strong>orientation</strong>: people who are able promptly and spontaneously to state their name, location, and the date or time are said to be oriented to self, place, and time, or &quot;oriented X3&quot;. A normal <strong>sleep</strong> stage from which a person is easily awakened is also considered a normal level of consciousness. &quot;Clouding of consciousness&quot; is a term for a mild alteration of consciousness with alterations in attention and wakefulness. People who do not respond quickly with information about their name, location, and the time are considered &quot;obtuse&quot; or &quot;confused&quot;. A confused person may be bewildered, disoriented, and have difficulty following instructions. The person may have slow thinking and possible memory time loss. This could be caused by sleep deprivation, malnutrition, allergies, environmental pollution, drugs (prescription and nonprescription), and infection.</td>
</tr>
<tr>
<td>Confused</td>
<td>Disoriented; impaired thinking and responses</td>
<td></td>
</tr>
<tr>
<td>Delirious</td>
<td>Disoriented; restlessness, hallucinations, sometimes delusions</td>
<td></td>
</tr>
<tr>
<td>Somnolent</td>
<td>Sleepy</td>
<td>Some scales have &quot;delirious&quot; below this level, in which a person may be restless or agitated and exhibit a marked deficit in <strong>attention</strong>.</td>
</tr>
<tr>
<td>Obtunded</td>
<td>Decreased alertness; slowed psychomotor responses</td>
<td></td>
</tr>
<tr>
<td>Stuporous</td>
<td>Sleep-like state (not unconscious); little/no spontaneous activity</td>
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In **obtundation**, a person has a decreased interest in their surroundings, slowed responses, and sleepiness. People with an even lower level of consciousness, stupor, only respond by **grimacing** or drawing away from painful stimuli.
Comatose

Cannot be aroused; no Comatose people do not even make this response to response to stimuli, have no corneal or gag reflex, and they may have no pupillary response to light.

Glasgow Coma Scale

The most commonly used tool for measuring LOC objectively is the Glasgow Coma Scale (GCS). It has come into almost universal use for assessing people with brain injury, or an altered level of consciousness. Verbal, motor, and eye-opening responses to stimuli are measured, scored, and added into a final score on a scale of 3–15, with a lower score being a more decreased level of consciousness.

Others

The AVPU scale is another means of measuring LOC: people are assessed to determine whether they are alert, responsive to verbal stimuli, responsive to painful stimuli, or unresponsive. To determine responsiveness to voice, a caregiver speaks to, or, failing that, yells at the person. Responsiveness to pain is determined with a mild painful stimulus such as a pinch; moaning or withdrawal from the stimulus is considered a response to pain. The ACDU scale, like AVPU, is easier to use than the GCS and produces similarly accurate results. Using ACDU, a patient is assessed for alertness, confusion, drowsiness, and unresponsiveness. The Grady Coma Scale classes people on a scale of I to V along a scale of confusion, stupor, deep stupor, abnormal posturing, and coma.

Differential diagnosis

A lowered level of consciousness indicate a deficit in brain function. Level of consciousness can be lowered when the brain receives insufficient oxygen (as occurs in hypoxia); insufficient blood (as occurs in shock); or has an alteration in the brain's chemistry. Metabolic disorders such as diabetes mellitus and uremia can alter consciousness. Hypo- or hypernatremia (decreased and elevated levels of sodium, respectively) as well as dehydration can also produce an altered LOC. A pH outside of the range the brain can tolerate will also alter LOC. Exposure to drugs (e.g. alcohol) or toxins may also lower LOC, as may a core temperature that is too high or too low (hyperthermia or hypothermia). Increases in intracranial pressure (the pressure within the skull) can also cause altered LOC. It can result from traumatic brain injury such as concussion. Stroke and intracranial hemorrhage are other causes. Infections of the central nervous system may also be associated with decreased LOC; for example, an altered LOC is the most common symptom of encephalitis. Neoplasms within the intracranial cavity can also affect consciousness, as can epilepsy and post-seizure states. A decreased LOC can also result from a combination of factors. A concussion, which is a mild traumatic brain injury (MTBI) may result in decreased LOC.

Pathophysiology

Although the neural science behind alertness, wakefulness, and arousal are not fully known, the reticular formation is known to play a role in these. The ascending reticular activating system is a postulated group of neural connections that receives sensory input and projects to the cerebral cortex through the midbrain and thalamus from the reticular formation. Since this system is thought to modulate wakefulness and sleep, interference with it, such as injury, illness, or metabolic disturbances, could alter the level of consciousness.

Normally, stupor and coma are produced by interference with the brain stem, such as can be caused by a lesion or indirect effects, such as brain herniation. Mass lesions in the brain stem normally cause coma due to their effects on the reticular formation. Mass lesions that occur above the tentorium cerebelli (pictured) normally do not significantly alter the level of consciousness unless they are very large or affect both cerebral hemispheres.
Diagnostic approach
Assessing LOC involves determining an individual's response to external stimuli. Speed and accuracy of responses to questions and reactions to stimuli such as touch and pain are noted. Reflexes, such as the cough and gag reflexes, are also means of judging LOC. Once the level of consciousness is determined, clinicians seek clues for the cause of any alteration.

Biofeedback

Biofeedback is the process of becoming aware of various physiological functions using instruments that provide information on the activity of those same systems, with a goal of being able to manipulate them at will. Processes that can be controlled include brainwaves, muscle tone, skin conductance, heart rate and pain perception. Biofeedback may be used to improve health or performance, and the physiological changes often occur in conjunction with changes to thoughts, emotions, and behavior. Eventually, these changes can be maintained without the use of extra equipment.

Definition
Three professional biofeedback organizations, the Association for Applied Psychophysiology and Biofeedback (AAPB), Biofeedback Certification Institution of America (BCIA), and the International Society for Neurofeedback and Research (ISNR), arrived at a consensus definition of biofeedback in 2008:

“Biofeedback is a process that enables an individual to learn how to change physiological activity for the purposes of improving health and performance. Precise instruments measure physiological activity such as brainwaves, heart function, breathing, muscle activity, and skin temperature. These instruments rapidly and accurately 'feed back' information to the user. The presentation of this information — often in conjunction with changes in thinking, emotions, and behavior — supports desired physiological changes. Over time, these changes can endure without continued use of an instrument.”

Table of Major Biofeedback Modalities

Electromyograph
An electromyograph (EMG) uses surface electrodes to detect muscle action potentials from underlying skeletal muscles that initiate muscle contraction. Clinicians record the surface electromyogram (SEMG) using one or more active electrodes that are placed over a target muscle and a reference electrode that is placed within six inches of either active. The SEMG is measured in microvolts (millionths of a volt). Biofeedback therapists use EMG biofeedback when treating anxiety and worry, chronic pain, computer-related disorder, essential hypertension, headache (migraine, mixed headache, and tension-type headache), low back pain, physical rehabilitation (cerebral palsy, incomplete spinal cord lesions, and stroke), temporomandibular joint disorder (TMD), torticollis, and fecal incontinence, urinary incontinence, and pelvic pain.

Feedback thermometer
A feedback thermometer detects skin temperature with a thermistor (a temperature-sensitive resistor) that is usually attached to a finger or toe and measured in degrees Celsius or Fahrenheit. Skin temperature mainly reflects arteriole diameter. Hand-warming and hand-cooling are produced by separate mechanisms, and their regulation involves different skills. Hand-warming involves arteriole vasodilation produced by a beta-2 adrenergic hormonal mechanism. Hand-cooling involves arteriole vasoconstriction produced by the increased firing of sympathetic C-fibers.
Biofeedback therapists use temperature biofeedback when treating chronic pain, edema, headache (migraine and tension-type headache), essential hypertension, Raynaud’s disease, anxiety, and stress.

**Electrodermograph**

An electrodermograph (EDG) measures skin electrical activity directly (skin conductance and skin potential) and indirectly (skin resistance) using electrodes placed over the digits or hand and wrist. Orienting responses to unexpected stimuli, arousal and worry, and cognitive activity can increase eccrine sweat gland activity, increasing the conductivity of the skin for electrical current. In skin conductance, an electrodermograph imposes an imperceptible current across the skin and measures how easily it travels through the skin. When anxiety raises the level of sweat in a sweat duct, conductance increases. Skin conductance is measured in microsiemens (millionths of a siemens). In skin potential, a therapist places an active electrode over an active site (e.g., the palmar surface of the hand) and a reference electrode over a relatively inactive site (e.g., forearm). Skin potential is the voltage that develops between eccrine sweat glands and internal tissues and is measured in millivolts (thousandths of a volt). In skin resistance, also called galvanic skin response (GSR), an electrodermograph imposes a current across the skin and measures the amount of opposition it encounters. Skin resistance is measured in kΩ (thousands of ohms).

Biofeedback therapists use electrodermal biofeedback when treating anxiety disorders, hyperhidrosis (excessive sweating), and stress. Electrodermal biofeedback is used as an adjunct to psychotherapy to increase client awareness of their emotions. In addition, electrodermal measures have long served as one of the central tools in polygraphy (lie detection) because they reflect changes in anxiety or emotional activation.

**Electroencephalograph**

An electroencephalograph (EEG) measures the electrical activation of the brain from scalp sites located over the human cortex. The EEG shows the amplitude of electrical activity at each cortical site, the amplitude and relative power of various wave forms at each site, and the degree to which each cortical site fires in conjunction with other cortical sites (coherence and symmetry). The EEG uses precious metal electrodes to detect a voltage between at least two electrodes located on the scalp. The EEG records both excitatory postsynaptic potentials (EPSPs) and inhibitory postsynaptic potentials (IPSPs) that largely occur in dendrites in pyramidal cells located in macrocolumns, several millimeters in diameter, in the upper cortical layers. Neurofeedback monitors both slow and fast cortical potentials.

Slow cortical potentials are gradual changes in the membrane potentials of cortical dendrites that last from 300 ms to several seconds. These potentials include the contingent negative variation (CNV), readiness potential, movement-related potentials (MRPs), and P300 and N400 potentials.

Fast cortical potentials range from 0.5 Hz to 100 Hz. The main frequency ranges include delta, theta, alpha, the sensorimotor rhythm, low beta, high beta, and gamma. The specific cutting points defining the frequency ranges vary considerably among professionals. Fast cortical potentials can be described by their predominant frequencies, but also by whether they are synchronous or asynchronous wave forms. Synchronous wave forms occur at regular periodic intervals, whereas asynchronous wave forms are irregular.

The synchronous delta rhythm ranges from 0.5 to 3.5 Hz. Delta is the dominant frequency from ages 1 to 2, and is associated in adults with deep sleep and brain pathology like trauma and tumors, and learning disability.

The synchronous theta rhythm ranges from 4 to 7 Hz. Theta is the dominant frequency in healthy young children and is associated with drowsiness or starting to sleep, REM sleep, hypnagogic
imagery (intense imagery experienced before the onset of sleep), hypnosis, attention, and processing of cognitive and perceptual information.

The synchronous alpha rhythm ranges from 8 to 13 Hz and is defined by its waveform and not by its frequency. Alpha activity can be observed in about 75% of awake, relaxed individuals and is replaced by low-amplitude desynchronized beta activity during movement, complex problem-solving, and visual focusing. This phenomenon is called alpha blocking.

The synchronous sensorimotor rhythm (SMR) ranges from 12 to 15 Hz and is located over the sensorimotor cortex (central sulcus). The sensorimotor rhythm is associated with the inhibition of movement and reduced muscle tone.

The beta rhythm consists of asynchronous waves and can be divided into low beta and high beta ranges (13–21 Hz and 20–32 Hz). Low beta is associated with activation and focused thinking. High beta is associated with anxiety, hypervigilance, panic, peak performance, and worry. EEG activity from 36 to 44 Hz is also referred to as gamma. Gamma activity is associated with perception of meaning and meditative awareness.

Neurotherapists use EEG biofeedback when treating addiction, attention deficit hyperactivity disorder (ADHD), learning disability, anxiety disorders (including worry, obsessive-compulsive disorder and posttraumatic stress disorder), depression, migraine, and generalized seizures.

**Photoplethysmograph**

A photoplethysmograph (PPG) measures the relative blood flow through a digit using a photoplethysmographic (PPG) sensor attached by a Velcro band to the fingers or to the temple to monitor the temporal artery. An infrared light source is transmitted through or reflected off the tissue, detected by a phototransistor, and quantified in arbitrary units. Less light is absorbed when blood flow is greater, increasing the intensity of light reaching the sensor.

A photoplethysmograph can measure blood volume pulse (BVP), which is the phasic change in blood volume with each heartbeat, heart rate, and heart rate variability (HRV), which consists of beat-to-beat differences in intervals between successive heartbeats.

A photoplethysmograph can provide useful feedback when temperature feedback shows minimal change. This is because the PPG sensor is more sensitive than a thermistor to minute blood flow changes. Biofeedback therapists can use a photoplethysmograph to supplement temperature biofeedback when treating chronic pain, edema, headache (migraine and tension-type headache), essential hypertension, Raynaud’s disease, anxiety, and stress.

**Electrocardiograph**

The electrocardiograph (ECG) uses electrodes placed on the torso, wrists, or legs, to measure the electrical activity of the heart and measures the interbeat interval (distances between successive R-wave peaks in the QRS complex). The interbeat interval, divided into 60 seconds, determines the heart rate at that moment. The statistical variability of that interbeat interval is what we call heart rate variability. The ECG method is more accurate than the PPG method in measuring heart rate variability.

Biofeedback therapists use HRV biofeedback when treating asthma, COPD, depression, fibromyalgia, heart disease, and unexplained abdominal pain.

**Pneumograph**

A pneumograph or respiratory strain gauge uses a flexible sensor band that is placed around the chest, abdomen, or both. The strain gauge method can provide feedback about the relative expansion/contraction of the chest and abdomen, and can measure respiration rate (the number of breaths per minute).[20] Clinicians can use a pneumograph to detect and correct dysfunctional breathing patterns and behaviors. Dysfunctional breathing patterns include clavicular breathing.
(breathing that primarily relies on the external intercostals and the accessory muscles of respiration to inflate the lungs), reverse breathing (breathing where the abdomen expands during exhalation and contracts during inhalation), and thoracic breathing (shallow breathing that primarily relies on the external intercostals to inflate the lungs). Dysfunctional breathing behaviors include apnea (suspension of breathing), gasping, sighing, and wheezing. A pneumograph is often used in conjunction with an electrocardiograph (ECG) or photoplethysmograph (PPG) in heart rate variability (HRV) training. Biofeedback therapists use pneumograph biofeedback with patients diagnosed with anxiety disorders, asthma, chronic pulmonary obstructive disorder (COPD), essential hypertension, panic attacks, and stress.

**Capnometer**
A capnometer or capnograph uses an infrared detector to measure end-tidal CO2 (the partial pressure of carbon dioxide in expired air at the end of expiration) exhaled through the nostril into a latex tube. The average value of end-tidal CO2 for a resting adult is 5% (36 Torr or 4.8 kPa). A capnometer is a sensitive index of the quality of patient breathing. Shallow, rapid, and effortful breathing lowers CO2, while deep, slow, effortless breathing increases it. Biofeedback therapists use capnometric biofeedback to supplement respiratory strain gauge biofeedback with patients diagnosed with anxiety disorders, asthma, chronic pulmonary obstructive disorder (COPD), essential hypertension, panic attacks, and stress.

**Hemoencephalography**
Hemoencephalography or HEG biofeedback is a functional infrared imaging technique. As its name describes, it measures the differences in the color of light reflected back through the scalp based on the relative amount of oxygenated and unoxygenated blood in the brain. Research continues to determine its reliability, validity, and clinical applicability. HEG is used to treat ADHD and migraine, and for research.

**Incontinence**
Mowrer detailed the use of a bedwetting alarm that sounds when children urinate while asleep. This simple biofeedback device can quickly teach children to wake up when their bladders are full and to contract the urinary sphincter and relax the detrusor muscle, preventing further urine release. Through classical conditioning, sensory feedback from a full bladder replaces the alarm and allows children to continue sleeping without urinating.

**EEG**
Caton recorded spontaneous electrical potentials from the exposed cortical surface of monkeys and rabbits, and was the first to measure event-related potentials (EEG responses to stimuli) in 1875. Danilevsky published Investigations in the Physiology of the Brain, which explored the relationship between the EEG and states of consciousness in 1877.
Beck published studies of spontaneous electrical potentials detected from the brains of dogs and rabbits, and was the first to document alpha blocking, where light alters rhythmic oscillations, in 1890.

Sherrington introduced the terms neuron and synapse and published the Integrative Action of the Nervous System in 1906.

Pravdich-Neminsky photographed the EEG and event related potentials from dogs, demonstrated a 12–14 Hz rhythm that slowed during asphyxiation, and introduced the term electrocerebrogram in 1912.

Forbes reported the replacement of the string galvanometer with a vacuum tube to amplify the EEG in 1920. The vacuum tube became the de facto standard by 1936.

Berger (1924) published the first human EEG data. He recorded electrical potentials from his son Klaus's scalp. At first he believed that he had discovered the physical mechanism for telepathy but was disappointed that the electromagnetic variations disappear only millimeters away from the skull. (He did continue to believe in telepathy throughout his life, however, having had a particularly confirming event regarding his sister). He viewed the EEG as analogous to the ECG and introduced the term elektenkephalogram. He believed that the EEG had diagnostic and therapeutic promise in measuring the impact of clinical interventions. Berger showed that these potentials were not due to scalp muscle contractions. He first identified the alpha rhythm, which he called the Berger rhythm, and later identified the beta rhythm and sleep spindles. He demonstrated that alterations in consciousness are associated with changes in the EEG and associated the beta rhythm with alertness. He described interictal activity (EEG potentials between seizures) and recorded a partial complex seizure in 1933. Finally, he performed the first QEEG, which is the measurement of the signal strength of EEG frequencies.

Adrian and Matthews confirmed Berger's findings in 1934 by recording their own EEGs using a cathode-ray oscilloscope. Their demonstration of EEG recording at the 1935 Physiological Society meetings in England caused its widespread acceptance. Adrian used himself as a subject and demonstrated the phenomenon of alpha blocking, where opening his eyes suppressed alpha rhythms.

Gibbs, Davis, and Lennox inaugurated clinical electroencephalography in 1935 by identifying abnormal EEG rhythms associated with epilepsy, including interictal spike waves and 3 Hz activity in absence seizures.

Bremer used the EEG to show how sensory signals affect vigilance in 1935.

Walter (1937, 1953) named the delta waves and theta waves, and the contingent negative variation (CNV), a slow cortical potential that may reflect expectancy, motivation, intention to act, or attention. He located an occipital lobe source for alpha waves and demonstrated that delta waves can help locate brain lesions like tumors. He improved Berger's electroencephalograph and pioneered EEG topography.

Kleitman has been recognized as the "Father of American sleep research" for his seminal work in the regulation of sleep-wake cycles, circadian rhythms, the sleep patterns of different age groups, and the effects of sleep deprivation. He discovered the phenomenon of rapid eye movement (REM) sleep with his graduate student Aserinsky in 1953.

Dement, another of Kleitman's students, described the EEG architecture and phenomenology of sleep stages and the transitions between them in 1955, associated REM sleep with dreaming in 1957, and documented sleep cycles in another species, cats, in 1958, which stimulated basic sleep research. He established the Stanford University Sleep Research Center in 1970.

Andersen and Andersson (1968) proposed that thalamic pacemakers project synchronous alpha rhythms to the cortex via thalamocortical circuits.
Kamiya (1968) demonstrated that the alpha rhythm in humans could be operantly conditioned. He published an influential article in Psychology Today that summarized research that showed that subjects could learn to discriminate when alpha was present or absent, and that they could use feedback to shift the dominant alpha frequency about 1 Hz. Almost half of his subjects reported experiencing a pleasant "alpha state" characterized as an "alert calmness." These reports may have contributed to the perception of alpha biofeedback as a shortcut to a meditative state. He also studied the EEG correlates of meditative states.

Brown (1970) demonstrated the clinical use of alpha-theta biofeedback. In research designed to identify the subjective states associated with EEG rhythms, she trained subjects to increase the abundance of alpha, beta, and theta activity using visual feedback and recorded their subjective experiences when the amplitude of these frequency bands increased. She also helped popularize biofeedback by publishing a series of books, including New Mind, New body (1974) and Stress and the Art of Biofeedback (1977).

Mulholland and Peper (1971) showed that occipital alpha increases with eyes open and not focused, and is disrupted by visual focusing; a rediscovery of alpha blocking.

Green and Green (1986) investigated voluntary control of internal states by individuals like Swami Rama and American Indian medicine man Rolling Thunder both in India and at the Menninger Foundation. They brought portable biofeedback equipment to India and monitored practitioners as they demonstrated self-regulation. A film containing footage from their investigations was released as Biofeedback: The Yoga of the West (1974). They developed alpha-theta training at the Menninger Foundation from the 1960s to the 1990s. They hypothesized that theta states allow access to unconscious memories and increase the impact of prepared images or suggestions. Their alpha-theta research fostered Peniston's development of an alpha-theta addiction protocol.

Sterman (1972) showed that cats and human subjects could be operantly trained to increase the amplitude of the sensorimotor rhythm (SMR) recorded from the sensorimotor cortex. He demonstrated that SMR production protects cats against drug-induced generalized seizures (tonic-clonic seizures involving loss of consciousness) and reduces the frequency of seizures in humans diagnosed with epilepsy. He found that his SMR protocol, which uses visual and auditory EEG biofeedback, normalizes their EEGs (SMR increases while theta and beta decrease toward normal values) even during sleep. Sterman also co-developed the Sterman-Kaiser (SKIL) QEEG database. Birbaumer and colleagues (1981) have studied feedback of slow cortical potentials since the late 1970s. They have demonstrated that subjects can learn to control these DC potentials and have studied the efficacy of slow cortical potential biofeedback in treating ADHD, epilepsy, migraine, and schizophrenia.

Lubar (1989) studied SMR biofeedback to treat attention disorders and epilepsy in collaboration with Sterman. He demonstrated that SMR training can improve attention and academic performance in children diagnosed with Attention Deficit Disorder with Hyperactivity (ADHD). He documented the importance of theta-to-beta ratios in ADHD and developed theta suppression-beta enhancement protocols to decrease these ratios and improve student performance.

**Electrodermal system**

Fére demonstrated the exosomatic method of recording of skin electrical activity by passing a small current through the skin in 1888.

Tarchanoff used the endosomatic method by recording the difference in skin electrical potential from points on the skin surface in 1889; no external current was applied.

Jung employed the galvanometer, which used the exosomatic method, in 1907 to study unconscious emotions in word-association experiments.
Marjorie and Hershel Toomim (1975) published a landmark article about the use of GSR biofeedback in psychotherapy.

**Musculoskeletal system**

Jacobson (1930) developed hardware to measure EMG voltages over time, showed that cognitive activity (like imagery) affects EMG levels, introduced the deep relaxation method Progressive Relaxation, and wrote Progressive Relaxation (1929) and You Must Relax (1934). He prescribed daily Progressive Relaxation practice to treat diverse psychophysiological disorders like hypertension.

Several researchers showed that human subjects could learn precise control of individual motor units (motor neurons and the muscle fibers they control). Lindsley (1935) found that relaxed subjects could suppress motor unit firing without biofeedback training.

Harrison and Mortensen (1962) trained subjects using visual and auditory EMG biofeedback to control individual motor units in the tibialis anterior muscle of the leg.

Basmajian (1963) instructed subjects using unfiltered auditory EMG biofeedback to control separate motor units in the abductor pollicis muscle of the thumb in his Single Motor Unit Training (SMUT) studies. His best subjects coordinated several motor units to produce drum rolls. Basmajian demonstrated practical applications for neuromuscular rehabilitation, pain management, and headache treatment.

Marinacci (1960) applied EMG biofeedback to neuromuscular disorders (where proprioception is disrupted) including Bell Palsy (one-sided facial paralysis), polio, and stroke.

"While Marinacci used EMG to treat neuromuscular disorders, his colleagues only used the EMG for diagnosis. They were unable to recognize its potential as a teaching tool even when the evidence stared them in the face! Many electromyographers who performed nerve conduction studies used visual and auditory feedback to reduce interference when a patient recruited too many motor units. Even though they used EMG biofeedback to guide the patient to relax so that clean diagnostic EMG tests could be recorded, they were unable to envision EMG biofeedback treatment of motor disorders."

Whatmore and Kohli (1968) introduced the concept of dysponesis (misplaced effort) to explain how functional disorders (where body activity is disturbed) develop. Bracing your shoulders when you hear a loud sound illustrates dysponesis since this action does not protect against injury. These clinicians applied EMG biofeedback to diverse functional problems like headache and hypertension. They reported case follow-ups ranging from 6 to 21 years. This was long compared with typical 0-24 month follow-ups in the clinical literature. Their data showed that skill in controlling misplaced efforts was positively related to clinical improvement. Last, they wrote The Pathophysiology and Treatment of Functional Disorders (1974) that outlined their treatment of functional disorders.

Wolf (1983) integrated EMG biofeedback into physical therapy to treat stroke patients and conducted landmark stroke outcome studies.

Peper (1997) applied SEMG to the workplace, studied the ergonomics of computer use, and promoted "healthy computing."

Taub (1999, 2006) demonstrated the clinical efficacy of constraint-induced movement therapy (CIMT) for the treatment of spinal cord-injured and stroke patients.

**Cardiovascular system**

Shearn (1962) operantly trained human subjects to increase their heart rates by 5 beats-per-minute to avoid electric shock. In contrast to Shearn's slight heart rate increases, Swami Rama used yoga to
produce atrial flutter at an average 306 beats per minute before a Menninger Foundation audience. This briefly stopped his heart's pumping of blood and silenced his pulse.

Engel and Chism (1967) operantly trained subjects to decrease, increase, and then decrease their heart rates (this was analogous to ON-OFF-ON EEG training). He then used this approach to teach patients to control their rate of premature ventricular contractions (PVCs), where the ventricles contract too soon. Engel conceptualized this training protocol as illness onset training, since patients were taught to produce and then suppress a symptom. Peper has similarly taught asthmatics to wheeze to better control their breathing.

Schwartz (1971, 1972) examined whether specific patterns of cardiovascular activity are easier to learn than others due to biological constraints. He examined the constraints on learning integrated (two autonomic responses change in the same direction) and differentiated (two autonomic responses change inversely) patterns of blood pressure and heart rate change.

Schultz and Luthe (1969) developed Autogenic Training, which is a deep relaxation exercise derived from hypnosis. This procedure combines passive volition with imagery in a series of three treatment procedures (standard Autogenic exercises, Autogenic neutralization, and Autogenic meditation). Clinicians at the Menninger Foundation coupled an abbreviated list of standard exercises with thermal biofeedback to create autogenic biofeedback. Luthe (1973) also published a series of six volumes titled Autogenic therapy.

Fahrion and colleagues (1986) reported on an 18-26 session treatment program for hypertensive patients. The Menninger program combined breathing modification, autogenic biofeedback for the hands and feet, and frontal EMG training. The authors reported that 89% of their medication patients discontinued or reduced medication by one-half while significantly lowering blood pressure. While this study did not include a double-blind control, the outcome rate was impressive.

Freedman and colleagues (1991) demonstrated that hand-warming and hand-cooling are produced by different mechanisms. The primary hand-warming mechanism is beta-adrenergic (hormonal), while the main hand-cooling mechanism is alpha-adrenergic and involves sympathetic C-fibers. This contradicts the traditional view that finger blood flow is exclusively controlled by sympathetic C-fibers. The traditional model asserts that when firing is slow, hands warm; when firing is rapid, hands cool. Freedman and colleagues’ studies support the view that hand-warming and hand-cooling represent entirely different skills.

Vaschillo and colleagues (1983) published the first studies of HRV biofeedback with cosmonauts and treated patients diagnosed with psychiatric and psychophysiological disorders. Lehrer collaborated with Smetankin and Potapova in treating pediatric asthma patients and published influential articles on HRV asthma treatment in the medical journal Chest.

**Pain**

Budzynski and Stoyva (1969) showed that EMG biofeedback could reduce frontalis muscle (forehead) contraction. They demonstrated in 1973 that analog (proportional) and binary (ON or OFF) visual EMG biofeedback were equally helpful in lowering masseter SEMG levels.

Budzynski, Stoyva, Adler, and Mullaney (1973) reported that auditory frontalis EMG biofeedback combined with home relaxation practice lowered tension headache frequency and frontalis EMG levels. A control group that received noncontingent (false) auditory feedback did not improve. This study helped make the frontalis muscle the placement-of-choice in EMG assessment and treatment of headache and other psychophysiological disorders.

Sargent, Green, and Walters (1972, 1973) demonstrated that hand-warming could abort migraines and that autogenic biofeedback training could reduce headache activity. The early Menninger migraine studies, although methodologically weak (no pretreatment baselines, control groups, or random assignment to conditions), strongly influenced migraine treatment.
Flor (2002) trained amputees to detect the location and frequency of shocks delivered to their stumps, which resulted in an expansion of corresponding cortical regions and significant reduction of their phantom limb pain. McNulty, Gevirtz, Hubbard, and Berkoff (1994) proposed that sympathetic nervous system innervation of muscle spindles underlies trigger points.

Module 3
SENSORY – PERCEPTUAL PROCESSES

Visual perception
Visual perception is the ability to interpret information and surroundings from visible light reaching the eye. The resulting perception is also known as eyesight, sight, or vision (adjectival form: visual, optical, or ocular). The various physiological components involved in vision are referred to collectively as the visual system, and are the focus of much research in psychology, cognitive science, neuroscience, and molecular biology.

Visual system
The visual system in humans allows individuals to assimilate information from the environment. The act of seeing starts when the lens of the eye focuses an image of its surroundings onto a light-sensitive membrane in the back of the eye, called the retina. The retina is actually part of the brain that is isolated to serve as a transducer for the conversion of patterns of light into neuronal signals. The lens of the eye focuses light on the photoreceptive cells of the retina, which detect the photons of light and respond by producing neural impulses. These signals are processed in a hierarchical fashion by different parts of the brain, from the retina to the lateral geniculate nucleus, to the primary and secondary visual cortex of the brain. Signals from the retina can also travel directly from the retina to the Superior colliculus.

Study of visual perception
The major problem in visual perception is that what people see is not simply a translation of retinal stimuli (i.e., the image on the retina). Thus people interested in perception have long struggled to explain what visual processing does to create what we actually see.

Early studies on visual perception
There were two major ancient Greek schools, providing a primitive explanation of how vision is carried out in the body. The first was the "emission theory" which maintained that vision occurs when rays emanate from the eyes and are intercepted by visual objects. If we saw an object directly it was by 'means of rays' coming out of the eyes and again falling on the object. A refracted image was, however, seen by 'means of rays' as well, which came out of the eyes, traversed through the air, and after refraction, fell on the visible object which was sighted as the result of the movement of the rays from the eye. This theory was championed by scholars like Euclid and Ptolemy and their followers. The second school advocated the so called 'intromission' approach which sees vision as coming from something entering the eyes representative of the object. With its main propagators Aristotle, Galen and their followers, this theory seems to have some contact with modern theories of what vision really is, but it remained only a speculation lacking any experimental foundation. Both schools of thought relied upon the principle that "like is only known by like," and thus upon the notion that the eye was composed of some "internal fire" which interacted with the "external
fire" of visible light and made vision possible. Plato makes this assertion in his dialogue, Timaeus; as does Aristotle, in his De Sensu.

Ibn al-Haytham (also known as Alhacen or Alhazen), the "father of optics", was the first to resolve this argument, by refining intromission theory into what is now the modern accepted theory of vision in his influential Book of Optics (1021). He argued that vision is due to light from objects entering the eye. However, he maintained that the part of the eye responsive to light was the lens, whereas we now know it is the retina. He developed an early scientific method emphasizing extensive experimentation. He pioneered the scientific study of the psychology of visual perception, being the first scientist to argue that vision occurs in the brain, rather than the eyes. He pointed out that personal experience has an effect on what people see and how they see, and that vision and perception are subjective. He explained possible errors in vision in detail, and as an example, describes how a small child with less experience may have more difficulty interpreting what he/she sees. He also gives an example of an adult that can make mistakes in vision because of how one's experience suggests that they are seeing one thing, when they are really seeing something else. This can be easily related to the famous saying "beauty lies in the eye of the beholder". Al-Haytham carried out many investigations and experiments on visual perception, extended the work of Ptolemy on binocular vision, and commented on the anatomical works of Galen.

Leonardo DaVinci (1452–1519) was the first to recognize the special optical qualities of the eye. He wrote "The function of the human eye ... was described by a large number of authors in a certain way. But I found it to be completely different." His main experimental finding was that there is only a distinct and clear vision at the line of sight, the optical line that ends at the fovea. Although he did not use these words literally he actually is the father of the modern distinction between foveal and peripheral vision.

Unconscious inference
Hermann von Helmholtz is often credited with the first study of visual perception in modern times. Helmholtz examined the human eye and concluded that it was, optically, rather poor. The poor quality information gathered via the eye seemed to him to make vision impossible. He therefore concluded that vision could only be the result of some form of unconscious inferences: a matter of making assumptions and conclusions from incomplete data, based on previous experiences. Inference requires prior experience of the world: examples of well-known assumptions, based on visual experience, are:
- light comes from above
- objects are normally not viewed from below
- faces are seen (and recognized) upright.

The study of visual illusions (cases when the inference process goes wrong) has yielded much insight into what sort of assumptions the visual system makes.

Another type of the unconscious inference hypothesis (based on probabilities) has recently been revived in so-called Bayesian studies of visual perception. Proponents of this approach consider that the visual system performs some form of Bayesian inference to derive a perception from sensory data. Models based on this idea have been used to describe various visual subsystems, such as the perception of motion or the perception of depth.

Gestalt theory
Gestalt psychologists working primarily in the 1930s and 1940s raised many of the research questions that are studied by vision scientists today.
The Gestalt Laws of Organization have guided the study of how people perceive visual components as organized patterns or wholes, instead of many different parts. Gestalt is a German word that translates to "configuration or pattern". According to this theory, there are six main factors that determine how we group things according to visual perception: Proximity, Similarity, Closure, Symmetry, Common fate and Continuity.

One of the reasons why Gestalt laws are often disregarded by cognitive psychologists is their inability to explain the nature of peripheral vision. In Gestalt theory, visual perception only takes place during fixations.

However, during fixations both the high definition foveal vision at the fixation point and the peripheral vision are functioning. Because of its lack of acuity and relative independence of eye position (due to its extreme wide angle), human vision is an image compressing system. While foveal vision is very slow (from only three to four high-quality telescopic images per second), peripheral vision is very inaccurate but also very fast (up to 90 images per second - permitting one to see the flicker of the European 50Hz TV images). Elements of the visual field are thus grouped automatically according to laws like Proximity, Similarity, Closure, Symmetry, Common fate and Continuity.

**Analysis of eye movement**

During the 1960s, technical development permitted the continuous registration of eye movement during reading in picture viewing and later in visual problem solving and when headset-cameras became available, also during driving.

The picture to the left shows what may happen during the first two seconds of visual inspection. While the background is out of focus, representing the peripheral vision, the first eye movement goes to the boots of the man (just because they are very near the starting fixation and have a reasonable contrast).

The following fixations jump from face to face. They might even permit comparisons between faces.

It may be concluded that the icon face is a very attractive search icon within the peripheral field of vision. The foveal vision adds detailed information to the peripheral first impression.

The cognitive and computational approaches

The major problem with the Gestalt laws (and the Gestalt school generally) is that they are descriptive not explanatory. For example, one cannot explain how humans see continuous contours by simply stating that the brain "prefers good continuity". Computational models of vision have had more success in explaining visual phenomena and have largely superseded Gestalt theory. More recently, the computational models of visual perception have been developed for Virtual Reality systems - these are closer to real life situation as they account for motion and activities which populate the real world. Regarding Gestalt influence on the study of visual perception, Bruce, Green & Georgeson conclude:

"The physiological theory of the Gestaltists has fallen by the wayside, leaving us with a set of descriptive principles, but without a model of perceptual processing. Indeed, some of their "laws" of perceptual organisation today sound vague and inadequate. What is meant by a "good" or "simple" shape, for example?"

In the 1970s David Marr developed a multi-level theory of vision, which analysed the process of vision at different levels of abstraction. In order to focus on the understanding of specific problems in vision, he identified (with Tomaso Poggio) three levels of analysis: the computational, algorithmic and implementational levels.

The computational level addresses, at a high level of abstraction, the problems that the visual system must overcome. The algorithmic level attempts to identify the strategy that may be used to
solve these problems. Finally, the implementational level attempts to explain how these problems are overcome in terms of the actual neural activity necessary. Marr suggested that it is possible to investigate vision at any of these levels independently. Marr described vision as proceeding from a two-dimensional visual array (on the retina) to a three-dimensional description of the world as output. His stages of vision include:

- a **2D** or **primal sketch** of the scene, based on feature extraction of fundamental components of the scene, including edges, regions, etc. Note the similarity in concept to a pencil sketch drawn quickly by an artist as an impression.

- a **2-1/2 D sketch** of the scene, where textures are acknowledged, etc. Note the similarity in concept to the stage in drawing where an artist highlights or shades areas of a scene, to provide depth.

- a **3 D model**, where the scene is visualized in a continuous, 3-dimensional map.

**Artificial Visual Perception**

The theory and the observations on visual perception have been the main source of inspiration for computer vision (also called machine vision, or computational vision). Special hardware structures and software algorithms provide machines with the capability to interpret the images coming from a camera or a sensor. Artificial Visual Perception has long been used in the industry and is now entering the domains of automotive and robotics.

**Auditory Perception**

**Hearing** (or **audition**; adjectival form: "auditory" or "aural") is one of the traditional five **senses**. It is the ability to perceive **sound** by detecting vibrations via an organ such as the **ear**. The inability to hear is called **deafness**.

In humans and other vertebrates, hearing is performed primarily by the **auditory system**: vibrations are detected by the **ear** and transduced into nerve impulses that are perceived by the **brain** (primarily in the **temporal lobe**). Like **touch**, audition requires sensitivity to the movement of molecules in the world outside the organism. Both hearing and touch are types of mechanosensation.

**Hearing tests**

Hearing can be measured by behavioral tests using an **audiometer**. Electrophysiological tests of hearing can provide accurate measurements of hearing thresholds even in unconscious subjects. Such tests include **auditory brainstem evoked potentials** (ABR), **otoacoustic emissions** (OAE) and **electrocochleography** (EchoG). Technical advances in these tests have allowed hearing screening for infants to become widespread.

**Hearing underwater**

Hearing threshold and the ability to localize sound sources are reduced underwater, in which the speed of sound is faster than in air. Underwater hearing is by **bone conduction**, and localization of sound appears to depend on differences in amplitude detected by bone conduction.

**Hearing in animals**

Not all sounds are normally audible to all animals. Each species has a range of normal hearing for both loudness (amplitude) and pitch (**frequency**). Many animals use sound to communicate with each other, and hearing in these species is particularly important for survival and reproduction. In species that use sound as a primary means of communication, hearing is typically most acute for the range of pitches produced in calls and speech. Frequencies capable of being heard by humans are called **audio** or sonic. The range is typically considered to be between 20Hz and 20,000Hz. Frequencies higher than audio are referred to as
ultrasonic, while frequencies below audio are referred to as infrasonic. Some bats use ultrasound for echolocation while in flight. Dogs are able to hear ultrasound, which is the principle of 'silent' dog whistles. Snakes sense infrasound through their bellies, and whales, giraffes, dolphins and elephants use it for communication.

Certain animals also have more sensitive hearing than humans which enable to hear sounds too faint to be detected by humans.

Introduction to ears and hearing

Audition is the scientific name for the sense of sound. Sound is a form of energy that moves through air, water, and other matter, in waves of pressure. Sound is the means of auditory communication, including frog calls, bird songs and spoken language. Although the ear is the vertebrate sense organ that recognizes sound, it is the brain and central nervous system that "hears". Sound waves are perceived by the brain through the firing of nerve cells in the auditory portion of the central nervous system. The ear changes sound pressure waves from the outside world into a signal of nerve impulses sent to the brain.

The outer part of the ear collects sound. That sound pressure is amplified through the middle portion of the ear and, in land animals, passed from the medium of air into a liquid medium. The change from air to liquid occurs because air surrounds the head and is contained in the ear canal and middle ear, but not in the inner ear. The inner ear is hollow, embedded in the temporal bone, the densest bone of the body. The hollow channels of the inner ear are filled with liquid, and contain a sensory epithelium that is studded with hair cells. The microscopic "hairs" of these cells are structural protein filaments that project out into the fluid. The hair cells are mechanoreceptors that release a chemical neurotransmitter when stimulated. Sound waves moving through fluid push the filaments; if the filaments bend over enough it causes the hair cells to fire. In this way sound waves are transformed into nerve impulses. In vision, the rods and cones of the retina play a similar role with light as the hair cells do with sound. The nerve impulses travel from the left and right ears through the eighth cranial nerve to both sides of the brain stem and up to the portion of the cerebral cortex dedicated to sound. This auditory part of the cerebral cortex is in the temporal lobe.
Anatomy of the human ear. The length of the auditory canal is exaggerated for viewing purposes. The part of the ear that is dedicated to sensing balance and position also sends impulses through the eighth cranial nerve, the VIIIth nerve's Vestibular Portion. Those impulses are sent to the vestibular portion of the central nervous system. The human ear can generally hear sounds with frequencies between 20 Hz and 20 kHz (the audio range). Although the sensation of hearing requires an intact and functioning auditory portion of the central nervous system as well as a working ear, human deafness (extreme insensitivity to sound) most commonly occurs because of abnormalities of the inner ear, rather than the nerves or tracts of the central auditory system.

Outer ear (pinna, ear canal, surface of ear drum)
The outer ear is the most external portion of the ear. The outer ear includes the pinna (also called auricle), the ear canal, and the very most superficial layer of the ear drum (also called the tympanic membrane). In humans, and almost all vertebrates, the only visible portion of the ear is the outer ear. Although the word "ear" may properly refer to the pinna (the flesh covered cartilage appendage on either side of the head), this portion of the ear is not vital for hearing. The outer ear does help get sound (and imposes filtering), but the ear canal is very important. Unless the canal is open, hearing will be dampened. Ear wax (cerumen) is produced by glands in the skin of the outer portion of the ear canal. This outer ear canal skin is applied to cartilage; the thinner skin of the deep canal lies on the bone of the skull. Only the thicker cerumen-producing ear canal skin has hairs. The outer ear ends at the most superficial layer of the tympanic membrane. The tympanic membrane is
commonly called the ear drum. The pinna helps direct sound through the ear canal to the tympanic membrane (eardrum).

The framework of the auricle consists of a single piece of yellow fibrocartilage with a complicated relief on the anterior, concave side and a fairly smooth configuration on the posterior, convex side. The Darwinian tubercle, which is present in some people, lies in the descending part of the helix and corresponds to the true ear tip of the long-eared mammals. The lobule merely contains subcutaneous tissue. In some animals with mobile pinnae (like the horse), each pinna can be aimed independently to better receive the sound. For these animals, the pinnae help localize the direction of the sound source. Human beings localize sound within the central nervous system, by comparing arrival-time differences and loudness from each ear, in brain circuits that are connected to both ears. This process is commonly referred to as EPS, or Echo Positioning System.

**Human outer ear and culture**

The auricles also have an effect on facial appearance. In Western societies, protruding ears (present in about 5% of ethnic Europeans) have been considered unattractive, particularly if asymmetric. The first surgery to reduce the projection of prominent ears was published in the medical literature in 1881.

The ears have also been ornamented with jewelry for thousands of years, traditionally by piercing of the earlobe. In some cultures, ornaments are placed to stretch and enlarge the earlobes to make them very large. Tearing of the earlobe from the weight of heavy earrings, or from traumatic pull of an earring (for example by snagging on a sweater being removed), is fairly common. The repair of such a tear is usually not difficult.

A cosmetic surgical procedure to reduce the size or change the shape of the ear is called an otoplasty. In the rare cases when no pinna is formed (atresia), or is extremely small (microtia) reconstruction of the auricle is possible. Most often, a cartilage graft from another part of the body (generally, rib cartilage) is used to form the matrix of the ear, and skin grafts or rotation flaps are used to provide the covering skin. Recently ears have been grown on a rat's back and attached to human heads after. However, when babies are born without an auricle on one or both sides, or when the auricle is very tiny, the ear canal is ordinarily either small or absent, and the middle ear often has deformities. The initial medical intervention is aimed at assessing the baby's hearing and the condition of the ear canal, as well as the middle and inner ear. Depending on the results of tests, reconstruction of the outer ear is done in stages, with planning for any possible repairs of the rest of the ear.

**Middle ear**

The middle ear, an air-filled cavity behind the ear drum (tympanic membrane), includes the three ear bones or ossicles: the malleus (or hammer), incus (or anvil), and stapes (or stirrup). The opening of the Eustachian tube is also within the middle ear. The malleus has a long process (the manubrium, or handle) that is attached to the mobile portion of the eardrum. The incus is the bridge between the malleus and stapes. The stapes is the smallest named bone in the human body. The three bones are arranged so that movement of the tympanic membrane causes movement of the malleus, which causes movement of the incus, which causes movement of the stapes. When the stapes footplate pushes on the oval window, it causes movement of fluid within the cochlea (a portion of the inner ear).

In humans and other land animals the middle ear (like the ear canal) is normally filled with air. Unlike the open ear canal, however, the air of the middle ear is not in direct contact with the atmosphere outside the body. The Eustachian tube connects from the chamber of the middle ear to the back of the pharynx. The middle ear is very much like a specialized paranasal sinus, called the
tympanic cavity; it, like the paranasal sinuses, is a hollow mucosa-lined cavity in the skull that is ventilated through the nose. The mastoid portion of the human temporal bone, which can be felt as a bump in the skull behind the pinna, also contains air, which is ventilated through the middle ear.

**Components of the middle ear**

Normally, the Eustachian tube is collapsed, but it gapes open both with swallowing and with positive pressure. When taking off in an airplane, the surrounding air pressure goes from higher (on the ground) to lower (in the sky). The air in the middle ear expands as the plane gains altitude, and pushes its way into the back of the nose and mouth. On the way down, the volume of air in the middle ear shrinks, and a slight vacuum is produced. Active opening of the Eustachian tube is required to equalize the pressure between the middle ear and the surrounding atmosphere as the plane descends. The diver also experiences this change in pressure, but with greater rates of pressure change; active opening of the Eustachian tube is required more frequently as the diver goes deeper into higher pressure.

The arrangement of the tympanic membrane and ossicles works to efficiently couple the sound from the opening of the ear canal to the cochlea. There are several simple mechanisms that combine to increase the sound pressure. The first is the “hydraulic principle”. The surface area of the tympanic membrane is many times that of the stapes footplate. Sound energy strikes the tympanic membrane and is concentrated to the smaller footplate. A second mechanism is the "lever principle". The dimensions of the articulating ear ossicles lead to an increase in the force applied to the stapes footplate compared with that applied to the malleus. A third mechanism channels the sound pressure to one end of the cochlea, and protects the other end from being struck by sound waves. In humans, this is called "round window protection", and will be more fully discussed in the next section.

Abnormalities such as impacted ear wax (occlusion of the external ear canal), fixed or missing ossicles, or holes in the tympanic membrane generally produce conductive hearing loss. Conductive hearing loss may also result from middle ear inflammation causing fluid build-up in the normally air-filled space. Tympanoplasty is the general name of the operation to repair the middle ear's tympanic membrane and ossicles. Grafts from muscle fascia are ordinarily used to rebuild an intact ear drum. Sometimes artificial ear bones are placed to substitute for damaged ones, or a disrupted ossicular chain is rebuilt in order to conduct sound effectively.

**Inner ear: cochlea, vestibule, and semi-circular canals**

The inner ear includes both the organ of hearing (the **cochlea**) and a sense organ that is attuned to the effects of both gravity and motion (**labyrinth** or vestibular apparatus). The balance portion of the inner ear consists of three **semi-circular canals** and the **vestibule**. The inner ear is encased in the hardest bone of the body. Within this ivory hard bone, there are fluid-filled hollows. Within the cochlea are three fluid filled spaces: the tympanic canal, the vestibular canal, and the middle canal. The eighth cranial nerve comes from the brain stem to enter the inner ear. When sound strikes the ear drum, the movement is transferred to the footplate of the stapes, which presses into one of the fluid-filled ducts of the cochlea. The fluid inside this duct is moved, flowing against the receptor cells of the **Organ of Corti**, which fire. These stimulate the **spiral ganglion**, which sends information through the auditory portion of the eighth cranial nerve to the brain.

Hair cells are also the receptor cells involved in balance, although the hair cells of the auditory and vestibular systems of the ear are not identical. Vestibular hair cells are stimulated by movement of fluid in the semicircular canals and the utricle and saccule. Firing of vestibular hair cells stimulates the Vestibular portion of the eighth cranial nerve.

Damage to the human ear
Outer ear trauma

Auricle
The auricle can be easily damaged. Because it is skin-covered cartilage, with only a thin padding of connective tissue, rough handling of the ear can cause enough swelling to jeopardize the blood-supply to its framework, the auricular cartilage. That entire cartilage framework is fed by a thin covering membrane called the perichondrium (meaning literally: around the cartilage). Any fluid from swelling or blood from injury that collects between the perichondrium and the underlying cartilage puts the cartilage in danger of being separated from its supply of nutrients. If portions of the cartilage starve and die, the ear never heals back into its normal shape. Instead, the cartilage becomes lumpy and distorted. Wrestler's Ear is one term used to describe the result, because wrestling is one of the most common ways such an injury occurs. Cauliflower ear is another name for the same condition, because the thickened auricle can resemble that vegetable.

The lobule of the ear (ear lobe) is the one part of the human auricle that normally contains no cartilage. Instead, it is a wedge of adipose tissue (fat) covered by skin. There are many normal variations to the shape of the ear lobe, which may be small or large. Tears of the earlobe can be generally repaired with good results. Since there is no cartilage, there is not the risk of deformity from a blood clot or pressure injury to the ear lobe. Other injuries to the external ear occur fairly frequently, and can leave a major deformity. Some of the more common ones include, laceration from glass, knives, and bite injuries, avulsion injuries, cancer, frostbite, and burns.

Ear canal
Ear canal injuries can come from firecrackers and other explosives, and mechanical trauma from placement of foreign bodies into the ear. The ear canal is most often self-traumatized from efforts at ear cleaning. The outer part of the ear canal rests on the flesh of the head; the inner part rests in the opening of the bony skull (called the external auditory meatus). The skin is very different on each part. The outer skin is thick, and contains glands as well as hair follicles. The glands make cerumen (also called ear wax). The skin of the outer part moves a bit if the pinna is pulled; it is only loosely applied to the underlying tissues. The skin of the bony canal, on the other hand, is not only among the most delicate skin in the human body, it is tightly applied to the underlying bone. A slender object used to blindly clean cerumen out of the ear often results instead with the wax being pushed in, and contact with the thin skin of the bony canal is likely to lead to laceration and bleeding.

Middle ear trauma
Like outer ear trauma, middle ear trauma most often comes from blast injuries and insertion of foreign objects into the ear. Skull fractures that go through the part of the skull containing the ear structures (the temporal bone) can also cause damage to the middle ear. Small perforations of the tympanic membrane usually heal on their own, but large perforations may require grafting. Displacement of the ossicles will cause a conductive hearing loss that can only be corrected with surgery. Forcible displacement of the stapes into the inner ear can cause a sensory neural hearing loss that cannot be corrected even if the ossicles are put back into proper position. Because human skin has a top waterproof layer of dead skin cells that are constantly shedding, displacement of portions of the tympanic membrane or ear canal into the middle ear or deeper areas by trauma can be particularly traumatic. If the displaced skin lives within a closed area, the shed surface builds up over months and years and forms a cholesteatoma. The -oma ending of that word indicates a tumour in medical terminology, and although cholesteatoma is not a neoplasm (but a skin cyst), it can expand and erode the ear structures. The treatment for cholesteatoma is surgical.
**Inner ear trauma**

There are two principal damage mechanisms to the inner ear in industrialized society, and both injure hair cells. The first is exposure to elevated sound levels (noise trauma), and the second is exposure to drugs and other substances (*ototoxicity*).

In 1972 the U.S. EPA told Congress that at least 34 million people were exposed to sound levels on a daily basis that are likely to lead to significant *hearing loss*. The worldwide implication for industrialized countries would place this exposed population in the hundreds of millions.

**Gustatory system**

Humans require a way to distinguish safe food from dangerous substances. Bitter and sour foods we find unpleasant, while salty, sweet, and meaty tasting foods generally provide a pleasurable sensation. The five specific tastes received by gustatory receptors are salty, sweet, bitter, sour, and umami, which means “savory” or “meaty” in Japanese.

According to Lindemann, both salt and sour taste mechanisms detect, in different ways, the presence of sodium chloride in the mouth. The detection of salt is important to many organisms, but specifically mammals, as it serves a critical role in ion and water *homeostasis* in the body. It is specifically needed in the mammalian *kidney* as an osmotically active compound which facilitates passive re-uptake of water into the blood. Because of this, salt elicits a pleasant response in most humans.

Sour taste can be mildly pleasant in small quantities, as it is linked to the salt flavour, but in larger quantities it becomes more and more unpleasant to taste. This is because the sour taste can signal over-ripe fruit, rotten meat, and other spoiled foods, which can be dangerous to the body because of bacteria which grow in such mediums. As well, sour taste signals *acids* (H+ ions), which can cause serious tissue damage.

The bitter taste is almost completely unpleasant to humans. This is because many *nitrogenous organic molecules* which have a pharmacological effect on humans taste bitter. These include caffeine, nicotine, and strychnine, which compose the stimulant in coffee, addictive agent in cigarettes, and active compound in many *pesticides*, respectively. It appears that some psychological process allows humans to overcome their innate aversion to bitter taste, as caffeinated drinks are widely consumed and enjoyed around the world. It is also interesting to note that many common medicines have a bitter taste if chewed; the gustatory system apparently interprets these compounds as poisons. In this manner, the unpleasant reaction to the bitter taste is a last-line warning system before the compound is ingested and can do damage.

Sweet taste signals the presence of carbohydrates in solution. Since carbohydrates have a very high calorie count (*saccharides* have many bonds, therefore much energy), they are desirable to the human body, which has evolved to seek out the highest calorie intake foods, as the human body in the distant past has never known when its next meal will occur. They are used as direct energy (*sugars*) and storage of energy (*glycogen*). However, there are many non-carbohydrate molecules that trigger a sweet response, leading to the development of many artificial sweeteners, including saccharin, sucralose, and aspartame. It is still unclear how these substances activate the sweet receptors and what evolutionary significance this has.
The umami taste, which signals the presence of the amino acid L-glutamate, triggers a pleasurable response and thus encourages the intake of peptides and proteins. The amino acids in proteins are used in the body to build muscles and organs, transport molecules (hemoglobin), antibodies, and the organic catalysts known as enzymes. These are all critical molecules, and as such it is important to have a steady supply of amino acids, hence the pleasurable response to their presence in the mouth.

Function

In the human body a stimulus refers to a form of energy which elicits a physiological or psychological action or response. Sensory receptors are the structures in the body which change the stimulus from one form of energy to another. This can mean changing the presence of a chemical, sound wave, source of heat, or touch to the skin into an electrical action potential which can be understood by the brain, the body’s control center. Sensory receptors are modified ends of sensory neurons; modified to deal with specific types of stimulus, thus there are many different types of sensory receptors in the body. The neuron is the primary component of the nervous system, which transmits messages from sensory receptors all over the body.

Taste (or, more formally, gustation; adjectival form: "gustatory") is a form of direct chemoreception and is one of the traditional five senses. It refers to the ability to detect the flavor of substances such as food, certain minerals, and poisons. In humans and many other vertebrate animals the sense of taste partners with the less direct sense of smell, in the brain's perception of flavor. In the West, experts traditionally identified four taste sensations: sweet, salty, sour, and bitter. In the Eastern hemisphere, piquance (the sensation provided by, among other things, chili peppers) and savoriness (also known as umami) have been traditionally identified as basic tastes as well. More recently, psychophysicists and neuroscientists have suggested other taste categories (fatty acid taste most prominently, as well as the sensation of metallic and water tastes, although the latter is commonly disregarded due to the phenomenon of taste adaptation.[citation needed]) Taste is a sensory function of the central nervous system. The receptor cells for taste in humans are found on the surface of the tongue, along the soft palate, and in the epithelium of the pharynx and epiglottis.

Psychophysicists have long suggested the existence of four taste 'primaries', referred to as the basic tastes: sweetness, bitterness, sourness and saltiness. Although first described in 1908, savoriness (also called "umami" in Japanese) has been only recently recognized as the fifth basic taste since the cloning of a specific amino acid taste receptor in 2002. The savory taste is exemplified by the non-salty sensations evoked by some free amino acids such as monosodium glutamate. Other possible categories have been suggested, such as a taste exemplified by certain fatty acids such as linoleic acid. Some researchers still argue against the notion of primaries at all and instead favor a continuum of percepts, similar to color vision.

All of these taste sensations arise from all regions of the oral cavity, despite the common misconception of a "taste map" of sensitivity to different tastes thought to correspond to specific areas of the tongue. This myth is generally attributed to the mistranslation of a German text, and perpetuated in North American schools since the early twentieth century. Very slight regional differences in sensitivity to compounds exist, though these regional differences are subtle and do not conform exactly to the mythical tongue map. Individual taste buds (which contain approximately 100 taste receptor cells), in fact, typically respond to compounds evoking each of the five basic tastes.
The "basic tastes" are those commonly recognized types of taste sensed by humans. Humans receive tastes through sensory organs called "taste buds" or "gustatory calyculi", concentrated on the upper surface of the tongue, but a few are also found on the roof of one's mouth, furthering the taste sensations we can receive. Scientists describe five basic tastes: bitter, salty, sour, sweet, and savory. The basic tastes are only one component that contributes to the sensation of food in the mouth—other factors include the food's smell, detected by the olfactory epithelium of the nose, its texture, detected by mechanoreceptors, and its temperature, detected by thermoreceptors. Taste and smell are subsumed under the term "flavor".
History
In Western culture, the concept of basic tastes can be traced back at least to Aristotle, who cited "sweet" and "bitter", with "succulent", "salt", "pungent", "harsh", "puckery" and "sour" as elaborations of those two basics. The ancient Chinese Five Elements philosophy lists slightly different five basic tastes: bitter, salty, sour, sweet and spicy. Ayurveda, the ancient Indian healing science refers astringent as the sixth taste. Japanese culture also adds its own sixth taste to the basic five.

For many years, books on the physiology of human taste contained diagrams of the tongue showing levels of sensitivity to different tastes in different regions. In fact, taste qualities are found in all areas of the tongue, in contrast with the popular view that different tastes map to different areas of the tongue.

Recent discoveries
The receptors for all known basic tastes have been identified. The receptors for sour and salty are ion channels while the receptors for sweet, bitter and savory belong to the class of G protein coupled receptors.

In November 2005, a team of researchers experimenting on rodents claimed to have evidence for a sixth taste, for fatty substances. It is speculated that humans may also have the same receptors. Fat has occasionally been raised as a possible basic taste in the past (Bravo 1592, Linnaeus 1751) but later classifications abandoned fat as a separate taste (Haller 1751 and 1763).

Basic tastes
For a long period, it was commonly accepted that there is a finite and small number of "basic tastes" of which all seemingly complex tastes are ultimately composed. Just as with primary colors, the "basic" quality of those sensations derives chiefly from the nature of human perception, in this case the different sorts of tastes the human tongue can identify. Until the 2000s, the number of "basic" tastes was considered to be four. More recently, a fifth taste, savory, has been proposed by a large number of authorities associated with this field.

Bitterness
Bitterness is the most sensitive of the tastes, and is perceived by many to be unpleasant, sharp, or disagreeable. Common bitter foods and beverages include coffee, unsweetened cocoa, South American mate, marmalade, bitter melon, beer, bitters, olives, citrus peel, many plants in the Brassicaceae family, dandelion greens, wild chicory, escarole and lemons. Quinine is also known for its bitter taste and is found in tonic water. The threshold for stimulation of bitter taste by quinine averages 0.000008 M. The taste thresholds of other bitter substances are rated relative to quinine, which is given an index of 1. For example, Brucine has an index of 11, is thus perceived as intensely more bitter than quinine, and is detected at a much lower solution threshold. The most bitter substance known is the synthetic chemical denatonium, which has an index of 1,000. It is used as an aversive agent that is added to toxic substances to prevent accidental ingestion. This was discovered in 1958 during research on lignocaine, a local anesthetic, by Macfarlan Smith of Edinburgh, Scotland.

Research has shown that TAS2Rs (taste receptors, type 2, also known as T2Rs) such as TAS2R38 coupled to the G protein gustducin are responsible for the human ability to taste bitter substances. They are identified not only by their ability to taste for certain "bitter" ligands, but also by the morphology of the receptor itself (surface bound, monomeric). Researchers use two synthetic substances, phenylthiocarbamide (PTC) and 6-n-propylthiouracil (PROP) to study the genetics of bitter perception. These two substances taste bitter to some people, but are virtually tasteless to.
others. Among the tasters, some are so-called "supertasters" to whom PTC and PROP are extremely bitter. The variation in sensitivity is determined by two common alleles at the TAS2R38 locus. This genetic variation in the ability to taste a substance has been a source of great interest to those who study genetics.

In addition, it is of interest to those who study evolution, as well as various health researchers since PTC-tasting is associated with the ability to taste numerous natural bitter compounds, a large number of which are known to be toxic. The ability to detect bitter-tasting, toxic compounds at low thresholds is considered to provide an important protective function. Plant leaves often contain toxic compounds, yet even amongst leaf-eating primates, there is a tendency to prefer immature leaves, which tend to be higher in protein and lower in fiber and poisons than mature leaves.

Amongst humans, various food processing techniques are used worldwide to detoxify otherwise inedible foods and make them palatable. Recently it is speculated that the selective constraints on the TAS2R family have been weakened due to the relatively high rate of mutation and pseudogenization.

**Saltiness**

Saltiness is a taste produced primarily by the presence of sodium ions. Other ions of the alkali metals group also taste salty, but the further from sodium the less salty the sensation is. The size of lithium and potassium ions most closely resemble those of sodium and thus the saltiness is most similar. In contrast rubidium and cesium ions are far larger so their salty taste differs accordingly. The saltiness of substances is rated relative to sodium chloride (NaCl), which has an index of 1. Potassium, as potassium chloride - KCl, is the principal ingredient in salt substitutes, and has a saltiness index of 0.6. Other monovalent cations, e.g. ammonium, NH4+, and divalent cations of the alkali earth metal group of the periodic table, e.g. calcium, Ca2+, ions generally elicit a bitter rather than a salty taste even though they, too, can pass directly through ion channels in the tongue, generating an action potential.

**Sourness**

Sourness is the taste that detects acidity. The sourness of substances is rated relative to dilute hydrochloric acid, which has a sourness index of 1. By comparison, tartaric acid has a sourness index of 0.7, citric acid an index of 0.46, and carbonic acid an index of 0.06. The mechanism for detecting sour taste is similar to that which detects salt taste. Hydrogen ion channels detect the concentration of hydronium ions that are formed from acids and water. Additionally, the taste receptor PKD2L1 has been found to be involved in tasting sourness.

Hydrogen ions are capable of permeating the amiloride-sensitive channels, but this is not the only mechanism involved in detecting the quality of sourness. Other channels have also been proposed in the literature. Hydrogen ions also inhibit the potassium channel, which normally functions to hyperpolarize the cell. By a combination of direct intake of hydrogen ions (which itself depolarizes the cell) and the inhibition of the hyperpolarizing channel, sourness causes the taste cell to fire in this specific manner. In addition, it has also been suggested that weak acids, such as CO2 which is converted into the bicarbonate ion by the enzyme carbonic anhydrase, to mediate weak acid transport. The most common food group that contains naturally sour foods is the fruit, with examples such as the lemon, grape, orange, and sometimes the melon. Wine also usually has a sour tinge to its flavor. If not kept correctly, milk can spoil and contain a sour taste. Sour candy is especially popular in North America including Cry Babies, Warheads, Lemon drops, Shock tarts and Sour Skittles and Starburst. Many of these candies contain citric acid.
Sweetness
Sweetness, usually regarded as a pleasurable sensation, is produced by the presence of sugars, some proteins and a few other substances. Sweetness is often connected to aldehydes and ketones, which contain a carbonyl group. Sweetness is detected by a variety of G protein coupled receptors coupled to the G protein gustducin found on the taste buds. At least two different variants of the "sweetness receptors" need to be activated for the brain to register sweetness. The compounds which the brain senses as sweet are thus compounds that can bind with varying bond strength to two different sweetness receptors. These receptors are T1R2+3 (heterodimer) and T1R3 (homodimer), which are shown to be accountable for all sweet sensing in humans and animals. Taste detection thresholds for sweet substances are rated relative to sucrose, which has an index of 1. The average human detection threshold for sucrose is 10 millimoles per litre. For lactose it is 30 millimoles per litre, with a sweetness index of 0.3, and 5-Nitro-2-propoxyaniline 0.002 millimoles per litre.

Savoriness
Savoriness is the name for the taste sensation produced by amino acids such as glutamate. The compounds that generate savoriness are commonly found in fermented and aged foods. It is also described as "meatiness", "relish", or having a "rich" taste. Savoriness is considered a fundamental taste in Chinese, Japanese, Thai and Korean cooking, but is not discussed as much in Western cuisine, at least prior to the introduction of the umami concept in the West.

Humans have taste receptors specifically for the detection of the amino acids, e.g., glutamic acid. Amino acids are the building blocks of proteins and are found in meats, cheese, fish, and other protein-heavy foods. Examples of food containing glutamate (and thus strong in savoriness) are beef, lamb, parmesan, and roquefort cheese as well as soy sauce and fish sauce. The glutamate taste sensation is most intense in combination with sodium ions, as found in table salt. Sauces with savory and salty tastes are very popular for cooking, such as Worcestershire sauce for Western cuisines and soy sauce and fish sauce for Oriental (East Asian) cuisines.

The additive monosodium glutamate (MSG), which was developed as a food additive in 1907 by Kikunae Ikeda, produces a strong savory taste. Savoriness is also provided by the nucleotides 5'-inosine monophosphate (IMP) and 5'-guanosine monophosphate (GMP). These are naturally present in many protein-rich foods. IMP is present in high concentrations in many foods, including dried skipjack tuna flakes and kombu used to make "dashi", a Japanese broth. GMP is present in high concentration in dried shiitake mushrooms, used in much of the cuisine of Asia. There is a synergistic effect between MSG, IMP, and GMP which together in certain ratios produce a strong savory taste.

Some savory taste buds respond specifically to glutamate in the same way that "sweet" ones respond to sugar. Glutamate binds to a variant of G protein coupled glutamate receptors.

Further sensations
The tongue can also feel other sensations, not generally classified as tastes or included in the five human tastes. These are largely detected by the somatosensory system.

Fattiness
Recent research has revealed a potential taste receptor called the CD36 receptor to be reacting to fat, more specifically, fatty acids. This receptor was found in mice, but probably exists among other mammals as well. In experiments, mice with a genetic defect that blocked this receptor didn't show the same urge to consume fatty acids as normal mice, and failed to prepare gastric juices in their digestive tracts to digest fat. This discovery may lead to a better understanding of the
biochemical reasons behind this behaviour, although more research is still necessary to confirm the relationship between CD36 and the perception of fat.

**Calcium**

In 2008, geneticists discovered a CaSR calcium receptor on the tongues of mice. The CaSR receptor is commonly found in the gastrointestinal tract, kidneys and brain. Along with the "sweet" T1R3 receptor, the CaSR receptor can detect calcium as a taste. Whether closely related genes in mice and humans means the phenomenon may exist in humans as well is unknown.

**Dryness**

Some foods, such as unripe fruits, contain tannins or calcium oxalate that cause an astringent or rough sensation of the mucous membrane of the mouth or the teeth. Examples include tea, red wine, rhubarb and unripe persimmons and bananas.

Less exact terms for the astringent sensation are "dry", "rough", "harsh" (especially for wine), "tart" (normally referring to sourness), "rubbery", "hard" or "styptic".

In the Indian tradition, one of the 6 tastes is astringency (Kasaaya in Sanskrit, the other five being sweet, sour, salty, bitter and hot/pungent).

In wine terms, "dry" is the opposite of "sweet" and does not refer to astringency. Wines that contain tannins and that cause astringent sensations in the mouth are not necessarily classified as "dry", and "dry" wines are not necessarily astringent.

**Metallicness**

Most people know this taste (e.g. Cu2+, FeSO4, or blood in mouth), however it is not only taste, but also olfactory receptors at work in this case. Metallic taste is commonly known, however biologists are reluctant to categorize it with the other taste sensations. One of the primary reasons is that it is not one commonly associated with consumption of food. Proponents of the theory contest that the sensation is readily detectable and distinguishable to test subjects.

**Prickliness or hotness**

Substances such as ethanol and capsaicin cause a burning sensation by inducing a trigeminal nerve reaction together with normal taste reception. The sensation of heat is caused by the food activating nerves that express TRPV1 and TRPA1 receptors. Two main plant derived compounds providing this sensation are capsaicin from chili peppers and piperine from black pepper. The piquant ("hot" or "spicy") sensation provided by chili peppers, black pepper and also other spices like ginger and horseradish plays an important role in a diverse range of cuisines across the world, such as Ethiopian, Peruvian, Hungarian, Indian, Korean, Indonesian, Lao, Malaysian, Mexican, Southwest Chinese (including Sichuan cuisine), and Thai cuisines.

If tissue in the oral cavity has been damaged or sensitised, ethanol may be experienced as pain rather than simply heat. Those who have had radiotherapy for oral cancer thus find it painful to drink alcohol.

This particular sensation is not considered a taste in the technical sense, because it is carried to the brain by a different set of nerves. Although taste nerves are also activated when consuming foods like chili peppers, the sensation commonly interpreted as "hot" results from the stimulation of somatosensory (pain/temperature) fibers on the tongue. Many parts of the body with exposed membranes but without taste sensors (such as the nasal cavity, under the fingernails, or a wound) produce a similar sensation of heat when exposed to hotness agents.
Coolness
Some substances activate cold trigeminal receptors. One can sense a cool sensation (also known as "fresh" or "minty") from, e.g., spearmint, menthol, ethanol or camphor, which is caused by the food activating the TRPM8 ion channel on nerve cells that also signal cold. Unlike the actual change in temperature described for sugar substitutes, coolness is only a perceived phenomenon.

Numbness
Both Chinese and Batak Toba cooking include the idea of má, or mati rasa the sensation of tingling numbness caused by spices such as Sichuan pepper. The cuisine of Sichuan province in China and of North Sumatra province in Indonesia, often combines this with chili pepper to produce a málà, "numbing-and-hot", or "mati rasa" flavor.

Heartiness (Kokumi)
Some Japanese researchers refer to the kokumi in foods laden with alcohol- and thiol-groups in their amino acid extracts which has been described variously as continuity, mouthfulness, mouthfeel, and thickness.

Temperature
Temperature is an essential element of human taste experience. Food and drink that—within a given culture—is considered to be properly served hot is often considered distasteful if cold, and vice versa.
Some sugar substitutes have strong heats of solution, as is the case of sorbitol, erythritol, xylitol, mannitol, lactitol, and maltitol. When they are dry and are allowed to dissolve in saliva, heat effects can be recognized. The cooling effect upon eating may be desirable, as in a mint candy made with crystalline sorbitol, or undesirable if it's not typical for that product, like in a cookie. Crystalline phases tend to have a positive heat of solution and thus a cooling effect. The heats of solution of the amorphous phases of the same substances are negative and cause a warm impression in the mouth.

Supertasters
A supertaster is a person whose sense of taste is significantly sharper than average. Women are more likely to be supertasters, as are Asians, Africans, and South Americans. The cause of this heightened response is currently unknown, although it is thought to be, at least in part, due to an increased number of fungiform papillae. The evolutionary advantage to supertasting is unclear. In some environments, heightened taste response, particularly to bitterness, would represent an important advantage in avoiding potentially toxic plant alkaloids. However, in other environments, increased response to bitter may have limited the range of palatable foods. In a modern, energy-rich environment, supertasting may be cardioprotective, due to decreased liking and intake of fat, but may increase cancer risk via decreased vegetable intake. It may be a cause of picky eating, but picky eaters are not necessarily supertasters, and vice versa.

Aftertaste
Aftertaste is the persistence of a sensation of flavor after the stimulating substance has passed out of contact with the sensory end organs for taste.[ Some aftertastes may be pleasant, others unpleasant.
Alcoholic beverages such as wine, beer and whiskey are noted for having particularly strong aftertastes. Foods with notable aftertastes include spicy foods, such as Mexican food (e.g., chili pepper), or Indian food (such as curry).
Medicines and tablets may also have a lingering aftertaste, as can certain artificial flavor compounds, such as aspartame (artificial sweetener).
Acquired taste
An acquired taste is an appreciation for a food or beverage that is unlikely to be enjoyed by a person who has not had substantial exposure to it, usually because of some unfamiliar aspect of the food or beverage, including a strong or strange odor, taste, or appearance. The process of "acquiring" a taste involves consuming a food or beverage in the hope of learning to enjoy it. Many of the world's delicacies are considered to be acquired tastes. A connoisseur is one who is held to have an expert judgement of taste.

Taste combinations — appetitive plus aversive
Salty, sweet and savory are "appetitive," and bitter and sour are "aversive." Appetitive tastes drive us toward essential nutrients. Aversive tastes alert us to potentially harmful substances. Mixing appetitive with aversive sends conflicting messages to the brain. Confusion is the result, and rejection tends to be the first reaction, as the negative signal can be useful, lifesaving information. Adults nevertheless acquire tastes for some foods that send mixed signals. Coffee with cream or sugar might be an example of this. Olives, strong cheese, sweet and sour Chinese cuisine might be additional examples. Other possible combinations are just about out of the question for most people. Few would enjoy the taste of pickles with cocoa for example.

Factors affecting taste perception
The perception of a mixture of ingredients does not simply equal the sum of the components. Several of the basic tastes compete with each other, so that adding one can reduce the perceived intensity of another. Lemonade, for example, is made by combining lemon juice (sour), sugar (sweet), and water. Without the sugar, the lemon juice—water mixture tastes very sour. The more sugar is added, the less sour the result tastes. Another example is tonic water, made by combining quinine (extremely bitter), sugar (sweet), and water. The bitterness causes many people to not perceive tonic water as sweet, even though it contains as much sugar as an ordinary soft drink.

Many factors affect taste perception, including:
- Aging
- Color/vision impairments
- Hormonal influences
- Genetic variations; see Phenylthiocarbamide
- Oral temperature
- Drugs and chemicals
- Natural Substances (such as Miracle fruit, which temporarily makes sour foods taste sweeter)
- CNS Tumors (esp. Temporal lobe lesions) and other neurological causes
- Plugged noses
- Zinc deficiency

It is also important to consider that flavor is the overall, total sensation induced during mastication (e.g. taste, touch, pain and smell). Smell (olfactory stimulation) plays a major role in flavor perception. In some cases, what you see can affect what you taste. For example, if you eat a potato while looking at an apple, you may have the sensation you are eating an apple. The stomach contains receptors that can "taste" various substances such as sodium, glutamate, glucose, carbohydrates, proteins, and fats. This information is passed to the lateral hypothalamus and limbic system in the brain as a palatability signal through the vagus nerve. This allows the brain to link nutritional value of foods to their orally determined tastes.

Innervation
• Taste is brought to the brainstem by 3 different cranial nerves:
  • Facial Nerve for the anterior 2/3 of the tongue.
  • Glossopharyngeal Nerve for the posterior 1/3 of the tongue.
  • Vagus Nerve for the small area on the epiglottis.

Disorders of taste
• ageusia (complete loss of taste)
• dysgeusia (persistent abnormal taste)

Taste modulators
• Compounds so called taste modulators that enhance the sweet and salty flavors of foods could combat obesity and heart disease. Researchers have discovered tiny compounds that make foods taste sweeter, saltier and more savory than they really are, which could reduce the sugar, salt and monosodium glutamate typically added. Several of these taste enhancers are being tested in commercial foods. Whether people will consume fewer calories if their foods become tastier remains to be seen; people might eat lots of sweet foods for reasons that have nothing to do with taste.

Olfaction

Olfaction (also known as olfactics; adjectival form: "olfactory") is the sense of smell. This sense is mediated by specialized sensory cells of the nasal cavity of vertebrates, and, by analogy, sensory cells of the antennae of invertebrates. Many vertebrates, including most mammals and reptiles, have two distinct olfactory systems - the main olfactory system, and the accessory olfactory system (mainly used to detect pheremones). For air-breathing animals, the main olfactory system detects volatile chemicals, and the accessory olfactory system detects fluid-phase chemicals.[ For water-dwelling organisms, e.g., fish or crustaceans, the chemicals are present in the surrounding aqueous medium. Olfaction, along with taste, is a form of chemoreception. The chemicals themselves which activate the olfactory system, generally at very low concentrations, are called odorants.

History

As the Epicurean and atomistic Roman philosopher Lucretius (1st Century BCE) speculated, different odors are attributed to different shapes and sizes of odor molecules that stimulate the olfactory organ. A modern demonstration of that theory was the cloning of olfactory receptor proteins by Linda B. Buck and Richard Axel (who were awarded the Nobel Prize in 2004), and subsequent pairing of odor molecules to specific receptor proteins. Each odor receptor molecule recognizes only a particular molecular feature or class of odor molecules. Mammals have about a thousand genes expressing for odor reception. Of these genes, only a portion are functional odor receptors. Humans have far fewer active odor receptor genes than other primates and other mammals.

In mammals, each olfactory receptor neuron expresses only one functional odor receptor. Odor receptor nerve cells function like a key-lock system: If the airborne molecules of a certain chemical can fit into the lock, the nerve cell will respond. There are, at present, a number of competing theories regarding the mechanism of odor coding and perception. According to the shape theory, each receptor detects a feature of the odor molecule. Weak-shape theory, known as odotope theory, suggests that different receptors detect only small pieces of molecules, and these minimal inputs are combined to form a larger olfactory perception (similar to the way visual perception is built up of smaller, information-poor sensations, combined and refined to create a detailed overall perception). An alternative theory, the vibration theory proposed by Luca Turin, posits that odor receptors detect...
the frequencies of vibrations of odor molecules in the infrared range by electron tunnelling. However, the behavioral predictions of this theory have been called into question. As of yet, there is no theory that explains olfactory perception completely.

Main olfactory system

Olfactory epithelium
In vertebrates smells are sensed by olfactory sensory neurons in the olfactory epithelium. The proportion of olfactory epithelium compared to respiratory epithelium (not innervated) gives an indication of the animal's olfactory sensitivity. Humans have about 10 cm² (1.6 sq in) of olfactory epithelium, whereas some dogs have 170 cm² (26 sq in). A dog's olfactory epithelium is also considerably more densely innervated, with a hundred times more receptors per square centimetre. Molecules of odorants passing through the superior nasal concha of the nasal passages dissolve in the mucus lining the superior portion of the cavity and are detected by olfactory receptors on the dendrites of the olfactory sensory neurons. This may occur by diffusion or by the binding of the odorant to odorant binding proteins. The mucus overlying the epithelium contains mucopolysaccharides, salts, enzymes, and antibodies (these are highly important, as the olfactory neurons provide a direct passage for infection to pass to the brain).

In insects smells are sensed by olfactory sensory neurons in the chemosensory sensilla, which are present in insect antenna, palps and tarsa, but also on other parts of the insect body. Odorants penetrate into the cuticle pores of chemosensory sensilla and get in contact with insect Odorant binding proteins (OBPs) or Chemosensory proteins (CSPs), before activating the sensory neurons.

Receptor neuron
The binding of the ligand (odor molecule or odorant) to the receptor leads to an action potential in the receptor neuron, via a second messenger pathway, depending on the organism. In mammals the odorants stimulate adenylate cyclase to synthesize cAMP via a G protein called Golf. cAMP, which is the second messenger here, opens a cyclic nucleotide-gated ion channel (CNG) producing an influx of cations (largely Ca²⁺ with some Na⁺) into the cell, slightly depolarising it. The Ca²⁺ in turn opens a Ca²⁺-activated chloride channel, leading to efflux of Cl⁻, further depolarising the cell and triggering an action potential. Ca²⁺ is then extruded through a sodium-calcium exchanger. A calcium-calmodulin complex also acts to inhibit the binding of cAMP to the cAMP-dependent channel, thus contributing to olfactory adaptation. This mechanism of transduction is somewhat unique, in that cAMP works by directly binding to the ion channel rather than through activation of protein kinase A. It is similar to the transduction mechanism for photoreceptors, in which the second messenger cGMP works by directly binding to ion channels, suggesting that maybe one of these receptors was evolutionarily adapted into the other. There are also considerable similarities in the immediate processing of stimuli by lateral inhibition.

Averaged activity of the receptor neurons can be measured in several ways. In vertebrates responses to an odor can be measured by an electroolfactogram or through calcium imaging of receptor neuron terminals in the olfactory bulb. In insects, one can perform electroantenogram or also calcium imaging within the olfactory bulb.

The receptor neurons in the nose are particularly interesting because they are the only direct recipient of stimuli in all of the senses which are nerves. Senses like hearing, tasting, and, to some extent, touch use cilia or other indirect pressure to stimulate nerves, and sight uses the chemical rhodopsin to stimulate the brain.

Olfactory bulb projections
Olfactory sensory neurons project axons to the brain within the olfactory nerve, (cranial nerve I). These axons pass to the olfactory bulb through the cribriform plate, which in turn projects olfactory...
information to the **olfactory cortex** and other areas. The axons from the **olfactory receptors** converge in the **olfactory bulb** within small (~50 micrometers in diameter) structures called **glomeruli**. **Mitral cells** in the olfactory bulb form synapses with the axons within glomeruli and send the information about the odor to multiple other parts of the olfactory system in the brain, where multiple signals may be processed to form a synthesized olfactory perception. There is a large degree of convergence here, with twenty-five thousand axons synapsing on one hundred or so mitral cells, and with each of these mitral cells projecting to multiple glomeruli. Mitral cells also project to **periglomerular cells** and **granular cells** that inhibit the mitral cells surrounding it (**lateral inhibition**). Granular cells also mediate inhibition and excitation of mitral cells through pathways from centrifugal fibres and the anterior olfactory nuclei.

The mitral cells leave the olfactory bulb in the **lateral olfactory tract**, which synapses on five major regions of the cerebrum: the **anterior olfactory nucleus**, the **olfactory tubercle**, the **amygdala**, the **piriform cortex**, and the **entorhinal cortex**. The anterior olfactory nucleus projects, via the **anterior commissure**, to the contralateral olfactory bulb, inhibiting it. The piriform cortex projects to the **medial dorsal nucleus** of the thalamus, which then projects to the orbitofrontal cortex. The orbitofrontal cortex mediates conscious perception of the odor. It also projects to the hippocampus and is involved in motivation and memory. Odor information is stored in **long-term memory** and has strong connections to **emotional memory**. This is possibly due to the olfactory system's close anatomical ties to the **limbic system** and **hippocampus**, areas of the brain that have long been known to be involved in emotion and place memory, respectively.

Since any one receptor is responsive to various odorants, and there is a great deal of convergence at the level of the olfactory bulb, it seems strange that human beings are able to distinguish so many different odors. It seems that there must be a highly-complex form of processing occurring; however, as it can be shown that, while many neurons in the olfactory bulb (and even the pyriform cortex and amygdala) are responsive to many different odors, half the neurons in the orbitofrontal cortex are responsive only to one odor, and the rest to only a few. It has been shown through microelectrode studies that each individual odor gives a particular specific spatial map of excitation in the olfactory bulb. It is possible that, through spatial encoding, the brain is able to distinguish specific odors. However, temporal coding must be taken into account. Over time, the spatial maps change, even for one particular odor, and the brain must be able to process these details as well.

Inputs from the two **nostrils** have separate inputs to the brain with the result that it is possible for humans to experience perceptual rivalry in the olfactory sense akin to that of **binocular rivalry** when there are two different inputs into the two nostrils. In **insects** smells are sensed by sensilla located on the antenna and first processed by the **antennal lobe** (analogous to the **olfactory bulb**), and next by the mushroom bodies.

**Accessory olfactory system**

Many animals, including most mammals and reptiles, have two distinct and segregated olfactory systems: a main olfactory system, which detects volatile stimuli, and an **accessory olfactory system**, which detects fluid-phase stimuli. Behavioral evidence suggests that these fluid-phase stimuli often function as **pheromones**, although pheromones can also be detected by the main olfactory system. In the **accessory olfactory system**, stimuli are detected by the **vomeronasal organ**, located in the vomer, between the nose and the mouth. Snakes use it to smell prey, sticking their tongue out and touching it to the organ. Some mammals make a face called **flehmen** to direct air to this organ.

The sensory receptors of the accessory olfactory system are located in the **vomeronasal organ**. As in the main olfactory system, the axons of these sensory neurons project from the vomeronasal organ.
to the accessory olfactory bulb, located on the dorsal-posterior portion of the main olfactory bulb. Unlike in the main olfactory system, the axons that leave the accessory olfactory bulb do not project to the brain's cortex but rather to targets in the amygdala and hypothalamus where they may influence aggressive and mating behavior.

In women, the sense of olfaction is strongest around the time of ovulation, significantly stronger than during other phases of the menstrual cycle and also stronger than the sense in males.[9] The MHC genes (known as HLA in humans) are a group of genes present in many animals and important for the immune system; in general, offspring from parents with differing MHC genes have a stronger immune system. Fish, mice and female humans are able to smell some aspect of the MHC genes of potential sex partners and prefer partners with MHC genes different from their own. Humans can detect individuals that are blood related kin (mothers and children but not husbands and wives) from olfaction. Mothers can identify by body odor their biological children but not their stepchildren. Preadolescent children can olfactory detect their full siblings but not half-siblings or step siblings and this might explain incest avoidance and the Westermarck effect. Functional imaging shows that this olfactory kinship detection process involves the frontal-temporal junction, the insula, and the dorsomedial prefrontal cortex but not the primary or secondary olfactory cortices, or the related piriform cortex or orbitofrontal cortex.

Olfactory coding and perception
How olfactory information is coded in the brain to allow for proper perception is still being researched and the process is not completely understood. However, what is known is that the chemical nature of the odorant is particularly important as there may be a chemotopic map in the brain; this map would show specific activation patterns for specific odorants. When an odorant is detected by receptors, the receptors in a sense break the odorant down and then the brain puts the odorant back together for identification and perception. The odorant binds to receptors which only recognize a specific functional group, or feature, of the odorant, which is why the chemical nature of the odorant is important. After binding the odorant, the receptor is activated and will send a signal to the glomeruli. Each glomerulus receive signals from multiple receptors that detect similar odorant features. Because multiple receptor types are activated due to the different chemical features of the odorant, multiple glomeruli will be activated as well. All of the signals from the glomeruli will then be sent to the brain, where the combination of glomeruli activation will encode the different chemical features of the odorant. The brain will then essentially put the pieces of the activation pattern back together in order to identify and perceive the odorant. Odorants that are similar in structure activate similar patterns of glomeruli, which lead to a similar perception in the brain. Data from animal models, suggests that the brain may have a chemotopic map. A chemotopic map is an area in the brain, specifically the olfactory bulb, in which glomeruli project their signals onto the brain in a specific pattern. The idea of the chemotopic map has been supported by the observation that chemicals containing similar functional groups have similar responses with overlapped areas in the brain. This is important because it allows the possibility to predict the neural activation pattern from an odorant and vice versa.

Interactions of Olfaction with other senses
Olfaction and taste
Olfaction, taste and trigeminal receptors together contribute to flavor. The human tongue can distinguish only among five distinct qualities of taste, while the nose can distinguish among hundreds of substances, even in minute quantities. It is during exhalation that the olfaction contribution to flavor occurs in contrast to that of proper smell which occurs during the inhalation phase.
Olfaction and audition
Olfaction and sound information has been shown to converge in the olfactory tubercles of rodents. This neural convergence is proposed to give rise to a percept termed smound. Whereas a flavor results from interactions between smell and taste, a smound may result from interactions between smell and sound.

Disorders of olfaction
The following are disorders of olfaction:

- **Anosmia** – lack of ability to smell
- **Cacosmia** – things smell like feces
- **Dysosmia** – things smell differently than they should
- **Hyperosmia** – an abnormally acute sense of smell
- **Hyposmia** – decreased ability to smell
- **Olfactory Reference Syndrome** – psychological disorder which causes the patient to imagine he has strong body odor
- **Parosmia** – things smell worse than they should
- **Phantosmia** – “hallucinated smell”, often unpleasant in nature

Olfaction in animals
The importance and sensitivity of smell varies among different organisms; most mammals have a good sense of smell, whereas most birds do not, except the tubenoses (e.g., petrels and albatrosses), and the kiwis. Among mammals, it is well-developed in the carnivores and ungulates, who must always be aware of each other, and in those that smell for their food, like moles. Having a strong sense of smell is referred to as macrosmatic.

Figures suggesting greater or lesser sensitivity in various species reflect experimental findings from the reactions of animals exposed to aromas in known extreme dilutions. These are, therefore, based on perceptions by these animals, rather than mere nasal function. That is, the brain's smell-recognizing centers must react to the stimulus detected, for the animal to show a response to the smell in question. It is estimated that dogs in general have an olfactory sense approximately a hundred thousand to a million times more acute than a human's. That is, they have a greater acuity. This does not mean they are overwhelmed by smells our noses can detect; rather, it means they can discern a molecular presence when it is in much greater dilution in the carrier, air. Scenthounds as a group can smell one- to ten-million times more acutely than a human, and Bloodhounds, which have the keenest sense of smell of any dogs, have noses ten- to one-hundred-million times more sensitive than a human's. They were bred for the specific purpose of tracking humans, and can detect a scent trail a few days old. The second-most-sensitive nose is possessed by the Basset Hound, which was bred to track and hunt rabbits and other small animals.

- **Bears**, such as the Silvertip Grizzly found in parts of North America, have a sense of smell seven times stronger than the bloodhound, essential for locating food underground. Using their elongated claws, bears dig deep trenches in search of burrowing animals and nests as well as roots, bulbs, and insects. Bears can detect the scent of food from up to 18 miles away; because of their immense size they often scavenge new kills, driving away the predators (including packs of wolves and human hunters) in the process.

The sense of smell is less-developed in the catarrhine primates (Catarrhini), and nonexistent in cetaceans, which compensate with a well-developed sense of taste. In some prosimians, such as the Red-bellied Lemur, scent glands occur atop the head. In many species, olfaction is highly tuned to pheromones; a male silkworm moth, for example, can sense a single molecule of bombykol.

Fish too have a well-developed sense of smell, even though they inhabit an aquatic environment. Salmon utilize their sense of smell to identify and return to their home stream waters. Catfish use
their sense of smell to identify other individual catfish and to maintain a social hierarchy. Many fishes use the sense of smell to identify mating partners or to alert to the presence of food. Insects primarily use their antennae for olfaction. Sensory neurons in the antenna generate odor-specific electrical signals called spikes in response to odor. They process these signals from the sensory neurons in the antennal lobe followed by the mushroom bodies and lateral horn of the brain. The antennae have the sensory neurons in the sensilla and they have their axons terminating in the antennal lobes where they synapse with other neurons there in semidelineated (with membrane boundaries) called glomeruli. These antennal lobes have two kinds of neurons, projection neurons (excitatory) and local neurons (inhibitory). The projection neurons send their axon terminals to mushroom body and lateral horn (both of which are part of the protocerebrum of the insects), and local neurons have no axons. Recordings from projection neurons show in some insects strong specialization and discrimination for the odors presented (especially for the projection neurons of the macroglomeruli, a specialized complex of glomeruli responsible for the pheromones detection). Processing beyond this level is not exactly known though some preliminary results are available.

**Thermoception**

Thermoception or thermoreception is the sense by which an organism perceives temperature. In larger animals, most thermoception is done by the skin. The details of how temperature receptors work is still being investigated. Mammals have at least two types of sensor: those that detect heat (i.e. temperatures above body temperature) and those that detect cold (i.e. temperatures below body temperature).

A particularly specialized form of thermoception is used by Crotalinae (pit viper) and Boidae (boa) snakes, which can effectively see the infrared radiation emitted by hot objects. The snake's face has a pair of holes, or pits, lined with temperature sensors. The sensors indirectly detect infrared radiation by its heating effect on the skin inside the pit. They can work out which part of the pit is hottest, and therefore the direction of the heat source, which could be a warm-blooded prey animal. By combining information from both pits, the snake can also estimate the distance of the object. The common vampire bat may also have specialized infrared sensors on its nose. A nucleus has been found in the brain of vampire bats that has a similar position and has similar histology to the infrared nucleus of infrared sensitive snakes.

Other animals with specialized heat detectors are forest fire seeking beetles (Melanophilia acuminata), which lay their eggs in conifers freshly killed by forest fires. Darkly pigmented butterflies Pachliopta aristolochiae and Troides rhadamathus use specialized heat detectors to avoid damage while basking. The blood sucking bugs Triatoma infestans may also have a specialised thermoception organ.

**Nociception**

Nociception (synonym: nocioception or nociperception) is defined as "the neural processes of encoding and processing noxious stimuli." It is the afferent activity produced in the peripheral and central nervous system by stimuli that have the potential to damage tissue. This activity is initiated by nociceptors, (also called pain receptors), that can detect mechanical, thermal or chemical changes above a set threshold. Once stimulated, a nociceptor transmits a signal along the spinal cord, to the brain. Nociception triggers a variety of autonomic responses and may also result in the experience of pain in sentient beings.

Detection of noxious stimuli

Mechanical, thermal, and chemical stimuli are detected by nerve endings called nociceptors, which are found in the skin and on internal surfaces such as the periosteum or joint surfaces. The concentration of nociceptors varies throughout the body, mostly found in the skin and less so in
deep internal surfaces. All nociceptors are free nerve endings that have their cell bodies outside the spinal column in the dorsal root ganglia and are named according to their appearance at their sensory ends.

Nociceptors have a certain threshold; that is, they require a minimum level of stimuli before they trigger a signal. In some conditions, excitation of pain fibers becomes greater as the pain stimulus continues, leading to a condition called hyperalgesia. Once the threshold is reached a signal is passed along the axon of the nerve into the spinal cord.

Transmission through central nervous system

Lateral spinothalamic tract

The Lateral spinothalamic tract has two pathways for nociceptive information to reach the brain, the neospinothalamic tract for "fast spontaneous pain" and the paleospinothalamic tract for "slow increasing pain".

Neospinothalamic tract

Fast pain travels via type Aδ fibers to terminate on the dorsal horn of the spinal cord where they synapse with the dendrites of the neospinothalamic tract. The axons of these neurons travel up the spine to the brain and cross the midline through the anterior white commissure, passing upwards in the contralateral anterolateral columns. These fibres terminate on the ventrobasal complex of the thalamus and synapse with the dendrites of the somatosensory cortex. Fast pain is felt within a tenth of a second of application of the pain stimulus and is a sharp, acute, prickling pain in response to mechanical and thermal stimulation. It can be localised easily if Aδ fibres are stimulated together with tactile receptors.

Paleospinothalamic tract

Slow pain is transmitted via slower type C fibers to laminae II and III of the dorsal horns, together known as the substantia gelatinosa. Impulses are then transmitted to nerve fibers that terminate in lamina V, also in the dorsal horn, synapsing with neurons that join fibers from the fast pathway, crossing to the opposite side via the anterior white commissure, and traveling upwards through the anterolateral pathway. These neurons terminate throughout the brain stem, with one tenth of fibres stopping in the thalamus and the rest stopping in the medulla, pons and periaqueductual grey of the midbrain tectum. Slow pain is stimulated by chemical stimulation, is poorly localized and is described as an aching, throbbing or burning pain.

Regulation

The body possesses an endogenous analgesia system, which can be supplemented with analgesic drugs to regulate nociception and pain. There is both an analgesia system in the central nervous system and peripheral receptors that decreases the grade in which nociception reaches the higher brain areas. The degree of pain can be modified by the periaqueductal gray before it reaches the thalamus and consciousness. According to gate control theory of pain, this area can also reduce pain when non-painful stimuli are received in conjunction with nociception.

Central

The central analgesia system is mediated by 3 major components: the periaqueductal grey matter, the nucleus raphe magnus and the nociception inhibitory neurons within the dorsal horns of the spinal cord, which act to inhibit nociception-transmitting neurons also located in the spinal dorsal horn.
Peripheral
The peripheral regulation consists of several different types of opioid receptors that are activated in response to the binding of the body's endorphins. These receptors, which exist in a variety of areas in the body, inhibit firing of neurons that would otherwise be stimulated to do so by nociceptors.

Factors
The gate control theory of pain, proposed by Patrick Wall and Ronald Melzack, postulates that nociception (pain) is "gated" by non-nociception stimuli such as vibration. Thus, rubbing a bumped knee seems to relieve pain by preventing its transmission to the brain. Pain is also "gated" by signals that descend from the brain to the spinal cord to suppress (and in other cases enhance) incoming nociception (pain) information.

Nociception response
When nociceptors are stimulated they transmit signals through sensory neurons in the spinal cord. These neurons release the excitatory neurotransmitter glutamate at their synapses. If the signals are sent to the reticular formation and thalamus, the sensation of pain enters consciousness in a dull poorly localized manner. From the thalamus, the signal can travel to the somatosensory cortex in the cerebrum, when the pain is experienced as localized and having more specific qualities.

Nociception can also cause generalized autonomic responses before or without reaching consciousness to cause pallor, diaphoresis, tachycardia, hypertension, lightheadedness, nausea and fainting.

Nociception in non-mammalian animals
Nociception has been documented in non-mammalian animals, including fishes and a wide range of invertebrates, including leeches, nematode worms, sea slugs, and fruit flies. As in mammals, nociceptive neurons in these species are typically characterized by responding preferentially to high temperature (40 degrees C or more), low pH, capsaicin, and tissue damage.

Illusion
An illusion is a distortion of the senses, revealing how the brain normally organizes and interprets sensory stimulation. While illusions distort reality, they are generally shared by most people. Illusions may occur with more of the human senses than vision, but visual illusions, optical illusions, are the most well known and understood. The emphasis on visual illusions occurs because vision often dominates the other senses. For example, individuals watching a ventriloquist will perceive the voice is coming from the dummy since they are able to see the dummy mouth the words. Some illusions are based on general assumptions the brain makes during perception. These assumptions are made using organizational principles, like Gestalt, an individual's ability of depth perception and motion perception, and perceptual constancy. Other illusions occur because of biological sensory structures within the human body or conditions outside of the body within one's physical environment.

The term illusion refers to a specific form of sensory distortion. Unlike a hallucination, which is a distortion in the absence of a stimulus, an illusion describes a misinterpretation of a true sensation. For example, hearing voices regardless of the environment would be a hallucination, whereas hearing voices in the sound of running water (or other auditory source) would be an illusion.

Mimes are known for a repertoire of illusions that are created by physical means. The mime artist creates an illusion of acting upon or being acted upon by an unseen object. These illusions exploit the audience's assumptions about the physical world. Well known examples include "walls", "climbing stairs", "leaning", "descending ladders", "pulling and pushing" etc.
Optical illusions

An optical illusion. Square A is exactly the same shade of grey as Square B. See Same color illusion

An optical illusion is always characterized by visually perceived images that, at least in common sense terms, are deceptive or misleading. Therefore, the information gathered by the eye is processed by the brain to give, on the face of it, a percept that does not tally with a physical measurement of the stimulus source. A conventional assumption is that there are physiological illusions that occur naturally and cognitive illusions that can be demonstrated by specific visual tricks that say something more basic about how human perceptual systems work. The human brain constructs a world inside our head based on what it samples from the surrounding environment. However sometimes it tries to organise this information it thinks best while other times it fills in the gaps. This way in which our brain works is the basis of an illusion.

Auditory illusions

An auditory illusion is an illusion of hearing, the sound equivalent of an optical illusion: the listener hears either sounds which are not present in the stimulus, or "impossible" sounds. In short, audio illusions highlight areas where the human ear and brain, as organic, makeshift tools, differ from perfect audio receptors (for better or for worse). One of example of an auditory illusions is a Shepard tone.

Tactile illusions

Examples of tactile illusions include phantom limb, the thermal grill illusion, the cutaneous rabbit illusion and a curious illusion that occurs when the crossed index and middle fingers are run along the bridge of the nose with one finger on each side, resulting in the perception of two separate noses. Interestingly, the brain areas activated during illusory tactile perception are similar to those activated during actual tactile stimulation. Tactile illusions can also be elicited through haptic technology. These "illusory" tactile objects can be used to create "virtual objects".

Other senses

Illusions can occur with the other senses including that of taste and smell. It was discovered that even if some portion of the taste receptor on the tongue became damaged that illusory taste could
be produced by tactile stimulation. Evidence of **olfactory** (smell) illusions occurred when positive or negative verbal labels were given prior to olfactory stimulation.

**Disorders**

Some illusions occur as a result of an illness or a disorder. While these types of illusions are not shared with everyone, they are typical of each condition. For example, migraine sufferers often report **Fortification illusions**.

**Philosophy and Illusion**

Just like many other words often used in a different sense in **spirituality** the word "illusion" is used to denote different aspects in Hindu Philosophy (Maya). Many Monist philosophies clearly demarcate illusion from truth and falsehood. As per Hindu advaita philosophy, Illusion is something which is not true and not false. Whereas in general usage, it is common to assume that illusion is false. Hindu philosophy makes a distinction between Maya (illusion) and falsehood. In terms of this philosophy, Maya is true in itself but it is not true in comparison with the truth. As per this philosophy, illusion is not the opposite of truth or reality. Based on these assumptions, Vedas declare that the world as humans normally see is illusion (Maya). It does not mean the world is not real. The world is only so much real as the image of a person in a mirror. The world is not real/true when compared to the reality. But the world is also not false. Falsehood is something which does not exist. If we apply this philosophy to the above example, the illusion is not actually illusion but is false. This is because in general usage people tend to consider illusion to be the same as falsehood. As per Adishankar's, a guru of monist teachings, the world we think is not true but is an illusion (not true not false). The truth of the world is something which can only be experienced by removing the identity (ego).

**Social perception**

**Social perception** is, in **psychology** and other **cognitive sciences**, that part of **perception** that allows us to understand the individuals and groups of our social world, and thus an element of **social cognition**.

It allows us to determine how people will affect our personal lives. While social perceptions can be flawed, they help people to form impressions of others by making the necessary information available to assess what people are like. Missing informations are filled in by using an **implicit personality theory**: If a person is observed to have one particular trait, we assume that he or she has other traits related to this observed one. These assumptions help us to "categorize" people and then infer additional facts and predict behavior.

Social perceptions are also interlinked with self-perceptions. Both are influenced by self-motives. Society has the desire to achieve beneficial outcomes for the self and to maintain a positive self-image, both for personal psychic benefits and because we know that others are perceiving us as well. Just as you prejudge the people you come across in society, you are being judged by them. It is human nature to want to put off a good impression on people, almost as if your self-perceptions are other's social perceptions.

**Structural and functional factors**

David Krech and Richard S. Crutchfield believe there to be two major determinants of perception, structural factors and functional factors.

**Structural factors**

By structural factors we mean those factors driving solely from the nature of the physical stimuli and the natural effects they evoke in the nervous system of the individual. Thus, for the Gestalt psychologist, perceptual organizations are determined primarily by the psychological events occurring in the nervous system of the individual in direct reaction to the stimulation by the
physical objects. Sensory factors are independent of the perceiving individual’s needs and personality.

**Functional factors**
The functional factors of perceptual organization are those, which derive primarily from the needs, moods, past experience and memory of the individual. All functional factors in perception are social in the usual sense of the term. In one experiment, for example, Levine, Chein and Murphy presented a series of ambiguous drawings to hungry college students and found a marked tendency for such drawings to be perceived as food objects such as sandwiches, salads, roasts etc. There was no such effect when the same drawings were shown to students who had just finished eating. The different perceptions of the hungry and not-hungry students could not be due to "structural" factors, since the same pictures were presented to both groups, but could be due only to the differences in need or motivation of the members of the two groups. While quantitative laws of how these functional factors actually operate in perception are lacking, a great deal of experimental work is available that demonstrates their pervasive influence in perception.

**Interrelationship between structural and functional factors**
The interaction that is true for most psychological processes is also characteristic of the operation of structural and functional factors in perception. Neither set operates alone and every perception involves both kinds of factors. Although we can experiment with structural factors alone in perception or with functional factors alone, we must realize that this is done only for experimental convenience. It means that whatever perception is being observed is a function of both sets of factors. It is important to recognize the relationship between these two sets of factors because it is at this point that reconciliation can be made between the behavioral psychologists who tend to break behavior down into its component parts and the gestalt psychologists who seek to understand man as an indivisible entity.

**Perceptual organization**
Physiological illusions, such as the afterimages following bright lights, or adapting stimuli of excessively longer alternating patterns (contingent perceptual aftereffect), are presumed to be the effects on the eyes or brain of excessive stimulation of a specific type - brightness, tilt, color, movement, etc. The theory is that stimuli have individual dedicated neural paths in the early stages of visual processing, and that repetitive stimulation of only one or a few channels causes a physiological imbalance that alters perception.

A scintillating grid illusion. Shape, position, colour, and 3D contrast converge to produce the illusion of black dots at the intersections.
The Hermann grid illusion and Mach bands are two illusions that are best explained using a biological approach. Lateral inhibition, where in the receptive field of the retina light and dark receptors compete with one another to become active, has been used to explain why we see bands of increased brightness at the edge of a color difference when viewing Mach bands. Once a receptor is active it inhibits adjacent receptors. This inhibition creates contrast, highlighting edges. In the Hermann grid illusion the gray spots appear at the intersection because of the inhibitory response which occurs as a result of the increased dark surround. Lateral inhibition has also been used to explain the Hermann grid illusion, but this has been disproved.

Cognitive illusions
Cognitive illusions are assumed to arise by interaction with assumptions about the world, leading to "unconscious inferences", an idea first suggested in the 19th century by Hermann Helmholtz. Cognitive illusions are commonly divided into ambiguous illusions, distorting illusions, paradox illusions, or fiction illusions.

1. Ambiguous illusions are pictures or objects that elicit a perceptual 'switch' between the alternative interpretations. The Necker cube is a well known example; another instance is the Rubin vase.

2. Distorting illusions are characterized by distortions of size, length, or curvature. A striking example is the Café wall illusion. Another example is the famous Müller-Lyer illusion.

3. Paradox illusions are generated by objects that are paradoxical or impossible, such as the Penrose triangle or impossible staircases seen, for example, in M. C. Escher's Ascending and Descending and Waterfall. The triangle is an illusion dependent on a cognitive misunderstanding that adjacent edges must join.

4. Fictional illusions are defined as the perception of objects that are genuinely not there to all but a single observer, such as those induced by schizophrenia or a hallucinogen. These are more properly called hallucinations.

Explanation of cognitive illusions

**Perceptual organization**

Reversible figure and vase
Duck-Rabbit illusion
To make sense of the world it is necessary to organize incoming sensations into information which is meaningful. Gestalt psychologists believe one way this is done is by perceiving individual sensory stimuli as a meaningful whole. Gestalt organization can be used to explain many illusions including the Duck-Rabbit illusion where the image as a whole switches back and forth from being a duck then being a rabbit and why in the figure-ground illusion the figure and ground are reversible.

Kanizsa triangle
In addition, Gestalt theory can be used to explain the illusory contours in the Kanizsa Triangle. A floating white triangle, which does not exist, is seen. The brain has a need to see familiar simple objects and has a tendency to create a "whole" image from individual elements. Gestalt means "form" or "shape" in German. However, another explanation of the Kanizsa Triangle is based in evolutionary psychology and the fact that in order to survive it was important to see form and edges. The use of perceptual organization to create meaning out of stimuli is the principle behind other well-known illusions including impossible objects. Our brain makes sense of shapes and symbols putting them together like a jigsaw puzzle, formulating that which isn't there to that which is believable.

Depth and motion perception
Illusions can be based on an individual's ability to see in three dimensions even though the image hitting the retina is only two dimensional. The Ponzo illusion is an example of an illusion which uses monocular cues of depth perception to fool the eye.
Ponzo illusion
In the Ponzo illusion the converging parallel lines tell the brain that the image higher in the visual field is farther away therefore the brain perceives the image to be larger, although the two images hitting the retina are the same size. The Optical illusion seen in a diorama/false perspective also exploits assumptions based on monocular cues of depth perception. The M. C. Escher painting Waterfall exploits rules of depth and proximity and our understanding of the physical world to create an illusion.
Like depth perception, motion perception is responsible for a number of sensory illusions. Film animation is based on the illusion that the brain perceives a series of slightly varied images produced in rapid succession as a moving picture. Likewise, when we are moving, as we would be while riding in a vehicle, stable surrounding objects may appear to move. We may also perceive a large object, like an airplane, to move more slowly, than smaller objects, like a car, although the larger object is actually moving faster. The Phi phenomenon is yet another example of how the brain perceives motion, which is most often created by blinking lights in close succession.

Color and brightness constancies

Simultaneous Contrast Illusion. The horizontal grey bar is the same shade throughout
In this illusion, the colored regions appear rather different, roughly orange and brown. In fact they are the same color, and in identical immediate surrounds, but the brain changes its assumption about colour due to the global interpretation of the surrounding image. Also, the white tiles that are shadowed are the same color as the grey tiles outside of the shadow.

Perceptual constancies are sources of illusions. Color constancy and brightness constancy are responsible for the fact that a familiar object will appear the same color regardless of the amount of or colour of light reflecting from it. An illusion of color or contrast difference can be created when the luminosity or colour of the area surrounding an unfamiliar object is changed. The contrast of the object will appear darker against a black field which reflects less light compared to a white field even though the object itself did not change in color. Similarly, the eye will compensate for colour contrast depending on the colour cast of the surrounding area.

Object consistencies
Like color, the brain has the ability to understand familiar objects as having a consistent shape or size. For example a door is perceived as rectangle regardless as to how the image may change on the retina as the door is opened and closed. Unfamiliar objects, however, do not always follow the rules of shape constancy and may change when the perspective is changed. The Shepard illusion of the changing table is an example of an illusion based on distortions in shape constancy.

Future perception
Researcher Mark Changizi of Rensselaer Polytechnic Institute in New York says optical illusions are due to a neural lag which most humans experience while awake. When light hits the retina, about one-tenth of a second goes by before the brain translates the signal into a visual perception of the world. Scientists have known of the lag, yet they have debated over how humans compensate, with some proposing that our motor system somehow modifies our movements to offset the delay. Changizi asserts that the human visual system has evolved to compensate for neural delays, generating images of what will occur one-tenth of a second into the future. This foresight enables human to react to events in the present. This allows humans to perform reflexive acts like catching a fly ball and to maneuver smoothly through a crowd. Illusions occur when our brains attempt to perceive the future, and those perceptions don't match reality. For example, one illusion called the Hering illusion, looks like bike spokes around a central point, with vertical lines on either side of this central, so-called vanishing point. The illusion tricks us into thinking we are moving forward, and thus, switches on our future-seeing abilities. Since we aren't actually moving and the figure is static, we misperceive the straight lines as curved ones.

Changizi said:
"Evolution has seen to it that geometric drawings like this elicit in us premonitions of the near future. The converging lines toward a vanishing point (the spokes) are cues that trick our brains into thinking we are moving forward - as we would in the real world, where the door frame (a pair..."
of vertical lines) seems to bow out as we move through it - and we try to perceive what that world will look like in the next instant."

Cognitive processes hypothesis
The hypothesis claims that visual illusions are because the neural circuitry in our visual system evolves, by neural learning, to a system that makes very efficient interpretations of usual 3D scenes based in the emergence of simplified models in our brain that speed up the interpretation process but give rise to optical illusions in unusual situations. In this sense, the cognitive processes hypothesis can be considered a framework for an understanding of optical illusions as the signature of the empirical statistical way vision has evolved to solve the inverse problem.

Research indicates that 3D vision capabilities emerge and are learned jointly with the planning of movements. After a long process of learning, an internal representation of the world emerges that is well adjusted to the perceived data coming from closer objects. The representation of distant objects near the horizon is less "adequate". In fact, it is not only the Moon that seems larger when we perceive it near the horizon. In a photo of a distant scene, all distant objects are perceived as smaller than when we observe them directly using our vision.

The retinal image is the main source driving vision but what we see is a "virtual" 3D representation of the scene in front of us. We don't see a physical image of the world. We see objects; and the physical world is not itself separated into objects. We see it according to the way our brain organizes it. The names, colors, usual shapes and other information about the things we see pop up instantaneously from our neural circuitry and influence the representation of the scene. We "see" the most relevant information about the elements of the best 3D image that our neural networks can produce. The illusions arise when the "judgments" implied in the unconscious analysis of the scene are in conflict with reasoned considerations about it.

Perception
In and cognitive science, perception is the process of attaining awareness or understanding of sensory information. The word "perception" comes from the Latin words perceptio, percipio, and means "receiving, collecting, action of taking possession, apprehension with the mind or senses."

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. The study of perception gave rise to the Gestalt school of psychology, with its emphasis on holistic approach.

What one perceives is a result of interplays between past experiences, including one’s culture, and the interpretation of the perceived. If the percept does not have support in any of these perceptual bases it is unlikely to rise above perceptual threshold.

Types
Two types of consciousness are considerable regarding perception: phenomenal (any occurrence that is observable and physical) and psychological. The difference everybody can demonstrate to him- or herself is by the simple opening and closing of his or her eyes: phenomenal consciousness is thought, on average, to be predominately absent without sight. Through the full or rich sensations present in sight, nothing by comparison is present while the eyes are closed. Using this precept, it is understood that, in the vast majority of cases, logical solutions are reached through simple human sensation. The analogy of Plato's Cave was coined to express these ideas.

Passive perception (conceived by René Descartes) can be surmised as the following sequence of events: surrounding → input (senses) → processing (brain) → output (re-action). Although still supported by mainstream philosophers, psychologists and neurologists, this theory is nowadays losing momentum. The theory of active perception has emerged from extensive research of sensory illusions, most notably the works of Richard L. Gregory. This theory, which is increasingly gaining
experimental support, can be surmised as dynamic relationship between "description" (in the brain) ↔ senses ↔ surrounding, all of which holds true to the linear concept of experience.

Perception and reality

Ambiguous images
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. The question, "Is the glass half empty or half full?" serves to demonstrate the way an object can be perceived in different ways.

Just as one object can give rise to multiple percepts, so an object may fail to give rise to any percept at all: if the percept has no grounding in a person's experience, the person may literally not perceive it.

The processes of perception routinely alter what humans see. When people view something with a preconceived concept about it, they tend to take those concepts and see them whether or not they are there. This problem stems from the fact that humans are unable to understand new information, without the inherent bias of their previous knowledge. A person’s knowledge creates his or her reality as much as the truth, because the human mind can only contemplate that to which it has been exposed. When objects are viewed without understanding, the mind will try to reach for something that it already recognizes, in order to process what it is viewing. That which most closely relates to the unfamiliar from our past experiences, makes up what we see when we look at things that we don’t comprehend.

This confusing ambiguity of perception is exploited in human technologies such as camouflage, and also in biological mimicry, for example by Peacock butterflies, whose wings bear eye markings that birds respond to as though they were the eyes of a dangerous predator. Perceptual ambiguity is not restricted to vision. For example, recent touch perception research Robles-De-La-Torre & Hayward 2001 found that kinesthesia based haptic perception strongly relies on the forces experienced during touch.

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. 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.
Preconceptions can influence how the world is perceived. For example, 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). 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-in-action**

An ecological understanding of perception derived from [Gibson's](https://en.wikipedia.org/wiki/Edward_Gibson) 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 social constructionism (held by such philosophers as [Ernst von Glasersfeld](https://en.wikipedia.org/wiki/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](https://en.wikipedia.org/wiki/General Tau Theory). According to this theory, tau information, or time-to-goal information is the fundamental 'percept' in perception.

**Form Perception**

**Definition**

Form perception refers to our ability to visually perceive objects in the world in response to the patterns of light that they caste on our retinas.

**Characteristics**

When an observer gazes steadily at a stationary object, form perception is facilitated by miniature eye movements, such as tremors, drifts, and micro saccades, that cause visually responsive cells to respond more vigorously to the object whenever the eyes move. Motion of an observer relative to the object also refreshes cell responses. Even when cells respond vigorously, form perception represents a major challenge for the brain because our retinas have a large blind spot and retinal veins that impede light from reaching photodetectors.

Boundary and surface processes facilitate this goal. Boundary processing includes perceptual grouping, boundary completion, and figure-ground separation. Surface processing includes compensation for variable illumination, also called “discounting the illuminant”, and surface filling-in using the surviving illuminant-discounted signals. These processes are carried out in different processing streams within the visual cortex. Both streams go through the Lateral
Geniculate Nucleus (LGN), which transmits signals from the retina to the visual cortex. Two streams (in blue) compute boundaries and surfaces. The third stream is sensitive to visual motion. The boundary stream goes from retina through the LGN parvo stage (named for its “parvocellular” cell type) to the cortical stages V1 interblob, V2 interstripe, V4, and on to inferotemporal cortex. The surface stream goes from retina through LGN parvo to V1 blob, V2 thin stripe, V4, and inferotemporal cortex.

Form perception means the experience of a shaped region in the field. Recognition means the experience that the shape is familiar. Identification means that the function or meaning or category of the shape is known. For those who have never seen the shape before, it will be perceived but not recognized or identified. For those who have, it will be perceived as a certain familiar shape and also identified. Recognition and identification obviously must be based on past experience, which means that through certain unknown processes, memory contributes to the immediate experience that one has, giving the qualities of familiarity and meaning.

The figure of a 4 in Fig. 1a is seen as one unit, separate from other units in the field, even if these units overlap. This means that the parts of the figure are grouped together by the perceptual system into a whole, and these parts are not grouped with the parts of other objects. This effect is called perceptual organization. There are other problems about form perception that remain to be unraveled. For example, the size of a figure can vary, as can its locus on the retina or even its color or type of contour, without affecting its perceived shape (Fig. 2).

Perceptual organization, (a) The figure of a four is immediately and spontaneously perceived despite the presence of other overlapping and adjacent lines, (b) The four, although physically present, is not spontaneously perceived and is even difficult to see when one knows it is there.

Transposition of form; the two shapes clearly look the same despite the difference in size.
A further fact about form perception is that it is dependent upon orientation. It is a commonplace observation that printed or written words are difficult to read when inverted, and faces look very odd or become unrecognizable when upside down. Simple figures also look different when their orientation is changed: a square looks like a diamond when tilted by 45°.
Perception of Space

Another very important aspect of our interaction with the environment is the perception of space. When the retinal image is two dimensional, how do we perceive the third dimension? The perception of space refers to the perception of size and distance. The available information on the retina can only indicate direction, but not in any obvious manner about distance from the eye. However, from our day to day experience we know that our perceptions of depth and distance are quite accurate. For example, our reaching movements are quite accurate, we can jump a pit accurately. All this is possible if we are able to accurately perceive depth and distance. You will learn, in the following paragraphs, that perception of space is possible, because, of the various cues available to us. Before we learn about the various cues available to us, we should clearly understand the terms depth, distance and size.

Retinal Disparity

When we look at an object with two eyes, we perceive it as singular, like we do other parts of the visual scene stimulating points on our retina that share a common visual direction. These points are termed "retinal corresponding points" and fall on an area called the "horopter". Points outside the horopter fall on slightly different retinal areas and so do not have the identical visual direction and lead to "retinal disparity", the basis of our depth discrimination. This retinal image disparity occurs due to the lateral displacement of the eyes. The region in visual space over which we perceive single vision is known as "Panum's fusional area", with objects in front and behind this area being in physiological diplopia (i.e. double vision). Our visual system suppresses this diplopia and hence we do not perceive double vision under normal viewing conditions. In order to understand the discussion on the horopter and Panum's fusional space, the sense of direction will be introduced. Two terms describing direction sense are:

- Oculocentric Visual Direction
- Egocentric Visual Direction

Oculocentric Visual Direction: The visual direction of an object can be represented by a line that joins the object and the fovea called the Principal Visual Direction or visual axis. Based on the principal visual direction, the direction of all other objects in the subjects visual field is determined. This is the called oculocentric visual direction. Therefore, each point of the retina can be considered to have it own sense of direction. For example, when we look at an object, the object is imaged on the fovea. Other objects imaged above the fovea are seen as "below" and those imaged below the fovea are seen as "above". Visual sense of direction is organised about the fovea. For a given position of the eye, objects having superimposed retinal images will be seen as being in alignment in the visual field, but at a different distance from the eye

(figure 1).
**Egocentric Visual Direction:** Egocentric visual direction refers to the direction of an object in space relative to one self, rather than the eyes. Egocentric direction is determined by retinal position, proprioceptive information about the eye, head and body position and the vestibular apparatus. All this information allows us to determine if a change in retinal position is due to object movement or due to eye or head movement. In figure 2a, a stationary object is imaged on the fovea with the head and the body stationary. When the eye moves, the stationary object is then imaged on a new retinal position. Therefore, oculocentric direction has changed but the egocentric direction has not changed as the object has remained stationary. In another example, the eye tracks a moving object (figure 2b). As the object is imaged on the fovea at all times, the oculocentric direction is the same but the egocentric direction is changing.

In binocular vision, the idea of corresponding retinal points have been used to describe the principle visual direction. Corresponding retinal points are points stimulated on the retina that give rise to the same visual direction. When objects stimulate non-corresponding points, this gives rise to different visual directions. These retinal points are called disparate points. Therefore, corresponding points
have the same principle visual direction and non-corresponding points have different visual directions (figure 3).

**Figure 3. Corresponding points of the two eyes.**
As we see the world single and not double, binocular vision can be represented by a single eye, the cyclopean eye. The cyclopean eye is an imaginary eye situated midway between the two eyes (figure 4).

**Figure 4. The cyclopean eye is used to determine the direction of point A and point B. Point A stimulating the temporal retina of right eye and the nasal retina of the left eye, that is, stimulates a retinal point to the right of the fovea.**
Disparate points give rise to physiological diplopia (double vision). In figure 5, it can be seen that point A stimulates disparate points (non-corresponding retinal points).
Figure 5. Point A and point B stimulating disparate points. Point A stimulates the nasal retina of both eyes.

Using the cyclopean eye, crossed and uncrossed diplopia can be explored. For an object closer than the fixation point such as point B in figure 6a, crossed diplopia occurs as the point B is imaged on the temporal retina of both eyes. This is termed crossed diplopia because the image in the left eye is seen on the right side. For an object located further than the fixation point, the image of the object falls on the nasal retina of both eyes producing uncrossed diplopia. This is termed uncrossed diplopia because the image in the left eye is seen on the left side (figure 6b).

Figure 6. Demonstrating (a) Crossed and (b) uncrossed diplopia using the cyclopean eye.

The principle of the cyclopean eye can be applied to patients with strabismus (a turned eye). Patients with strabismus are usually classified according to the direction of the eye turn. Two common types of strabismus are patients with an esotropia, their eye(s) turned in, and patients with exotropia, their eye(s) turned out. Patients with an exotropia will have crossed diplopia while patients with an esotropia will have uncrossed diplopia (figure 7).
The Horopter

Our visual world comprises of multiple points, hence, the need to develop concepts to deal with the whole visual space. This concept is called the horopter. The horopter is the locus of points in space that stimulates corresponding points. That is, a multitude of points in visual space that lead to single vision.

1. Vieth-Muller Circle
2. Measuring the Horopter
3. Relationship of the Horopter to Panum's fusional area

1) The Vieth-Muller circle
The Vieth-Muller circle is a theoretical horopter. All points on this circle should stimulate corresponding points on the retina and lead to single vision, provided that the fixation point lies on the centre of the circle and the eyes rotate about its nodal point (instead of their centre of rotation). The Vieth-Muller circle assumes there is angular symmetry of the corresponding points (figure 8).
2) Measuring the horopter

The horopter can be measured through several methods. These methods include:

1. Haplopic method
2. Nonius method
3. Apparent front-parallel plane (AFPP) method

The Nonius and AFPP methods directly determine the longitudinal horopter, whereas the haplopic method does not. Instead, the haplopic method determines the inner and outer boundaries of single binocular vision and the horopter is taken as the midline.

**Haplopic Method**

The haplopic method (method of the region of singular binocular vision) is based on the primary definition of corresponding points; retinal points which correspond give rise to identical visual directions and, as a consequence, single vision. Thus if diplopia is observed, disparate points are being stimulated. Therefore the method involves determining the boundaries of single binocular vision (figure 9).

**Nonius Method**

Since corresponding points give rise to identical visual directions, the position of an object which stimulates a pair of corresponding points can be located if each eye sees a different part of the object. If the two parts are seen in the same direction then the objects are in that position where they stimulate corresponding points. This is the basis of the Nonius method (method of equating visual directions; (figure 10).

The Apparent Fronto-Parallel Plane (AFPP) Method

The theory of stereopsis holds that stimulation of disparate points is necessary for the perception of relative depth by stereopsis. If there is no depth difference between an object and the fixation point then they stimulate corresponding points. Thus if the subject is asked to arrange a series of objects so that they appear to be in a fronto-parallel plane (ie. no depth difference between them) then they will lie on the horopter. This is the apparent fronto-parallel plane method (figure 11). Note the change in shape of the horopter at different distances.

Relationship of the Horopter to Panum’s Fusional Area

The haplopic method demonstrates the existence of Panum's fusional area. This concept allows for single binocular vision about the point of fixation even when corresponding retinal points are not being stimulated. An image on the retina of one eye can be fused (and seen as single) with a similar image on the retina of the other eye, even though disparity in the retinal image exists. Panum's fusional area is needed for stereopsis; if images do not fall in Panum's area then diplopia results and so Panum's fusional area defines the zone of stereo vision.

Aniseikonia.

Aniseikonia describes a subject's spatial perception when there is a difference in retinal image size of the same object between the two eyes. Aniseikonia can be investigated by placing an aniseikonic lens in front of one eye (to magnify the retinal image in one eye) while plotting the horopter using the AFPP method. When this is performed, the apparent fronto-parallel plane becomes skewed about the fixation point, with the horopter being nearer on the side of the eye having the increased magnification (figure 12). Note that magnification cannot be too large, otherwise, diplopia would result as the two retinal images would fall outside Panum's fusional area. Aniseikonia identifies reshaping of visual space within Panum's fusional area.
Figure 12. Plot of the horopter at 40 cm using the AFPP method with different magnification (2% and 4% magnification) lenses in front of one eye. (From Ogle, K. N., Researches in Binocular Vision. London: Saunders, 1950).

The importance of these plots with the aniseikonic lens is to demonstrate stable corresponding retinal points. As long as the magnification difference between the two eyes is not too large, fusion will be maintained although spatial distortions will occur. Once the magnification difference exceeds Panum’s fusional space, diplopia will result. Aniseikonic symptoms are a common complaint of patients with unequal refractive errors or large astigmatic corrections. The magical two weeks rule applies, ie, the time taken for sensory adaptation. If symptoms persist, reducing the magnification difference or reducing the correction are two clinical options.

Depth perception

Depth perception is the visual ability to perceive the world in three dimensions (3D).

Depth sensation is the ability to move accurately, or to respond consistently, based on the distances of objects in an environment.

Depth perception arises from a variety of depth cues. These are typically classified into binocular cues that require input from both eyes and monocular cues that require the input from just one eye. Binocular cues include stereopsis, yielding depth from binocular vision through exploitation of parallax. Monocular cues include size: distant objects subtend smaller visual angles than near objects. A third class of cues requires synthetic integration of binocular and monocular cues.

Monocular cues

Monocular cues provide depth information when viewing a scene with one eye.

Motion parallax - When an observer moves, the apparent relative motion of several stationary objects against a background gives hints about their relative distance. If information about the direction and velocity of movement is known, motion parallax can provide absolute depth information[3]. This effect can be seen clearly when driving in a car. Nearby things pass quickly, while far off objects appear stationary. Some animals that lack binocular vision due to wide placement of the eyes employ parallax more explicitly than humans for depth cueing (e.g. some types of birds, which bob their heads to achieve motion parallax, and squirrels, which move in lines orthogonal to an object of interest to do the same).

Depth from motion - One form of depth from motion, kinetic depth perception, is determined by dynamically changing object size. As objects in motion become smaller, they appear to recede into the distance or move farther away; objects in motion that appear to be getting larger seem to be coming closer. Using kinetic depth perception enables the brain to calculate time to crash distance.
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(aka time to collision or time to contact - TTC) at a particular velocity. When driving, we are constantly judging the dynamically changing headway (TTC) by kinetic depth perception.

**Perspective** - The property of parallel lines converging at infinity allows us to reconstruct the relative distance of two parts of an object, or of landscape features.

Relative size - If two objects are known to be the same size (e.g., two trees) but their absolute size is unknown, relative size cues can provide information about the relative depth of the two objects. If one subtends a larger visual angle on the retina than the other, the object which subtends the larger visual angle appears closer.

Familiar size - Since the visual angle of an object projected onto the retina decreases with distance, this information can be combined with previous knowledge of the object's size to determine the absolute depth of the object. For example, people are generally familiar with the size of an average automobile. This prior knowledge can be combined with information about the angle it subtends on the retina to determine the absolute depth of an automobile in a scene.

**Aerial perspective** - Due to light scattering by the atmosphere, objects that are a great distance away have lower luminance contrast and lower color saturation. In computer graphics, this is often called "distance fog". The foreground has high contrast; the background has low contrast. Objects differing only in their contrast with a background appear to be at different depths.[4] The color of distant objects are also shifted toward the blue end of the spectrum (e.g., distance mountains). Some painters, notably Cézanne, employ "warm" pigments (red, yellow and orange) to bring features forward towards the viewer, and "cool" ones (blue, violet, and blue-green) to indicate the part of a form that curves away from the picture plane.

**Accommodation** - This is an oculomotor cue for depth perception. When we try to focus on far away objects, the ciliary muscles stretches the eye lens, making it thinner, and hence changing the focal length. The kinesthetic sensations of the contracting and relaxing ciliary muscles (intraocular muscles) is sent to the visual cortex where it is used for interpreting distance/depth. Accommodation is only effective for distances less than 2 meters.

**Occlusion** (also referred to as interposition) - Occlusion (blocking the sight) of objects by others is also a clue which provides information about relative distance. However, this information only allows the observer to create a "ranking" of relative nearness.

**Peripheral vision** - At the outer extremes of the visual field, parallel lines become curved, as in a photo taken through a fish-eye lens. This effect, although it's usually eliminated from both art and photos by the cropping or framing of a picture, greatly enhances the viewer's sense of being positioned within a real, three dimensional space. (Classical perspective has no use for this so-called "distortion", although in fact the "distortions" strictly obey optical laws and provide perfectly valid visual information, just as classical perspective does for the part of the field of vision that falls within its frame.)

**Texture gradient** - Suppose you are standing on a gravel road. The gravel near you can be clearly seen in terms of shape, size and colour. As your vision shifts towards the distant road the texture cannot be clearly differentiated.

**Lighting and shading** - The way that light falls on an object and reflects off its surfaces, and the shadows that are cast by objects provide an effective cue for the brain to determine the shape of objects and their position in space.

**Binocular cues**

Binocular cues provide depth information when viewing a scene with both eyes.

**Stereopsis** or retinal(binocular) disparity - Animals that have their eyes placed frontally can also use information derived from the different projection of objects onto each retina to judge depth. By using two images of the same scene obtained from slightly different angles, it is possible to triangulate the distance to an object with a high degree of accuracy. If an object is far away, the
disparity of that image falling on both retinas will be small. If the object is close or near, the
disparity will be large. It is stereopsis that tricks people into thinking they perceive depth when
viewing Magic Eyes, Autostereograms, 3D movies and stereoscopic photos.

Convergence - This is a binocular oculomotor cue for distance/depth perception. By virtue of
stereopsis the two eye balls focus on the same object. In doing so they converge. The convergence
will stretch the extraocular muscles. Kinesthetic sensations from these extraocular muscles also
help in depth/distance perception. The angle of convergence is smaller when the eye is fixating on
far away objects. Convergence is effective for distances less than 10 meters.

Of these various cues, only convergence, accommodation and familiar size provide absolute
distance information. All other cues are relative (i.e., they can only be used to tell which objects are
closer relative to others). Stereopsis is merely relative because a greater or lesser disparity for
nearby objects could either mean that those objects differ more or less substantially in relative
depth or that the foveated object is nearer or further away (the further away a scene is, the smaller
is the retinal disparity indicating the same depth difference).

Inferred cues
It would be over-simplification to ignore the mental processes at work as a person sees with two
normal eyes. The fact that binocular stereopsis is occurring, enables the brain to infer and perceive
certain additional depth in the form of a mental construct. Closing one eye shuts down this stereo
construct. Recent work toward improving digital display of stereoscopic images has re-vitalized the
field, as practical applications often do. Those working in the field have identified several processes
of interpolation, previously ignored or considered irrelevant. These provide a linkage in the mental
construct of objects visible to only one eye, while viewing with both eyes in a forward direction.

Recent literature has addressed the relationship between the stereo viewing area and the periphery.
Recent analysis has demonstrated that objects just outside the angle of double visual coverage, are,
in fact, integrated by the mind into the stereo construct by a process of inference. Briefly stated, "all
objects, in even moderate focus, within the central viewing field of a single eye, are, an
important part of the stereo construct". Their physical position is noted, and SEEN very accurately
in the mental stereo visualization process, though visible to only one of the 2 eyes in use.

Evolution
Most open-plains herbivores, especially hoofed grazers, lack binocular vision because they have
their eyes on the sides of the head, providing a panoramic, almost 360°, view of the horizon -
enabling them to notice the approach of predators from almost any direction. However most
predators have both eyes looking forwards, allowing binocular depth perception and helping them
to judge distances when they pounce or swoop down onto their prey. Animals that spend a lot of
time in trees take advantage of binocular vision in order to accurately judge distances when rapidly
moving from branch to branch.

Matt Cartmill, a physical anthropologist & anatomist at Boston University, has criticized this
theory, citing other arboreal species which lack binocular vision, such as squirrels and certain birds.
Instead, he proposes a "Visual Predation Hypothesis," which argues that ancestral primates were
insectivorous predators resembling tarsiers, subject to the same selection pressure for frontal vision
as other predatory species. He also uses this hypothesis to account for the specialization of primate
hands, which he suggests became adapted for grasping prey, somewhat like the way raptors employ
their talons.

Depth perception in art
**Photographs** capturing perspective are two-dimensional images that often illustrate the illusion of depth. (This differs from a **painting**, which may use the physical matter of the paint to create a real presence of convex forms and spatial depth.) **Stereoscopes** and **Viewmasters**, as well as **3D** movies, employ binocular vision by forcing the viewer to see two images created from slightly different positions (points of view). By contrast, a **telephoto lens**—used in televised sports, for example, to zero in on members of a stadium audience—has the opposite effect. The viewer sees the size and detail of the scene as if it were close enough to touch, but the camera's perspective is still derived from its actual position a hundred meters away, so background faces and objects appear about the same size as those in the foreground.

Trained artists are keenly aware of the various methods for indicating spatial depth (color shading, **distance fog**, **perspective** and relative size), and take advantage of them to make their works appear "real". The viewer feels it would be possible to reach in and grab the nose of a Rembrandt portrait or an apple in a Cézanne still life—or step inside a landscape and walk around among its trees and rocks. **Cubism** was based on the idea of incorporating multiple points of view in a painted image, as if to simulate the visual experience of being physically in the presence of the subject, and seeing it from different angles. The radical "High Cubist" experiments of Braque and Picasso circa 1909 are interesting but more bizarre than convincing in visual terms. Slightly later paintings by their followers, such as Robert Delaunay's views of the Eiffel Tower, or John Marin's Manhattan cityscapes, borrow the explosive angularity of Cubism to exaggerate the traditional illusion of three-dimensional space. A century after the Cubist adventure, the verdict of art history is that the most subtle and successful use of multiple points of view can be found in the pioneering late work of Cézanne, which both anticipated and inspired the first actual Cubists. Cézanne's landscapes and still lifes powerfully suggest the artist's own highly-developed depth perception. At the same time, like the other **Post-Impressionists**, Cézanne had learned from **Japanese art** the significance of respecting the flat (two-dimensional) rectangle of the picture itself; Hokusai and Hiroshige ignored or even reversed linear perspective and thereby remind the viewer that a the picture can only be "true" when it acknowledges the truth of its own flat surface. By contrast, European "academic" painting was devoted to a sort of Big Lie that the surface of the canvas is only an enchanted doorway to a "real" scene unfolding beyond, and that the artist's main task is to distract the viewer from any disenchanting awareness of the presence of the painted canvas. **Cubism**, and indeed most of modern art is a struggle to confront, if not resolve, the paradox of suggesting spatial depth on a flat surface, and explore that inherent contradiction through innovative ways of seeing, as well as new methods of drawing and painting.

Disorders affecting depth perception

- Ocular conditions such as **amblyopia**, **optic nerve hypoplasia**, and **strabismus** may reduce the perception of depth.
- Since (by definition), binocular depth perception requires two functioning eyes, a person with only one functioning eye has no binocular depth perception.

It is typically felt that Depth perception must be learned in infancy using an **unconscious inference**.

**Attentional Process**

**Attention** is the **cognitive process** of selectively concentrating on one aspect of the environment while ignoring other things. Attention has also been referred to as the allocation of processing resources. Examples include listening carefully to what someone is saying while ignoring other conversations in a room (the **cocktail party effect**) or listening to a cell phone conversation while driving a car. Attention is one of the most intensely studied topics within **psychology** and **cognitive neuroscience**.
William James, in his textbook Principles of Psychology, remarked:

“Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatterbrained state which in French is called distraction, and Zerstreutheit in German.”

Attention remains a major area of investigation within education, psychology and neuroscience. Areas of active investigation involve determining the source of the signals that generate attention, the effects of these signals on the tuning properties of sensory neurons, and the relationship between attention and other cognitive processes like working memory and vigilance. A relatively new body of research is investigating the phenomenon of traumatic brain injuries and their effects on attention.

Selective attention

![Selective attention diagram]

In cognitive psychology there are at least two models which describe how visual attention operates. These models may be considered loosely as metaphors which are used to describe internal processes and to generate hypotheses that are falsifiable. Generally speaking, visual attention is thought to operate as a two-stage process. In the first stage, attention is distributed uniformly over the external visual scene and processing of information is performed in parallel. In the second stage, attention is concentrated to a specific area of the visual scene (i.e. it is focused), and processing is performed in a serial fashion.

The first of these models to appear in the literature is the spotlight model. The term "spotlight" was first used by David LaBerge, and was inspired by the work of William James who described attention as having a focus, a margin, and a fringe. The focus is an area that extracts information from the visual scene with a high-resolution, the geometric center of which being where visual attention is directed. Surrounding the focus is the fringe of attention which extracts information in a much more crude fashion (i.e. low-resolution). This fringe extends out to a specified area and this cut-off is called the margin.

The second model is called the zoom-lens model, and was first introduced in 1983. This model inherits all properties of the spotlight model (i.e. the focus, the fringe, and the margin) but has the added property of changing in size. This size-change mechanism was inspired by the zoom lens you
might find on a camera, and any change in size can be described by a trade-off in the efficiency of processing. The zoom-lens of attention can be described in terms of an inverse trade-off between the size of focus and the efficiency of processing: because attentional resources are assumed to be fixed, then it follows that the larger the focus is, the slower processing will be of that region of the visual scene since this fixed resource will be distributed over a larger area. It is thought that the focus of attention can subtend a minimum of 1° of visual angle, however the maximum size has not yet been determined.

Overt and covert attention
Attention may be differentiated according to its status as "overt" versus "covert." Overt attention is the act of directing sense organs towards a stimulus source. Covert attention is the act of mentally focusing on one of several possible sensory stimuli. Covert attention is thought to be a neural process that enhances the signal from a particular part of the sensory panorama. There are studies that suggest the mechanisms of overt and covert attention may not be as separate as previously believed. Though humans and primates can look in one direction but attend in another, there may be an underlying neural circuitry that links shifts in covert attention to plans to shift gaze. For example, if individuals attend to the right hand corner field of view, movement of the eyes in that direction may have to be actively suppressed.

The current view is that visual covert attention is a mechanism for quickly scanning the field of view for interesting locations. This shift in covert attention is linked to eye movement circuitry that sets up a slower saccade to that location.

Clinical model of attention
Attention is best described as the sustained focus of cognitive resources on information while filtering or ignoring extraneous information. Attention is a very basic function that often is a precursor to all other neurological/cognitive functions. As is frequently the case, clinical models of attention differ from investigation models. One of the most used models for the evaluation of attention in patients with very different neurologic pathologies is the model of Sohlberg and Mateer. This hierarchic model is based in the recovering of attention processes of brain damage patients after coma. Five different kinds of activities of growing difficulty are described in the model; connecting with the activities that patients could do as their recovering process advanced.

- Focused attention: The ability to respond discretely to specific visual, auditory or tactile stimuli.
- Sustained attention (vigilance): The ability to maintain a consistent behavioral response during continuous and repetitive activity.
- Selective attention: The ability to maintain a behavioral or cognitive set in the face of distracting or competing stimuli. Therefore it incorporates the notion of "freedom from distractibility."
- Alternating attention: The ability of mental flexibility that allows individuals to shift their focus of attention and move between tasks having different cognitive requirements.
- Divided attention: This is the highest level of attention and it refers to the ability to respond simultaneously to multiple tasks or multiple task demands.

This model has been shown to be very useful in evaluating attention in very different pathologies, correlates strongly with daily difficulties and is especially helpful in designing stimulation programs such as APT (attention process training), a rehabilitation program for neurologic patients of the same authors.

Executive attention
Inevitably situations arise where it is advantageous to have cognition independent of incoming sensory data or motor responses. There is a general consensus in psychology that there is an executive system based in the frontal cortex that controls our thoughts and actions to produce coherent behavior. This function is often referred to as **executive function**, executive attention, or cognitive control.

No exact definition has been agreed upon. However, typical descriptions involve maintaining behavioral goals, and using these goals as a basis for choosing what aspects of the environment to attend to and which action to select.

**Neural correlates of attention**

Most experiments show that one **neural correlate** of attention is enhanced firing. If a neuron has a certain response to a stimulus when the animal is not attending to the stimulus, then when the animal does attend to the stimulus, the neuron's response will be enhanced even if the physical characteristics of the stimulus remain the same.

In a recent review, Knudsen describes a more general model which identifies four core processes of attention, with **working memory** at the center:

- **Working memory** temporarily stores information for detailed analysis.
- Competitive selection is the process that determines which information gains access to working memory.
- Through top-down sensitivity control, higher cognitive processes can regulate signal intensity in information channels that compete for access to working memory, and thus give them an advantage in the process of competitive selection. Through top-down sensitivity control, the momentary content of working memory can influence the selection of new information, and thus mediate voluntary control of attention in a recurrent loop (endogenous attention).
- Bottom-up saliency filters automatically enhance the response to infrequent stimuli, or stimuli of instinctive or learned biological relevance (exogenous attention).

Neurally, at different hierarchical levels spatial maps can enhance or inhibit activity in sensory areas, and induce orienting behaviors like eye movement.

At the top of the hierarchy, the **frontal eye fields** (FEF) on the dorsolateral **frontal cortex** contain a retinocentric spatial map. Microstimulation in the FEF induces monkeys to make a **saccade** to the relevant location. Stimulation at levels too low to induce a saccade will nonetheless enhance cortical responses to stimuli located in the relevant area.

At the next lower level, a variety of spatial maps are found in the **parietal cortex**. In particular, the lateral intraparietal area (LIP) contains a saliency map and is interconnected both with the FEF and with sensory areas.

Certain automatic responses that influence attention, like orienting to a highly salient stimulus, are mediated subcortically by the **superior colliculi**.

At the neural network level, it is thought that processes like lateral inhibition mediate the process of competitive selection.

In many cases attention produces changes in the **EEG**. Many animals, including humans, produce gamma waves (40-60 Hz) when focusing attention on a particular object or activity.

**Sustained Attention (Attention and Vigilance)**

In modern **psychology**, vigilance, also termed sustained **attention**, is defined as the ability to maintain attention and **alertness** over prolonged periods of time. The study of vigilance has expanded since the 1940’s mainly due to the increased interaction of people with machines for
applications involving monitoring and detection of rare events and weak signals. Such applications include air traffic control, inspection and quality control, automated navigation, and military and border surveillance.

**Origins of Vigilance Research**
The systematic study of vigilance was initiated by Norman Mackworth during World War II. Mackworth authored The breakdown of vigilance during prolonged visual search in 1948 and this paper is the seminal publication on vigilance. Mackworth’s 1948 study investigated the tendency of radar and sonar operators to miss rare irregular event detections near the end of their watch. Mackworth simulated rare irregular events on a radar display by having the test participants watch an unmarked clock face over a 2 hour period. A single clock hand moved in small equal increments around the clock face, with the exception of occasional larger jumps. This device became known as the Mackworth Clock. Participants were tasked to report when they detected the larger jumps. Mackworth’s results indicated a decline in signal detection over time, known as a vigilance decrement. The participants’ event detection declined between 10 and 15 percent in the first 30 minutes and then continued to decline more gradually for the remaining 90 minutes. Mackworth’s method became known as the “Clock Test” and this method has been employed in subsequent investigations.

**Vigilance Decrement**
Vigilance decrement is defined as “deterioration in the ability to remain vigilant for critical signals with time, as indicated by a decline in the rate of the correct detection of signals”. Vigilance decrement is most commonly associated with monitoring to detect a weak target signal. Detection performance loss is less likely to occur in cases where the target signal exhibits a high saliency. For example, a radar operator would be unlikely to miss a rare target at the end of a watch if it were a large bright flashing signal, but might miss a small dim signal.

Under most conditions, vigilance decrement becomes significant within the first 15 minutes of attention, but a decline in detection performance can occur more quickly if the task demand conditions are high. This occurs in both experienced and novice task performers. Vigilance had traditionally been associated with low cognitive demand and vigilance decrement with a decline in arousal pursuant to the low cognitive demand, but these views are no longer widely held. More recent studies indicate that vigilance is hard work, requiring the allocation of significant cognitive resources, and inducing significant levels of stress.

**Vigilance Decrement and Signal Detection Theory**
Green and Swets formulated the Signal Detection Theory, or SDT, in 1966 to characterize detection task performance sensitivity while accounting for both the observer’s perceptual ability and willingness to respond. SDT assumes an active observer making perceptual judgments as conditions of uncertainty vary. A decision maker can vary their sensitivity, characterized by d’, to allow more or less correct detections, but at the respective cost of more or less false alarms. This is termed a criterion shift. The degree to which the observer tolerates false alarms to achieve a higher rate of detection is termed the bias. Bias represents a strategy to minimize the consequences of missed targets and false alarms. As an example, the lookout during a bank robbery must set a threshold for how “cop-like” an approaching individual or vehicle may be. Failing to detect the “cop” in a timely fashion may result in jail time, but a false alarm will result in a lost opportunity to steal money. In order to produce a bias-free measure, d’ is calculated by measuring the distance between the means of the signal and non-signals (noise) and scaling by the standard deviation of the noise. Mathematically, this can be accomplished by subtracting the z-score of the hit rate from the z-score of the false alarm rate. Application of SDT to the study of vigilance indicates that in
most, but not all cases, vigilance decrement is not the result of a reduction in sensitivity over time. In most cases a reduction of detections is accompanied by a commensurate reduction in false alarms, such that $d'$ is relatively unchanged.

**Vigilance Taxonomy: Discrimination Type and Event Rate**

Mental workload, or *cognitive load*, based on task differences can significantly affect the degree of vigilance decrement. In 1977, Parasuraman and Davies investigated the effect of two task difference variables on $d'$, and proposed the existence of a vigilance taxonomy based on discrimination type and event rate. Parasuraman and Davies employed discrimination tasks which were either successive or simultaneous, and presented both at high and low event rates. Successive discrimination tasks where critical information must be retained in working memory generate a greater mental workload than simultaneous comparison tasks. Their results indicate the type of discrimination and the rate at which discriminable events occur interact to affect sustained attention. Successive discrimination tasks indicate a greater degree of vigilance decrement than simultaneous discriminations, such as comparisons, but only when event rates are relatively high. For detection tasks, empirical evidence suggests that an event rate at or above 24 events per minute significantly reduces sensitivity. Further investigation has indicated that when the discrimination task is difficult, a decrement can occur when the mental workload is low, as with simultaneous comparisons, at both high and low event rates.

The effect of event rate on monitoring task performance can be affected by the addition of non-target salient objects at varying frequencies. Clock test research conducted in the late 1950s and 1960s indicates that an increase in event rate for rare irregular low salience signals reduced the vigilance decrement. When non-target “artificial” signals similar to target signals were introduced, the vigilance decrement was also reduced. When the “artificial” signal differed significantly from the target signal, no performance improvement was measured. Other dimensions beyond event rate and discrimination task difficulty affect the performance of vigilance tasks and are factors in the Vigilance Taxonomy. These include but are not limited to: sensory modality, or combinations of sensory modalities; source complexity; signal duration; signal intensity; multiple signal sources; discrete versus continuous events; intermittent versus continuous attention requirement; observer skill level; and stimulation value.

**Measuring Mental Workload During Vigilance Tasks**

Initial Vigilance Taxonomy studies relied on assumptions regarding the mental workload associated with discrimination tasks, rather than a direct quantification of that workload. Successive discriminations, for example, were assumed to impose a greater workload than simultaneous discriminations. Beginning in the late 1990’s, neuroimaging techniques such as *Positron Emission Tomography* (PET), *functional Magnetic Resonance Imaging* (fMRI) and *Transcranial Doppler sonography* (TCD) have been employed to independently assess brain activation and mental workload during vigilance experiments. These neuroimaging techniques estimate brain activation by measuring the blood flow (fMRI and TCD) or glucose metabolism (PET) associated with specific brain regions. Research employing these techniques has linked increases in mental workload and allocation of attentional resources with increased activity in the prefrontal cortex. Studies employing PET, fMRI and TCD indicate a decline in activity in the prefrontal cortex correlates with vigilance decrement. Neuroimaging studies also indicate that the control of vigilance may reside in the right cerebral hemisphere in a variety of brain regions.

**Brain Regions Associated with Vigilance**

Reductions in arousal generally correspond to reductions in vigilance. *Arousal* is a component of vigilance, though not, as once believed, the sole source of the main effect of the vigilance
Subcortical brain regions associated with arousal include the basal forebrain cholinergic system, and the locus coreulus (LC) noradrenergic system. Both regions are components of the **Reticular Activating System (RAS)**. The basal forebrain cholinergic system is associated with cortical acetylcholine release, which is associated with cortical arousal. Blocking the release of acetylcholine in the forebrain with GABAergic compounds impairs vigilance performance. Several cortical brain regions are associated with attention and vigilance. These include the right frontal, inferior parietal, prefrontal, superior temporal cortices and cingulate gyrus. In the frontal lobe, fMRI and TCD data indicate that brain activation increases during vigilance tasks with greater activation in the right hemisphere. Lesion and split brain studies indicate better right-brain performance on vigilance tasks, indicating an important role for the right frontal cortex in vigilance tasks. Activity in the LC noradrenergic system is associated with the alert waking state in animals through the release of noradrenaline. Chemically blocking the release of noradrenaline induces drowsiness and lapses in attention associated with a vigilance decrement. The dorsolateral prefrontal cortex exhibits a higher level of activation than other significantly active areas, indicating a key role in vigilance.

The cingulate gyrus differs from other brain regions associated with vigilance in that it exhibits less activation during vigilance tasks. The role of the cingulate gyrus in vigilance is unclear, but its proximity and connections to the **corpus callosum**, which regulates interhemispheric activity, may be significant. Reduced activation in the cingulate gyrus may be a by-product of asymmetrical frontal lobe activation initiated in the corpus callosum.

**Vigilance and Stress**

Stressful activities involve continuous application of extensive cognitive resources. If the vigilance decrement were the result of less brain activity rather than more, vigilance tasks could not be expected to be stressful. High levels of **epinephrine** and **norepinephrine** are correlated with continuous extensive mental workloads, making these compounds good chemical indicators of stress levels. Subjects performing vigilance tasks exhibit elevated levels of epinephrine and norepinephrine, consistent with high stress levels and indicative of a significant mental workload. Vigilance tasks may therefore be assumed to be stressful hard mental work.

**Individual Differences in Vigilance Performance**

Large individual differences in monitoring task performance have been reported in a number of vigilance studies. For a given task, however, the vigilance decrement between subjects is generally consistent over time, such that individuals exhibiting relatively higher levels of performance for a given task maintain that level of performance over time. For different tasks, however, individual performance differences are not consistent. For any one individual may not correlate well from one task to another. An individual exhibiting no significant decrement while performing a counting monitoring task may exhibit a significant decrement during a clock test. Relative performance between subjects may also vary based on the nature of the task. For example, subjects whose task performance is well correlated for a successive task may exhibit a poor performance correlation for a simultaneous task. Conversely, subjects performing similar monitoring tasks, such as radar versus sonar target detection, can be expected to exhibit similar patterns of task performance.

Levine et al. propose that individual differences in task performance may be influenced by task demands. For example, some tasks may require rapid comparisons or “perceptual speed”, while others may require “flexibility of closure”, such as detection of some predefined object within a cluttered scene. Linking task performance differences to task demands is consistent with the
Vigilance Taxonomy proposed by Parasuraman and Davies described above, and also supports the hypothesis that vigilance requires mental work, rather than being a passive activity.

**Reducing the Vigilance Decrement with Amphetamines**

Considerable research has been devoted to the reduction of the vigilance decrement. As noted above, the addition of non-target signals can improve task performance over time if the signals are similar to the target signals. Additionally, practice, performance feedback, amphetamines and rest are believed to moderate temporal performance decline without reducing sensitivity. Beginning in the mid-1940s research was conducted to determine whether amphetamines could reduce or counteract the vigilance decrement. In 1965, Jane Mackworth conducted clock test experiments in which half of 56 participants were given a strong amphetamine and half were given a placebo. Mackworth also provided false feedback and feedback in separate trials. Mackworth analyzed detection and false alarm rates to determine $d'$, the measure of sensitivity. Participants dosed with amphetamine exhibited no increased sensitivity but did exhibit a highly significant reduction in vigilance decrement. In feedback trials, sensitivity increased while the performance decline was significantly reduced. In trials where both amphetamine and feedback were given, sensitivity was increased and there was no significant vigilance decrement.

**Practice and Sustained Attention**

Training and practice significantly reduce the vigilance decrement, reduce the false alarm rate, and may improve sensitivity for many sustained attention tasks. Changes in strategy or bias may improve task performance. Improvements based on such a criterion shift would be expected to occur early in the training process. Experiments involving both audio and visual stimuli indicate the expected training performance improvement within the first five to ten hours of practice or less. Training improvements may also occur due to the reduced mental workload associated with task automaticity. In pilotage and airport security screening experiments, trained or expert subjects exhibit better detection of low salience targets, a reduction in false alarms, improved sensitivity, and a significantly reduced vigilance decrement. In some cases the vigilance decrement was eliminated or not apparent.

**Vigilance and Aging**

Vigilance research conducted with subjects across a range of ages conflict regarding the ability to maintain alertness and sustained attention with age. In 1991, Parasuraman and Giambra reported a trend towards lower detection rates and higher false alarm rates with age when comparing groups between 19 and 27, 40 and 55, and 70 and 80 years old. Deaton and Parasuraman reported in 1993 that beyond the age of 40 years, a trend towards lower detection rates and higher false alarm rates occurs in both cognitive tasks and sensory tasks, with higher and lower mental workloads respectively. Berardi, Parasuraman and Haxby reported no differences in 2001 in the overall levels of vigilance and the ability to sustain attention over time for when comparing middle aged (over 40) and younger subjects. Age dependent differences in cognitive tasks may differ with task type and workload, and some differences in detection and false alarms may be due to the reduction in the sensitivity of sensory organs.

**Vigilance and the Lack of Habituation**

Early theories of vigilance explained the reduction of electrophysiological activity over time associated with the vigilance decrement as a result of neural habituation. Habituation is the decrease in neural responsivity due to repeated stimulation. Under passive conditions, when no task is performed, participants exhibit attenuated N100 Event Related Potentials (ERP) that indicate neural habituation, and it was assumed that habituation was also responsible for the vigilance
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decrement. More recent ERP studies indicate that when performance declines during a vigilance task, N100 amplitude was not diminished. These results indicate that vigilance is not the result of boredom or a reduction in neurological sensitivity.

Module 4

COGNITIVE PROCESSES - LEARNING

Learning

Learning is acquiring new knowledge, behaviors, skills, values, preferences or understanding, 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[1][2]. 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.[3]

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

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 learned through association with a separate, pre-occurring element. It is also referred to as classical conditioning.

**Operant conditioning**

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 deals with the modification of voluntary behavior. Discrimination learning is a major form of operant conditioning. One form of it is called Errorless learning.

**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).

**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 behaviour, such as a dance. Humans can copy three types of information simultaneously: the demonstrator's goals, actions and environmental outcomes (results, see Emulation (observational learning)). 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 behaviours 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
The learning where learner uses multimedia learning environments (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), it uses different mobile telecommunication equipments, 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.

**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.

**Non-formal learning and combined approaches**
The educational system may use a combination of formal, informal, and non-formal 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 proof this offered valuable new insights, 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 some portion of people will self-educate if a topic is exposed to them in something that they already enjoy such as playing a musical instrument.

**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).

Classical conditioning

Classical conditioning (also Pavlovian or respondent conditioning, Pavlovian reinforcement) is a form of associative learning that was first demonstrated by Ivan Pavlov. The typical procedure for inducing classical conditioning involves presentations of a neutral stimulus along with a stimulus of some significance. The neutral stimulus could be any event that does not result in an overt behavioral response from the organism under investigation. Pavlov referred to this as a conditioned stimulus (CS). Conversely, presentation of the significant stimulus necessarily evokes an innate, often reflexive, response. Pavlov called these the unconditioned stimulus (US) and unconditioned response (UR), respectively. If the CS and the US are repeatedly paired, eventually the two stimuli become associated and the organism begins to produce a behavioral response to the CS. Pavlov called this the conditioned response (CR).

Popular forms of classical conditioning that are used to study neural structures and functions that underlie learning and memory include fear conditioning, eyeblink conditioning, and the foot contraction conditioning of *Hermissenda crassicornis*.

The original and most famous example of classical conditioning involved the salivary conditioning of Pavlov's dogs. During his research on the physiology of digestion in dogs, Pavlov noticed that, rather than simply salivating in the presence of meat powder (an innate response to food that he called the unconditioned response), the dogs began to salivate in the presence of the lab technician who normally fed them. Pavlov called these psychic secretions. From this observation he predicted that, if a particular stimulus in the dog's surroundings were present when the dog was presented with meat powder, then this stimulus would become associated with food and cause salivation on its own. In his initial experiment, Pavlov used a bell to call the dogs to their food and, after a few repetitions, the dogs started to salivate in response to the bell.

Types

![Diagram representing forward conditioning](chart)

Forward conditioning: During forward conditioning the onset of the CS precedes the onset of the US. Two common forms of forward conditioning are delay and trace conditioning.
**Delay Conditioning:** In delay conditioning the CS is presented and is overlapped by the presentation of the US

**Trace conditioning:** During trace conditioning the CS and US do not overlap. Instead, the CS is presented, a period of time is allowed to elapse during which no stimuli are presented, and then the US is presented. The stimulus free period is called the *trace interval*. It may also be called the "conditioning interval"

**Simultaneous conditioning:** During simultaneous conditioning, the CS and US are presented and terminated at the same time.

**Backward conditioning:** Backward conditioning occurs when a conditioned stimulus immediately follows an unconditioned stimulus. Unlike traditional conditioning models, in which the conditioned stimulus precedes the unconditioned stimulus, the conditioned response tends to be inhibitory. This is because the conditioned stimulus serves as a signal that the unconditioned stimulus has ended, rather than a reliable method of predicting the future occurrence of the unconditioned stimulus.

**Temporal conditioning:** The US is presented at regularly timed intervals, and CR acquisition is dependent upon correct timing of the interval between US presentations. The background, or context, can serve as the CS in this example.

**Unpaired conditioning:** The CS and US are not presented together. Usually they are presented as independent trials that are separated by a variable, or pseudo-random, interval. This procedure is used to study non-associative behavioral responses, such as *sensitization*.

**CS-alone extinction:** The CS is presented in the absence of the US. This procedure is usually done after the CR has been acquired through Forward conditioning training. Eventually, the CR frequency is reduced to pre-training levels.

Procedure variations

In addition to the simple procedures described above, some classical conditioning studies are designed to tap into more complex learning processes. Some common variations are discussed below.

**Classical discrimination/reversal conditioning**

In this procedure, two CSs and one US are typically used. The CSs may be the same modality (such as lights of different intensity), or they may be different modalities (such as auditory CS and visual CS). In this procedure, one of the CSs is designated CS+ and its presentation is always followed by the US. The other CS is designated CS- and its presentation is never followed by the US. After a number of trials, the organism learns to *discriminate* CS+ trials and CS- trials such that CRs are only observed on CS+ trials.

During *Reversal Training*, the CS+ and CS- are reversed and subjects learn to suppress responding to the previous CS+ and show CRs to the previous CS-.

**Classical ISI discrimination conditioning**

This is a discrimination procedure in which two different CSs are used to signal two different *interstimulus intervals*. For example, a dim light may be presented 30 seconds before a US, while a very bright light is presented 2 minutes before the US. Using this technique, organisms can learn to perform CRs that are appropriately timed for the two distinct CSs.

**Latent inhibition conditioning**

In this procedure, a CS is presented several times before paired CS-US training commences. The pre-exposure of the subject to the CS before paired training slows the rate of CR acquisition relative to organisms that are not CS pre-exposed. Also see *Latent inhibition* for applications.
**Conditioned inhibition conditioning**

Three phases of conditioning are typically used:

**Phase 1:**
A CS (CS+) is not paired with a US until asymptotic CR levels are reached.

**Phase 2:**
CS+/US trials are continued, but interspersed with trials on which the CS+ in compound with a second CS, but not with the US (i.e., CS+/CS- trials). Typically, organisms show CRs on CS+/US trials, but suppress responding on CS+/CS- trials.

**Phase 3:**
In this retention test, the previous CS- is paired with the US. If conditioned inhibition has occurred, the rate of acquisition to the previous CS- should be impaired relative to organisms.

**Blocking**

This form of classical conditioning involves two phases.

**Phase 1:**
A CS (CS1) is paired with a US.

**Phase 2:**
A compound CS (CS1+CS2) is paired with a US.

**Test:**
A separate test for each CS (CS1 and CS2) is performed. The blocking effect is observed in a lack of conditioned response to CS2, suggesting that the first phase of training blocked the acquisition of the second CS.

**Applications**

John B. Watson, founder of behaviorism, demonstrated classical conditioning empirically through experimentation using the Little Albert experiment in which a child ("Albert") was presented with a white rat (CS). After a control period in which the child reacted normally to the presence of the rat, the experimentors paired the presence of the rat with a loud, jarring noise caused by clanging two pipes together behind the child's head (US). As the trials progressed, the child began showing signs of distress at the sight of the rat, even when unaccompanied by the frightening noise. Furthermore, the child demonstrated generalization of stimulus associations, and showed distress when presented with any white, furry object—even such things as a rabbit, dog, a fur coat, and a Santa Claus mask with hair.

**Behavioral therapies**

In human psychology, implications for therapies and treatments using classical conditioning differ from operant conditioning. Therapies associated with classical conditioning are aversion therapy, flooding and systematic desensitization.

Classical conditioning is short-term, usually requiring less time with therapists and less effort from patients, unlike humanistic therapies. The therapies mentioned are designed to cause either aversive feelings toward something, or to reduce unwanted fear and aversion.

**Theories of classical conditioning**

There are two competing theories of how classical conditioning works. The first, stimulus-response theory, suggests that an association to the unconditioned stimulus is made with the conditioned
stimulus within the brain, but without involving conscious thought. The second theory stimulus-stimulus theory involves cognitive activity, in which the conditioned stimulus is associated to the concept of the unconditioned stimulus, a subtle but important distinction.

**Stimulus-response theory**, referred to as S-R theory, is a theoretical model of behavioral psychology that suggests humans and other animals can learn to associate a new stimulus — the conditioned stimulus (CS) — with a pre-existing stimulus — the unconditioned stimulus (US), and can think, feel or respond to the CS as if it were actually the US.

The opposing theory, put forward by cognitive behaviorists, is stimulus-stimulus theory (S-S theory). **Stimulus-stimulus theory**, referred to as S-S theory, is a theoretical model of classical conditioning that suggests a cognitive component is required to understand classical conditioning and that stimulus-response theory is an inadequate model. It proposes that a cognitive component is at play. S-R theory suggests that an animal can learn to associate a conditioned stimulus (CS) such as a bell, with the impending arrival of food termed the unconditioned stimulus, resulting in an observable behavior such as salivation. Stimulus-stimulus theory suggests that instead the animal salivates to the bell because it is associated with the concept of food, which is a very fine but important distinction.

To test this theory, psychologist Robert Rescorla undertook the following experiment. Rats learned to associate a loud noise as the unconditioned stimulus, and a light as the conditioned stimulus. The response of the rats was to freeze and cease movement. What would happen then if the rats were habituated to the US? S-R theory would suggest that the rats would continue to respond to the CS, but if S-S theory is correct, they would be habituated to the concept of a loud sound (danger), and so would not freeze to the CS. The experimental results suggest that S-S was correct, as the rats no longer froze when exposed to the signal light. His theory still continues and is applied in everyday life.

**Operant conditioning**

Operant conditioning is the use of consequences to modify the occurrence and form of behavior. Operant conditioning is distinguished from classical conditioning (also called respondent conditioning, or Pavlovian conditioning) in that operant conditioning deals with the modification of "voluntary behavior" or operant behavior. Operant behavior "operates" on the environment and is maintained by its consequences, while classical conditioning deals with the conditioning of respondent behaviors which are elicited by antecedent conditions. Behaviors conditioned via a classical conditioning procedure are not maintained by consequences. The main dependent variable is the rate of response that is developed over a period of time. New operant responses can be further developed and shaped by reinforcing close approximations of the desired response.

Reinforcement, punishment, and extinction

Reinforcement and punishment, the core tools of operant conditioning, are either positive (delivered following a response), or negative (withdrawn following a response). This creates a total of four basic consequences, with the addition of a fifth procedure known as extinction (i.e. no change in consequences following a response).

It's important to note that organisms are not spoken of as being reinforced, punished, or extinguished; it is the response that is reinforced, punished, or extinguished. Additionally, reinforcement, punishment, and extinction are not terms whose use is restricted to the laboratory. Naturally occurring consequences can also be said to reinforce, punish, or extinguish behavior and are not always delivered by people.

Reinforcement is a consequence that causes a behavior to occur with greater frequency.

Punishment is a consequence that causes a behavior to occur with less frequency.

Extinction is the lack of any consequence following a behavior. When a behavior is inconsequential, producing neither favorable nor unfavorable consequences, it will occur with less
frequency. When a previously reinforced behavior is no longer reinforced with either positive or negative reinforcement, it leads to a decline in the response. Four contexts of operant conditioning: Here the terms "positive" and "negative" are not used in their popular sense, but rather: "positive" refers to addition, and "negative" refers to subtraction. What is added or subtracted may be either reinforcement or punishment. Hence positive punishment is sometimes a confusing term, as it denotes the addition of a stimulus or increase in the intensity of a stimulus that is aversive (such as spanking or an electric shock). The four procedures are:

1. **Positive reinforcement** (Reinforcement) occurs when a behavior (response) is followed by a stimulus (commonly seen as pleasant) that increases the frequency of that behavior. In the Skinner box experiment, a stimulus such as food or sugar solution can be delivered when the rat engages in a target behavior, such as pressing a lever.

2. **Negative reinforcement** (Escape) occurs when a behavior (response) is followed by the removal of a stimulus (commonly seen as unpleasant) thereby increasing that behavior's frequency. In the Skinner box experiment, negative reinforcement can be a loud noise continuously sounding inside the rat's cage until it engages in the target behavior, such as pressing a lever, upon which the loud noise is removed.

3. **Positive punishment** (Punishment) (also called "Punishment by contingent stimulation") occurs when a behavior (response) is followed by a stimulus, such as introducing a shock or loud noise, resulting in a decrease in that behavior.

4. **Negative punishment** (Penalty) (also called "Punishment by contingent withdrawal") occurs when a behavior (response) is followed by the removal of a stimulus, such as taking away a child's toy following an undesired behavior, resulting in a decrease in that behavior.

Also:

- **Avoidance learning** is a type of learning in which a certain behavior results in the cessation of an aversive stimulus. For example, performing the behavior of shielding one's eyes when in the sunlight (or going indoors) will help avoid the aversive stimulation of having light in one's eyes.

- **Extinction** occurs when a behavior (response) that had previously been reinforced is no longer effective. In the Skinner box experiment, this is the rat pushing the lever and being rewarded with a food pellet several times, and then pushing the lever again and never receiving a food pellet again. Eventually the rat would cease pushing the lever.

- **Noncontingent** reinforcement refers to delivery of reinforcing stimuli regardless of the organism's (aberrant) behavior. The idea is that the target behavior decreases because it is no longer necessary to receive the reinforcement. This typically entails time-based delivery of stimuli identified as maintaining aberrant behavior, which serves to decrease the rate of the target behavior. As no measured behavior is identified as being strengthened, there is controversy surrounding the use of the term noncontingent "reinforcement".

**Thorndike's law of effect**
Operant conditioning, sometimes called instrumental conditioning or instrumental learning, was first extensively studied by Edward L. Thorndike (1874–1949), who observed the behavior of cats trying to escape from home-made puzzle boxes. When first constrained in the boxes, the cats took a
long time to escape. With experience, ineffective responses occurred less frequently and successful
responses occurred more frequently, enabling the cats to escape in less time over successive trials.
In his Law of Effect, Thorndike theorized that successful responses, those producing satisfying
consequences, were "stamped in" by the experience and thus occurred more frequently. Unsuccessful
responses, those producing annoying consequences, were stamped out and subsequently occurred less frequently. In short, some consequences strengthened behavior and some consequences weakened behavior. Thorndike produced the first known learning curves
through this procedure. B.F. Skinner (1904–1990) formulated a more detailed analysis of operant
conditioning based on reinforcement, punishment, and extinction. Following the ideas of Ernst
Mach, Skinner rejected Thorndike’s mediating structures required by "satisfaction" and constructed
a new conceptualization of behavior without any such references. So, while experimenting with
some homemade feeding mechanisms, Skinner invented the operant conditioning chamber which
allowed him to measure rate of response as a key dependent variable using a cumulative record of
lever presses or key pecks.

Biological correlates of operant conditioning
The first scientific studies identifying neurons that responded in ways that suggested they encode
for conditioned stimuli came from work by Rusty Richardson and Mahlon deLong. They showed
that nucleus basalis neurons, which release acetylcholine broadly throughout the cerebral cortex,
are activated shortly after a conditioned stimulus, or after a primary reward if no conditioned
stimulus exists. These neurons are equally active for positive and negative reinforcers, and have
been demonstrated to cause plasticity in many cortical regions. Evidence also exists that dopamine
is activated at similar times. There is considerable evidence that dopamine participates in both
reinforcement and aversive learning. Dopamine pathways project much more densely onto frontal
cortex regions. Cholinergic projections, in contrast, are dense even in the posterior cortical regions
like the primary visual cortex. A study of patients with Parkinson’s disease, a condition attributed to
the insufficient action of dopamine, further illustrates the role of dopamine in positive
reinforcement. It showed that while off their medication, patients learned more readily with
aversive consequences than with positive reinforcement. Patients who were on their medication
showed the opposite to be the case, positive reinforcement proving to be the more effective form of
learning when the action of dopamine is high.

Factors that alter the effectiveness of consequences
When using consequences to modify a response, the effectiveness of a consequence can be
increased or decreased by various factors. These factors can apply to either reinforcing or punishing
consequences.

1. Satiation/Deprivation: The effectiveness of a consequence will be reduced if the
individual’s "appetite" for that source of stimulation has been satisfied. Inversely, the
effectiveness of a consequence will increase as the individual becomes deprived of that
stimulus. If someone is not hungry, food will not be an effective reinforcer for behavior.
Satiation is generally only a potential problem with primary reinforcers, those that do not
need to be learned such as food and water.

2. Immediacy: After a response, how immediately a consequence is then felt determines the
effectiveness of the consequence. More immediate feedback will be more effective than less
immediate feedback. If someone's license plate is caught by a traffic camera for speeding and they receive a speeding ticket in the mail a week later, this consequence will not be very effective against speeding. But if someone is speeding and is caught in the act by an officer who pulls them over, then their speeding behavior is more likely to be affected.

3. **Contingency**: If a consequence does not contingently (reliably, or consistently) follow the target response, its effectiveness upon the response is reduced. But if a consequence follows the response consistently after successive instances, its ability to modify the response is increased. The schedule of reinforcement, when consistent, leads to faster learning. When the schedule is variable the learning is slower. Extinction is more difficult when learning occurred during intermittent reinforcement and more easily extinguished when learning occurred during a highly consistent schedule.

4. **Size**: This is a "cost-benefit" determinant of whether a consequence will be effective. If the size, or amount, of the consequence is large enough to be worth the effort, the consequence will be more effective upon the behavior. An unusually large lottery jackpot, for example, might be enough to get someone to buy a one-dollar lottery ticket (or even buying multiple tickets). But if a lottery jackpot is small, the same person might not feel it to be worth the effort of driving out and finding a place to buy a ticket. In this example, it's also useful to note that "effort" is a punishing consequence. How these opposing expected consequences (reinforcing and punishing) balance out will determine whether the behavior is performed or not.

Most of these factors exist for biological reasons. The biological purpose of the Principle of Satiation is to maintain the organism's **homeostasis**. When an organism has been deprived of sugar, for example, the effectiveness of the taste of sugar as a reinforcer is high. However, as the organism reaches or exceeds their optimum blood-sugar levels, the taste of sugar becomes less effective, perhaps even aversive.

The principles of Immediacy and Contingency exist for neurochemical reasons. When an organism experiences a reinforcing stimulus, **dopamine** pathways in the brain are activated. This network of pathways "releases a short pulse of dopamine onto many **dendrites**, thus broadcasting a rather global reinforcement signal to postsynaptic neurons. This results in the plasticity of these synapses allowing recently activated synapses to increase their sensitivity to efferent signals, hence increasing the probability of occurrence for the recent responses preceding the reinforcement. These responses are, statistically, the most likely to have been the behavior responsible for successfully achieving reinforcement. But when the application of reinforcement is either less immediate or less contingent (less consistent), the ability of dopamine to act upon the appropriate synapses is reduced.

Operant variability

Operant variability is what allows a response to adapt to new situations. Operant behavior is distinguished from reflexes in that its response topography (the form of the response) is subject to slight variations from one performance to another. These slight variations can include small differences in the specific motions involved, differences in the amount of force applied, and small changes in the timing of the response. If a subject's history of reinforcement is consistent, such variations will remain stable because the same successful variations are more likely to be reinforced than less successful variations. However, behavioral variability can also be altered when subjected to certain controlling variables.

Avoidance learning
Avoidance training belongs to negative reinforcement schedules. The subject learns that a certain response will result in the termination or prevention of an aversive stimulus. There are two kinds of commonly used experimental settings: discriminated and free-operant avoidance learning.

**Discriminated avoidance learning**

In discriminated avoidance learning, a novel stimulus such as a light or a tone is followed by an aversive stimulus such as a shock (CS-US, similar to classical conditioning). During the first trials (called escape-trials) the animal usually experiences both the CS (Conditioned Stimulus) and the US (Unconditioned Stimulus), showing the operant response to terminate the aversive US. By the time, the animal will learn to perform the response already during the presentation of the CS thus preventing the aversive US from occurring. Such trials are called avoidance trials.

**Free-operant avoidance learning**

In this experimental session, no discrete stimulus is used to signal the occurrence of the aversive stimulus. Rather, the aversive stimulus (mostly shocks) are presented without explicit warning stimuli. There are two crucial time intervals determining the rate of avoidance learning. This first one is called the S-S-interval (shock-shock-interval). This is the amount of time which passes during successive presentations of the shock (unless the operant response is performed). The other one is called the R-S-interval (response-shock-interval) which specifies the length of the time interval following an operant response during which no shocks will be delivered. Note that each time the organism performs the operant response, the R-S-interval without shocks begins anew.

Two-process theory of avoidance

This theory was originally established to explain learning in discriminated avoidance learning. It assumes two processes to take place. a) Classical conditioning of fear. During the first trials of the training, the organism experiences both CS and aversive US (escape-trials). The theory assumed that during those trials classical conditioning takes place by pairing the CS with the US. Because of the aversive nature of the US the CS is supposed to elicit a conditioned emotional reaction (CER) - fear. In classical conditioning, presenting a CS conditioned with an aversive US disrupts the organism's ongoing behavior. b) Reinforcement of the operant response by fear-reduction. Because during the first process, the CS signaling the aversive US has itself become aversive by eliciting fear in the organism, reducing this unpleasant emotional reaction serves to motivate the operant response. The organism learns to make the response during the US, thus terminating the aversive internal reaction elicited by the CS. An important aspect of this theory is that the term "Avoidance" does not really describe what the organism is doing. It does not "avoid" the aversive US in the sense of anticipating it. Rather the organism escapes an aversive internal state, caused by the CS.

One of the practical aspects of operant conditioning with relation to animal training is the use of shaping (reinforcing successive approximations and not reinforcing behavior past approximating), as well as chaining.

**Verbal Behavior**

In 1957, Skinner published *Verbal Behavior*, a theoretical extension of the work he had pioneered since 1938. This work extended the theory of operant conditioning to human behavior previously assigned to the areas of language, linguistics and other areas. Verbal Behavior is the logical extension of Skinner's ideas, in which he introduced new functional relationship categories such as intraverbals, autoclitics, mands, tacts and the controlling relationship of the audience. All of these relationships were based on operant conditioning and relied on no new mechanisms despite the introduction of new functional categories.

**Four term contingency**
Applied behavior analysis, which is the name of the discipline directly descended from Skinner's work, holds that behavior is explained in four terms: conditional stimulus (S\text{C}), a discriminative stimulus (S\text{d}), a response (R), and a reinforcing stimulus (S\text{rein} or S\text{r} for reinforcers, sometimes S\text{ave} for aversive stimuli).

Operant hoarding

Operant hoarding is a referring to the choice made by a rat, on a compound schedule, that maximizes its rate of reinforcement in an operant conditioning context. More specifically, rats were shown to have allowed food pellets to accumulate in a food tray by continuing to press a lever on a continuous reinforcement schedule instead of retrieving those pellets. Retrieval of the pellets always instituted a one-minute period of extinction during which no additional food pellets were available but those that had been accumulated earlier could be consumed. This finding appears to contradict the usual finding that rats behave impulsively in situations in which there is a choice between a smaller food object right away and a larger food object after some delay. See schedules of reinforcement.

An alternative to the Law of Effect

However, an alternative perspective has been proposed by R. Allen and Beatrix Gardner. Under this idea, which they called "feedforward", animals learn during operant conditioning by simple pairing of stimuli, rather than by the consequences of their actions. Skinner asserted that a rat or pigeon would only manipulate a lever if rewarded for the action, a process he called shaping (reward for approaching then manipulating a lever). However, in order to prove the necessity of reward (reinforcement) in lever pressing, a control condition where food is delivered without regard to behavior must also be conducted. Skinner never published this control group. Only much later was it found that rats and pigeons do indeed learn to manipulate a lever when food comes irrespective of behavior. This phenomenon is known as autoshaping. Autoshaping demonstrates that consequence of action is not necessary in an operant conditioning chamber, and it contradicts the Law of Effect. Further experimentation has shown that rats naturally handle small objects, such as a lever, when food is present. Rats seem to insist on handling the lever when free food is available (contra-freeloading) and even when pressing the lever leads to less food (omission training). Whenever food is presented, rats handle the lever, regardless if lever pressing leads to more food. Therefore, handling a lever is a natural behavior that rats do as preparatory feeding activity, and in turn, lever pressing cannot logically be used as evidence for reward or reinforcement to occur. In the absence of evidence for reinforcement during Operant conditioning, learning which occurs during Operant experiments is actually only Pavlovian (Classical) conditioning. The dichotomy between Pavlovian and Operant conditioning is therefore an inappropriate separation.

Extinction

Extinction is the conditioning phenomenon in which a previously learned response to a cue is reduced when the cue is presented in the absence of the previously paired aversive or appetitive stimulus.

Fear conditioning

Extinction is typically studied within the Pavlovian fear conditioning framework in which extinction refers to the reduction in a conditioned response (CR; e.g., fear response/freezing) when a conditioned stimulus (CS; e.g., neutral stimulus/light or tone) is repeatedly presented in the absence of the unconditioned stimulus (US; e.g., foot shock/loud noise) with which it has been previously paired.

The simplest explanation of extinction is that as the CS is presented without the aversive US, the animal gradually "unlearns" the CS-US association which is known as the associative loss theory. However, this explanation is complicated by observations where there is some fear restoration,
such as reinstatement (restoration of CR in the context where extinction training occurred but not a different context after aversive US is presented again), renewal (restoration of CR in context A but not in B when learning occurred in context A and extinction in context B), and spontaneous recovery (restoration of CR when the retention test occurs after a long but not a short delay after extinction training) and alternative explanations have been offered. Research on fear extinction in animals models (typically rats) has clinical implications such as exposure-based therapies for the treatment of phobias and anxiety conditions.

Theories
The dominant account of extinction involves associative models. However, there is debate over whether extinction involves simply "unlearning" the US-CS association (e.g. the Rescorla-Wagner account) or alternatively whether a "new learning" of an inhibitory association that masks the original excitatory association (e.g. Konorski, Pearce and Hall account). A third account concerns non-associative mechanisms such as habituation, modulation and response fatigue. Myers and Davis laboratory work with fear extinction in rodents has suggested that multiple mechanisms may be at work depending on the timing and circumstances in which the extinction occurs.

Given the competing views and difficult observations for the various accounts researchers have turned to investigations at the cellular level (most often in rodents) to tease apart the specific brain mechanisms of extinction in particular the role of the brain structures (amygdala, hippocampus, the prefrontal cortex), and specific neurotransmitter systems (e.g. GABA, NMDA). A recent study in rodents by Amano, Unal and Paré published in Nature Neuroscience found that extinction is correlated with synaptic inhibition in the fear output neurons of the central amygdala that project to the periaqueductal gray that controls freezing behavior. They infer that inhibition derives from the prefrontal cortex and suggest promising targets at the cellular for new treatments of anxiety.

Operant conditioning
In operant conditioning paradigm, extinction refers to the decline of an operant response when it is no longer reinforced in the presence of its discriminative stimulus. Extinction is observed after withholding of reinforcement for a previously reinforced behavior which decreases the future probability of that behavior. For example, a child who climbs under his desk, a response which has been reinforced by attention, is subsequently ignored until the attention-seeking behavior no longer occurs. In his autobiography, B. F. Skinner noted how he accidentally discovered the extinction of an operant response due to the malfunction of his laboratory equipment:

My first extinction curve showed up by accident. A rat was pressing the lever in an experiment on satiation when the pellet dispenser jammed. I was not there at the time, and when I returned I found a beautiful curve. The rat had gone on pressing although no pellets were received.... The change was more orderly than the extinction of a salivary reflex in Pavlov’s setting, and I was terribly excited. It was a Friday afternoon and there was no one in the laboratory who I could tell. All that weekend I crossed streets with particular care and avoided all unnecessary risks to protect my discovery from loss through my accidental death.

When the extinction of a response has occurred, the discriminative stimulus is then known as an extinction stimulus (SΔ or s delta). When an S delta is present, the reinforcing consequence which characteristically follows a behavior does not occur. This is the opposite of a discriminative stimulus which is a signal that reinforcement will occur. For instance, in an operant chamber, if food pellets are only delivered when a response is emitted in the presence of a green light, the green light is a discriminative stimulus. If when a red light is present food will not be delivered, then the red light is an extinction stimulus. (food here is used as an example of a reinforcer).
Successful extinction procedures
In order for extinction to work effectively, it must be done consistently. Extinction is considered successful when responding in the presence of an extinction stimulus (a red light or a teacher not giving a bad student attention, for instance) is zero. When a behavior reappears again after it has gone through extinction, it is called spontaneous recovery.

Extinction burst
While extinction, when implemented consistently over time, results in the eventual decrease of the undesired behavior, in the near-term the subject might exhibit what is called an extinction burst. An extinction burst will often occur when the extinction procedure has just begun. This consists of a sudden and temporary increase in the response's frequency, followed by the eventual decline and extinction of the behavior targeted for elimination.

Take, as an example, a pigeon that has been reinforced to peck an electronic button. During its training history, every time the pigeon pecked the button, it will have received a small amount of bird seed as a reinforcer. So, whenever the bird is hungry, it will peck the button to receive food. However, if the button were to be turned off, the hungry pigeon will first try pecking the button just as it has in the past. When no food is forthcoming, the bird will likely try again... and again, and again. After a period of frantic activity, in which their pecking behavior yields no result, the pigeon's pecking will decrease in frequency.

The evolutionary advantage of this extinction burst is clear. In a natural environment, an animal that persists in a learned behavior, despite not resulting in immediate reinforcement, might still have a chance of producing reinforcing consequences if they try again. This animal would be at an advantage over another animal that gives up too easily.

Extinction-induced variability
Extinction-induced variability serves an adaptive role similar to the extinction burst. When extinction begins, subjects can exhibit variations in response topography (the movements involved in the response). Response topography is always somewhat variable due to differences in environment or idiosyncratic causes but normally a subject's history of reinforcement keeps slight variations stable by maintaining successful variations over less successful variations. Extinction can increase these variations significantly as the subject attempts to acquire the reinforcement that previous behaviors produced. If a person attempts to open a door by turning the knob, but is unsuccessful, they may next try jiggling the knob, pushing on the frame, knocking on the door or other behaviors to get the door to open. Extinction-induced variability can be used in shaping to reduce problematic behaviors by reinforcing desirable behaviors produced by extinction-induced variability.

D-Cycloserine
D-Cycloserine (DCS) is being trialed as an adjuvant to conventional exposure-based treatments for anxiety disorders. The psychotropic responses are related to D-cycloserine's action as a partial agonist of the neuronal NMDA receptor for glutamate and have been examined in implications with sensory-related fear extinction in the amygdala.

Spontaneous recovery
In classical conditioning, spontaneous recovery, or resurgence in operant conditioning, refers to the reemergence of conditioned responses (CRs) which have previously undergone extinguishing training following an elapse of time without any further extinction training. Spontaneous recoveries tend to yield somewhat muted responses in which extinction occurs more readily.

For example, a dog's conditioned response of salivating to a bell will often, after it has been extinguished, reappear when the dog later hears the sound of a bell. This phenomenon is known as
"spontaneous recovery." To Ivan Pavlov (1927), the phenomenon of spontaneous recovery indicated that extinction is not simply a process of unlearning the conditioning that has taken place. Rather, extinction involves learning something new, namely, to inhibit the occurrence of the conditioned response in the presence of the conditioned stimulus. For example, rather than unlearning the response of salivation to the metronome during extinction, the dog learns to inhibit the response of salivation to the metronome, with the connection between metronome and salivation remaining intact on some underlying level. Spontaneous recovery may therefore represent the partial dissipation of this inhibition during the rest period between extinction sessions. Spontaneous recovery may help explain why it is so hard to overcome drug addictions. For example, cocaine addicts who are thought to be "cured" can experience an irresistible impulse to use the drug again if they are subsequently confronted by a stimulus with strong connections to the drug, such as a white powder (O’Brien et al., 1992; Drummond et al., 1995; DiCano & Everitt, 2002).

Stimulus Generalization

In classical conditioning, stimulus generalization is the tendency for the conditioned stimulus to evoke similar responses after the response has been conditioned. For example, if a rat has been conditioned to fear a stuffed white rabbit, it will exhibit fear of objects similar to the conditioned stimulus.

Stimulus generalization is the tendency of a subject to respond to a stimulus or a group of stimuli similar but not identical to the original CS. For example, a subject may initially make the desired response when exposed to any sound (that is, to a generalized stimulus) rather than making such a response only to a specific sound. Such generalization can occur in both classical and operant conditioning (if a CS is used). However, a subject can be taught to discriminate among sounds and to respond only to a specific sound.

Once an animal or person has learned a specific behavior, how do you ensure generalization? First of all allow me to define what I mean when I say generalization. How can you ensure that this behavior will occur in all relevant situations with all relevant stimuli for as long as desired? There are seven strategies which are used to ensure generalization.

Reinforce all instances of generalization, or in other words, every time the specimen appears to generalize, reinforce this. For example, if you taught your child to never talk to strangers by reprimanding her for talking to bums, and then she refuses to talk to a jogger, reinforce this. Use self-generated mediators of generalization, for example, give your child a wrist band that says NTTS, which she knows “Never Talk To Strangers” a self-generated mediator is something that increases the chances of generalization at all times.

Train a skill which taps into natural reinforcement or punishment. For example, horses are taught to round over jumps, (this refers to the angle which their back is at). When a horse rounds properly, it cracks their back, which is typically reinforcing. There is no outside interference needed. Likewise, if a child touches a hot pot, it burns automatically. Social stimuli are often natural reinforcers or punishers. Such natural contingencies reinforce or punish generalization at all times, thus promoting generalization.

Train the specimen in functionally equivalent behaviors. For example, training a child to avoid abduction by screaming would be one skill, however if you also taught the child to run away, the child would have a greater chance of success. Modifying the natural contingencies in the environment is also useful to promote generalization. For example, if you are trying to teach a child to smile more in class, tell the teachers to give the child special attention every time he smiled. By the smile being automatically reinforced, thee is a higher chance of generalization.

Remember to use common stimuli in all training exercises. For example, if you are trying to teach a child to do her homework, you would use a number of different subjects, but you would always
have her do her homework at her desk in her room. This desk then becomes the homework desk, making one stimulus the discriminative stimulus. However, incorporating different stimuli is also a very effective technique. For example, if you are trying to teach a child to use the bathroom, you don’t want to only use one particular toilet and location, however change the location as to create a pattern of generalization.

Using these seven techniques, generalization of a behavior should quickly be ensured.

**Stimulus Discrimination**

A phenomenon identified in behaviourist learning theory: the individual learns to distinguish, for response purposes, between similar stimuli. In classical conditioning, discrimination is the ability to differentiate between a conditioned stimulus and other stimuli that have not been paired with an unconditioned stimulus. For example, if a bell tone were the conditioned stimulus, discrimination would involve being able to tell the difference between the bell tone and other similar sounds. Thus, an organism becomes conditioned to respond to a specific stimulus and not to other stimuli. For example: a puppy may initially respond to lots of different people, but over time it learns to respond to only one or a few people’s commands.

In addition to response differentiation the animal must also learn to discriminate the discriminative stimulus. This task can most clearly be seen when a number of stimuli can be presented to the animal only one of which is the true SD. The number of responses the animal makes to colours which differ slightly if the factor which distinguishes the SD is its colour then we soon see that the nutty from the SD colour is far fewer than would be the case if the SD did not have to be distinguished like this.

**Schedules of reinforcement**

When an animal's surroundings are controlled, its behavior patterns after reinforcement become predictable, even for very complex behavior patterns. A schedule of reinforcement is the protocol for determining when responses or behaviors will be reinforced, ranging from continuous reinforcement, in which every response is reinforced, and extinction, in which no response is reinforced. Between these extremes is intermittent or partial reinforcement where only some responses are reinforced.

Specific variations of intermittent reinforcement reliably induce specific patterns of response, irrespective of the species being investigated (including humans in some conditions). The orderliness and predictability of behaviour under schedules of reinforcement was evidence for B. F. Skinner’s claim that using operant conditioning he could obtain "control over behavior", in a way that rendered the theoretical disputes of contemporary comparative psychology obsolete. The reliability of schedule control supported the idea that a radical behaviourist experimental analysis of behavior could be the foundation for a psychology that did not refer to mental or cognitive processes. The reliability of schedules also led to the development of Applied Behavior Analysis as a means of controlling or altering behavior.

Many of the simpler possibilities, and some of the more complex ones, were investigated at great length by Skinner using pigeons, but new schedules continue to be defined and investigated.
Simple schedules

A chart demonstrating the different response rate of the four simple schedules of reinforcement, each hatch mark designates a reinforcer being given. Simple schedules have a single rule to determine when a single type of reinforcer is delivered for specific response.

- **Fixed ratio** (FR) schedules deliver reinforcement after every \( n \)th response
  - **Example:** FR2 = every second response is reinforced
  - **Lab example:** FR5 = rat reinforced with food after each 5 bar-presses in a Skinner box.
  - **Real-world example:** FR10 = Used car dealer gets a $1000 bonus for each 10 cars sold on the lot.
- **Continuous ratio** (CR) schedules are a special form of a fixed ratio. In a continuous ratio schedule, reinforcement follows each and every response.
  - **Lab example:** each time a rat presses a bar it gets a pellet of food
  - **Real world example:** each time a dog defecates outside its owner gives it a treat
- **Fixed interval** (FI) schedules deliver reinforcement for the first response after a fixed length of time since the last reinforcement, while premature responses are not reinforced.
  - **Example:** FI1" = reinforcement provided for the first response after 1 second
  - **Lab example:** FI15" = rat is reinforced for the first bar press after 15 seconds passes since the last reinforcement
  - **Real world example:** FI24 hour = calling a radio station is reinforced with a chance to win a prize, but the person can only sign up once per day
- **Variable ratio** (VR) schedules deliver reinforcement after a random number of responses (based upon a predetermined average)
  - **Example:** VR3 = on average, every third response is reinforced
  - **Lab example:** VR10 = on average, a rat is reinforced for each 10 bar presses
Real world example: VR37/VR38 = a roulette player betting on specific numbers will win on average once every 37 or 38 tries, depending on whether the wheel has a 00 slot.

- **Variable interval** (VI) schedules deliver reinforcement for the first response after a random average length of time passes since the last reinforcement
  - **Example:** VI3" = reinforcement is provided for the first response after an average of 3 seconds since the last reinforcement.
  - **Lab example:** VI10" = a rat is reinforced for the first bar press after an average of 10 seconds passes since the last reinforcement.
  - **Real world example:** a predator can expect to come across a prey on a variable interval schedule

Other simple schedules include:

- **Differential reinforcement of incompatible behavior** (DRI) is used to reduce a frequent behavior without punishing it by reinforcing an incompatible response. An example would be reinforcing clapping to reduce nose picking.

- **Differential reinforcement of other behavior** (DRO) is used to reduce a frequent behavior by reinforcing *any* behavior other than the undesired one. An example would be reinforcing any hand action other than nose picking.

- **Differential reinforcement of low response rate** (DRL) is used to encourage low rates of responding. It is like an interval schedule, except that premature responses reset the time required between behavior.
  - **Lab example:** DRL10" = a rat is reinforced for the first response after 10 seconds, but if the rat responds earlier than 10 seconds there is no reinforcement and the rat has to wait 10 seconds from that premature response without another response before bar pressing will lead to reinforcement.
  - **Real world example:** "If you ask me for a potato chip no more than once every 10 minutes, I will give it to you. If you ask more often, I will give you none."

- **Differential reinforcement of high rate** (DRH) is used to increase high rates of responding. It is like an interval schedule, except that a minimum number of responses are required in the interval in order to receive reinforcement.
  - **Lab example:** DRH10'/15 responses = a rat must press a bar 15 times within a 10 second increment in order to be reinforced.
  - **Real world example:** "If Lance Armstrong is going to win the Tour de France he has to pedal x number of times during the y hour race."

- **Fixed Time** (FT) provides reinforcement at a fixed time since the last reinforcement, irrespective of whether the subject has responded or not. In other words, it is a non-contingent schedule
  - **Lab example:** FT5": rat gets food every 5" regardless of the behavior.
  - **Real world example:** a person gets an annuity check every month regardless of behavior between checks
• **Variable Time (VT)** provides reinforcement at an average variable time since last reinforcement, regardless of whether the subject has responded or not.

**Effects of different types of simple schedules**

• Ratio schedules produce higher rates of responding than interval schedules, when the rates of reinforcement are otherwise similar.

• Variable schedules produce higher rates and greater resistance to extinction than most fixed schedules. This is also known as the Partial Reinforcement Extinction Effect (PREE)

• The variable ratio schedule produces both the highest rate of responding and the greatest resistance to extinction (an example would be the behavior of gamblers at slot machines)

• Fixed schedules produce 'post-reinforcement pauses' (PRP), where responses will briefly cease immediately following reinforcement, though the pause is a function of the upcoming response requirement rather than the prior reinforcement.
  
  o The PRP of a fixed interval schedule is frequently followed by an accelerating rate of response which is "scallop shaped," while those of fixed ratio schedules are more angular.

• Organisms whose schedules of reinforcement are 'thinned' (that is, requiring more responses or a greater wait before reinforcement) may experience 'ratio strain' if thinned too quickly. This produces behavior similar to that seen during extinction.

• Partial reinforcement schedules are more resistant to extinction than continuous reinforcement schedules.
  
  o Ratio schedules are more resistant than interval schedules and variable schedules more resistant than fixed ones.
  
  o Momentary changes in reinforcement value lead to dynamic changes in behavior.

  Compound schedules

Compound schedules combine two or more different simple schedules in some way using the same reinforcer for the same behaviour. There are many possibilities; among those most often used are:

• **Alternative schedules** - A type of compound schedule where two or more simple schedules are in effect and whichever schedule is completed first results in reinforcement.

• **Conjunctive schedules** - A complex schedule of reinforcement where two or more simple schedules are in effect independently of each other and requirements on all of the simple schedules must be met for reinforcement.

• **Multiple schedules** - Two or more schedules alternate over time, with a stimulus indicating which is in force. Reinforcement is delivered if the response requirement is met while a schedule is in effect.
  
  o **Example**: FR4 when given a whistle and FI 6 when given a bell ring.

• **Mixed schedules** - either of two, or more, schedules may occur with no stimulus indicating which is in force. Reinforcement is delivered if the response requirement is met while a schedule is in effect.
  
  o **Example**: FI6 and then VR 3 without any stimulus warning of the change in schedule.
Concurrent schedules - two schedules are simultaneously in force though not necessarily on two different response devices, and reinforcement on those schedules is independent of each other.

Interlocking Schedules - A single schedule with two components where progress in one component affects progress in the other component. An interlocking FR60-FI120, for example, each response subtracts time from the interval component such that each response is "equal" to removing two seconds from the FI.

Chained schedules - reinforcement occurs after two or more successive schedules have been completed, with a stimulus indicating when one schedule has been completed and the next has started.

- Example: FR10 in a green light when completed it goes to a yellow light to indicate FR 3, after it's completed it goes into red light to indicate VI 6, etc. At the end of the chain, a reinforcer is given.

Tandem schedules - reinforcement occurs when two or more successive schedule requirements have been completed, with no stimulus indicating when a schedule has been completed and the next has started.

- Example: VR 10, after it is completed the schedule is changed without warning to FR 10, after that it is changed without warning to FR 16, etc. At the end of the series of schedules, a reinforcer is finally given.

Higher order schedules - completion of one schedule is reinforced according to a second schedule; e.g. in FR2 (FI 10 secs), two successive fixed interval schedules would have to be completed before a response is reinforced.

Superimposed schedules
Superimposed schedules of reinforcement is a term in psychology which refers to a structure of rewards where two or more simple schedules of reinforcement operate simultaneously. The reinforcers can be positive and/or negative. An example would be a person who comes home after a long day at work. The behavior of opening the front door is rewarded by a big kiss on lips by the person's spouse and a rip in the pants from the family dog jumping enthusiastically. Another example of superimposed schedules of reinforcement would be a pigeon in an experimental cage pecking at a button. The pecks result in a hopper of grain being delivered every twentieth peck and access to water becoming available after every two hundred pecks.

Superimposed schedules of reinforcement are a type of compound schedule that evolved from the initial work on simple schedules of reinforcement by B. F. Skinner and his colleagues (Skinner and Ferster, 1957). They demonstrated that reinforcers could be delivered on schedules, and further that organisms behaved differently under different schedules. Rather than a reinforcer, such as food or water, being delivered every time as a consequence of some behavior, a reinforcer could be delivered after more than one instance of the behavior. For example, a pigeon may be required to peck a button switch ten times before food is made available to the pigeon. This is called a "ratio schedule." Also, a reinforcer could be delivered after an interval of time passed following a target behavior. An example is a rat that is given a food pellet immediately following the first response that occurs after two minutes has elapsed since the last lever press. This is called an "interval schedule." In addition, ratio schedules can deliver reinforcement following fixed or variable number of behaviors by the individual organism. Likewise, interval schedules can deliver reinforcement following fixed or variable intervals of time following a single response by the
organism. Individual behaviors tend to generate response rates that differ based upon how the reinforcement schedule is created. Much subsequent research in many labs examined the effects on behaviors of scheduling reinforcers. If an organism is offered the opportunity to choose between or among two or more simple schedules of reinforcement at the same time, the reinforcement structure is called a "concurrent schedule of reinforcement." Brechner (1974, 1977) introduced the concept of "superimposed schedules of reinforcement" in an attempt to create a laboratory analogy of social traps, such as when humans overharvest their fisheries or tear down their rainforests. Brechner created a situation where simple reinforcement schedules were superimposed upon each other. In other words, a single response or group of responses by an organism led to multiple consequences. Concurrent schedules of reinforcement can be thought of as "or" schedules, and superimposed schedules of reinforcement can be thought of as "and" schedules. Brechner and Linder (1981) and Brechner (1987) expanded the concept to describe how superimposed schedules and the social trap analogy could be used to analyze the way energy flows through systems. Superimposed schedules of reinforcement have many real-world applications in addition to generating social traps. Many different human individual and social situations can be created by superimposing simple reinforcement schedules. For example a human being could have simultaneous tobacco and alcohol addictions. Even more complex situations can be created or simulated by superimposing two or more concurrent schedules. For example, a high school senior could have a choice between going to Stanford University or UCLA, and at the same time have the choice of going into the Army or the Air Force, and simultaneously the choice of taking a job with an internet company or a job with a software company. That would be a reinforcement structure of three superimposed concurrent schedules of reinforcement. Superimposed schedules of reinforcement can be used to create the three classic conflict situations (approach-approach conflict, approach-avoidance conflict, and avoidance-avoidance conflict) described by Kurt Lewin (1935) and can be used to operationalize other Lewinian situations analyzed by his force field analysis. Another example of the use of superimposed schedules of reinforcement as an analytical tool is its application to the contingencies of rent control (Brechner, 2003).

**Concurrent schedules**

In operant conditioning, concurrent schedules of reinforcement are schedules of reinforcement that are simultaneously available to an animal subject or human participant, so that the subject or participant can respond on either schedule. For example, a pigeon in a Skinner box might be faced with two pecking keys; pecking responses can be made on either, and food reinforcement might follow a peck on either. The schedules of reinforcement arranged for pecks on the two keys can be different. They may be independent, or they may have some links between them so that behaviour on one key affects the likelihood of reinforcement on the other.

It is not necessary for the responses on the two schedules to be physically distinct: in an alternative way of arranging concurrent schedules, introduced by Findley in 1958, both schedules are arranged on a single key or other response device, and the subject or participant can respond on a second key in order to change over between the schedules. In such a "Findley concurrent" procedure, a stimulus (e.g. the colour of the main key) is used to signal which schedule is currently in effect. Concurrent schedules often induce rapid alternation between the keys. To prevent this, a "changeover delay" is commonly introduced: each schedule is inactivated for a brief period after the subject switches to it.

When both the concurrent schedules are variable intervals, a quantitative relationship known as the matching law is found between relative response rates in the two schedules and the relative reinforcement rates they deliver; this was first observed by R. J. Herrnstein in 1961. Animals and humans have a tendency to prefer choice in schedules.
Verbal learning

Theories that interpret verbal learning as a process that develops in stages also have been worked out. In one variety of rote learning the subject is to respond with a specific word whenever another word with which it has been paired is presented. In learning lists that include such paired-associates as *house–girl*, *table–happy*, and *parcel–chair*, the correct responses would be *girl* (for *house*), *happy* (for *table*), and *chair* (for *parcel*). By convention the first word in each pair is called the stimulus term and the second the response term. Paired-associate learning is theorized to require subprocesses: one to discriminate among stimulus terms, another to select the second terms as the set of responses, and a third to associate or link each response term with its stimulus term. Although these posited phases seem to overlap, there is evidence indicating that the first two (stimulus discrimination and response selection) precede the associative stage.

Cognitive learning is about enabling people to learn by using their reason, intuition and perception. This technique is often used to change peoples' behaviour. But people's behaviour is influenced by many factors such as culture, upbringing, education and motivation. Therefore cognitive learning involves understanding how these factors influence behaviour and then using this information to develop learning programmes.

So it is far more subtle than just telling people what you want them to do differently it involves presenting the message in such a way that it allows people to work out the answer themselves. This can be achieved a number of ways

- **Response consequences** - should you reward for demonstrating the right behaviour or punish for demonstrating the wrong behaviour? Which approach will achieve the required outcomes? In reality there needs to be a combination of both as people will be motivated by different things.

- **Observation** - observation is a very powerful learning tool as it enables us to see whether performing an action is desirable or not without making the mistake ourselves. Also employees will be more likely to demonstrate the right behaviours if they see managers and senior managers doing so.

- **Symbolism** - allows us to create mental pictures and act out scenarios so that we can think through the consequences without actually performing it.

Therefore cognitive awareness involves using cognitive learning techniques which are then used to Complex behaviors are the result of relatively simple neural circuits (fixed action patterns) that are triggered by sign stimuli. In contrast, imprinting reflects a learning process that takes place within a very short period, but this learning of mother by offspring undoubtedly has some hard-wired circuits devoted to the process. Such a view cannot explain all cases of behavior. It is not just nature, but nurture. More properly it is not just genes, but the interaction between genes, the emergent properties of genes (epigenetics), and the interaction of genes with the environment. In this chapter, we will explore the higher-order interactions underlying behaviors -- learning and cognition.

The theory of learning maintains that the organism is born with relatively flexible neural circuits, but that such circuits have the capacity to be programmed by learning. The circuits become conditioned through trial and error associations. Finally, some behaviors could be the result of this learning and conditioning process, whereas others might be the result of true intelligence or at the
very least, cognition. At the highest level humans use reasoning and abstraction to make decisions. Whether or not some animals are capable of such higher level cognitive processes is not certain. We will explore the distinction between learning and conditioning theories, and cognitive views of behavior.

Processes of learning and cognition are, by there very nature, performance based. An important aspect to consider in measuring performance is whether or not the animal is motivated to perform a behavior. We must consider motivation in our study of learning and cognition because such an analysis may be confounded by a lack of motivation or differences in states of arousal between the subjects.

At another level, proximate causal mechanisms underlying motivation may also explain differences in the behavior of individuals in the wild. For example, the a subordinate in a troop of baboons is supressed from engaging in copulation, and such supression may be because an important causal agent, testosterone, is at lower levels or perhaps because corticosterone, a stress hormone is at higher levels in the subordinates. In contrast, levels of testosterone may be at very high levels in a dominant. A dominant has the motivational state to engage in copulations with most receptive females.

Finally, the proximate causal mechanisms underlying both motivation and learning may also serve us with powerful explanations of differences in behavior between organisms. For example, song bird males and females differ in the capacity to learn song. Such constraints on learning arise from the basic neural architecture of songbirds. In cases where female song may be important, for example in the formation of a pair bond in a monogamous species, the regions of the brain are elaborated by natural selection and such constraints do not hamper the learning of song in female birds.

COGNITION IN LEARNING

Cognitive Learning

Not all cases of learning can easily be captured by classical conditioning and operant conditioning. Learning would be extremely inefficient if we had to rely completely on conditioning for all our learning. Human beings can learn efficiently by observation, taking instruction, and imitating the behavior of others.

Cognitive learning is a powerful mechanism that provides the means of knowledge, and goes well beyond simple imitation of others. Conditioning can never explain what you are learning from reading our web-site. This learning illustrates the importance of cognitive learning. Cognitive learning is defined as the acquisition of knowledge and skill by mental or cognitive processes — the procedures we have for manipulating information 'in our heads'. Cognitive processes include creating mental representations of physical objects and events, and other forms of information processing.

How do we learn cognitive?
In cognitive learning, the individual learns by listening, watching, touching, reading, or experiencing and then processing and remembering the information. Cognitive learning might seem to be passive learning, because there is no motor movement. However, the learner is quite active, in a cognitive way, in processing and remembering newly incoming information.

Cognitive learning enables us to create and transmit a complex culture that includes symbols, values, beliefs and norms. Because cognitive activity is involved in many aspects of human behavior, it might seem that cognitive learning only takes place in human beings. However, many different species of animals are capable of observational learning. For example, a monkey in the zoo, sometimes imitates human visitors or other monkeys. Nevertheless, most information about cognitive learning is obtained from studies on human beings.

Piaget's Theory of Cognitive Development
For years, sociologists and psychologists have conducted studies on cognitive development or the construction of human thought or mental processes.

Jean Piaget was one of the more important and influential people in the field of Developmental Psychology. He believed that humans are unique in comparison to animals because we have the ability to do "abstract symbolic reasoning." His work can be compared to Lev Vygotsky, Sigmund Freud, and Erik Erikson who were also great contributors in the field of Developmental Psychology.

Piaget's theory of Developmental Psychology tackled cognitive development from infancy to adulthood.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Age or Period</th>
<th>Description</th>
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<tbody>
<tr>
<td>Sensorimotor stage</td>
<td>Infancy</td>
<td>Intelligence is present; motor activity but no symbols; knowledge is developing yet limited; knowledge is based on experiences/interactions; mobility allows child to learn new things; some language skills are developed at the end of this stage</td>
</tr>
<tr>
<td>Pre-operational stage</td>
<td>Toddler and Early Childhood</td>
<td>Symbols or language skills are present; memory and imagination are developed; nonreversible and nonlogical thinking; egocentric thinking predominates</td>
</tr>
<tr>
<td>Concrete operational stage</td>
<td>Elementary and Early Adolescence</td>
<td>Logical and systematic form of intelligence; manipulation of symbols related to concrete objects; operational thinking predominates nonreversible and egocentric thinking</td>
</tr>
<tr>
<td>Formal operational stage</td>
<td>Adolescence and Adulthood</td>
<td>Logical use of symbols related to abstract concepts; egocentric thinking comes back early in this stage; formal thinking is uncommon</td>
</tr>
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</table>

Cognitive Influence on Learning
A cognitivist view of behavior contends that sensory data are organized by internal mechanisms, and abstracted into a internalized representation of the world. Recall Leslie Real’s definition of a cognitive mechanism that we considered in memory and foraging of honey bees:
1. **perception** -- a unit of information from the environment is collected and stored in memory,

2. **data manipulation** -- several units of information that are stored in memory are analyzed according to computational rules built into the nervous system,

3. **forming a representation of the environment** -- a complete "picture" is formed from the processing of all the information and the organism bases its decision on the complete picture or representation of the environment.

Let us explore this definition in terms of our example of risk aversion in bumble bees:

**Perception.** The bee drinks nectar and either the time it takes to feed from a flower or how stretched its crop becomes from feeding are fed into memory, along with the color of the flower.

**Data manipulation.** Based on this single piece of data the bee decides to visit the same color flower or ignore the same flower and by default sample another flower. Thus, the fullness from feeding is used in conjunction with a simple decision, and the avoidance or attraction to flowers results.

**The representation of the environment** is made in terms of energy content or reward (or risks in reward) and flower color -- the abstraction. The bee somehow forms an association between energy and reward (or risk in the reward) that forms the abstraction of the environment.

**Motivational influence on Learning**

It is a concept in **Behaviorism** involving the effectiveness of consequences in **Operant conditioning**. They explain why a person wants or does not want something and why they act or do not act in a particular moment.

**History**

It was introduced by **Jack Michael** around 1980. Different Terminology was introduced to describe the concept in 2004, changing it from Establishing operation to Motivating operation.

**Concept**

The concept primarily is concerned with the motivation of an organism, or what behavior a person will engage in a particular moment. It focuses on the idea that an organism is constantly fluctuating between states of satiation and deprivation of reinforcers. A simple example is created with food, food deprivation makes you "want" food and food satiation makes you "want" food less.

A motivating operation with respect to motivation has two effects: Value Altering and Behavior Altering. The value altering effect states that it alters the value of a consequence of behavior by making it more or less reinforcing. The behavior altering effect states that it immediately evokes or suppresses behaviors that have resulted in the consequence linked to the behavior in the past. The motivating operation of deprivation of food in this particular example would, establish the stimulus of food as reinforcing and evoke behaviors that in the past have resulted in food. While the motivating operation of being satiated of food, abolishes the stimulus of food's reinforcing effect and abates behaviors that in the past have resulted in food.

Note that this concept is different than a that of the stimulus discriminate. The stimulus discriminate is correlated with the differential availability of reinforcement, while the motivating operation is correlated with the differential effectiveness of a reinforcer.

In B.F. Skinner's Book **Verbal Behavior**, conditioned motivating operations are broken into 3 categories: CMO-surrogate CMO-transitive CMO-reflexive

**Controversy**

There is some debate as to whether an organism's states of deprivation and satiation are only biological states or if they can be metaphysical states. That is, whether an organism can be deprived or satiated from only unconditioned reinforcers or if they can be deprived and satiated from
conditioned reinforcers. Leading to theory that there are unconditioned motivating operations (UMO) and conditioned motivating operations (CMO).

Observational Learning

**Definition**

Observational learning, also called social learning theory, occurs when an observer’s behavior changes after viewing the behavior of a model. An observer’s behavior can be affected by the positive or negative consequences—called vicarious reinforcement or vicarious punishment—of a model’s behavior.

**Discussion**

There are several guiding principles behind observational learning, or social learning theory:

1. The observer will imitate the model’s behavior if the model possesses characteristics—things such as talent, intelligence, power, good looks, or popularity—that the observer finds attractive or desirable.

2. The observer will react to the way the model is treated and mimic the model’s behavior. When the model’s behavior is rewarded, the observer is more likely to reproduce the rewarded behavior. When the model is punished, an example of vicarious punishment, the observer is less likely to reproduce the same behavior.

3. A distinction exists between an observer’s “acquiring” a behavior and “performing” a behavior. Through observation, the observer can acquire the behavior without performing it. The observer may then later, in situations where there is an incentive to do so, display the behavior.

4. Learning by observation involves four separate processes: attention, retention, production and motivation.

   a. Attention: Observers cannot learn unless they pay attention to what’s happening around them. This process is influenced by characteristics of the model, such as how much one likes or identifies with the model, and by characteristics of the observer, such as the observer’s expectations or level of emotional arousal.

   b. Retention: Observers must not only recognize the observed behavior but also remember it at some later time. This process depends on the observer’s ability to code or structure the information in an easily remembered form or to mentally or physically rehearse the model’s actions.

   c. Production: Observers must be physically and/intellectually capable of producing the act. In many cases the observer possesses the necessary responses. But sometimes, reproducing the model’s actions may involve skills the observer has not yet acquired. It is one thing to carefully watch a circus juggler, but it is quite another to go home and repeat those acts.

   d. Motivation: In general, observers will perform the act only if they have some motivation or reason to do so. The presence of reinforcement or punishment, either to the model or directly to the observer, becomes most important in this process.

5. Attention and retention account for acquisition or learning of a model’s behavior; production and motivation control the performance.

6. Human development reflects the complex interaction of the person, the person’s behavior, and the environment. The relationship between these elements is called reciprocal
determinism. A person’s cognitive abilities, physical characteristics, personality, beliefs, attitudes, and so on influence both his or her behavior and environment. These influences are reciprocal, however. A person’s behavior can affect his feelings about himself and his attitudes and beliefs about others. Likewise, much of what a person knows comes from environmental resources such as television, parents, and books. Environment also affects behavior: what a person observes can powerfully influence what he does. But a person’s behavior also contributes to his environment.

Observational learning (also known as vicarious learning, social learning, or modeling) is a type of learning that occurs as a function of observing, retaining and replicating novel behavior executed by others. It is argued that reinforcement has the effect of influencing which responses one will partake in, more than it influences the actual acquisition of the new response. Although observational learning can take place at any stage in life, it is thought to be of greater importance during childhood, particularly as authority becomes important. The best role models are those a year or two older for observational learning. Because of this, social learning theory has influenced debates on the effect of television violence and parental role models. Albert Bandura called the process of social learning modeling and gave four conditions required for a person to successfully model the behavior of someone else:

- Attention to the model –In order for the behaviour to be learned, the observer must see the modeled behaviour
- Retention of details –The observer must be able to recall the modeled behaviour
- Motor reproduction –The observer must have the motor skills to reproduce the action, the observer must also have the motivation to carry out the action
- Motivation and opportunity – The observer must be motivated to carry out the action they have observed and remembered, and must have the opportunity to do so. Motivations may include past reinforcement, promised incentives, and vicarious reinforcement. Punishment may discourage repetition of the behaviour

Effect on behavior
Social learning may affect behavior in the following ways:

- Teaches new behaviors
- Increases or decreases the frequency with which previously learned behaviors are carried out
- Can encourage previously forbidden behaviors
- Can increase or decrease similar behaviors. For example, observing a model excelling in piano playing may encourage an observer to excel in playing the saxophone.

Compared to Imitation
Imitation is very different from observational learning in that the latter leads to a change in behavior due to observing a model. Observational learning does not require that the behavior exhibited by the model is duplicated. For example, the learner may observe an unwanted behaviour and the subsequent consequences, and would therefore learn to refrain from that behaviour.

Bobo Doll Experiment
Albert Bandura's Bobo doll experiment is widely cited in psychology as a demonstration of observational learning and demonstrated that children are more likely to engage in violent play with a life size rebounding doll after watching an adult do the same. However, it may be that children
will only reproduce a model's behavior if it has been reinforced. This may be the problem with television because it was found, by Otto Larson and his coworkers (1968), that 56% of the time children's television characters achieve their goals through violent acts. It is said that observational learning allows for learning without any change in behavior, therefore it been used as an argument against strict behaviorism which argues that behavior must be reinforced for new behaviors to be acquired. Bandura noted that "social imitation may hasten or short-cut the acquisition of new behaviors without the necessity of reinforcing successive approximations as suggested by Skinner (1953)."[1] However, the argument does not dispute claims made by behaviorism because if an individual's behavior does not contact reinforcement following the imitation of the modeled behavior, the behavior will not maintain and therefore is not truly learned. It would remain an individual occurrence of imitation unless reinforcement was contacted. Observational learning is a powerful means of social learning. It principally occurs through the cognitive processing of information displayed by models. The information can be conveyed verbally, textually, and auditorially, and through actions either by live or symbolic models such as television, movies, and the Internet. Regardless of the medium used to present the modeled activities, the same psychological processes underlie observational learning. These include attention and memory processes directed to establish a conceptual representation of the modeled activity. This representation guides the enactment of observationally learned patterns of conduct. Whether the learned patterns will be performed or not depends on incentive structures and observers' actual and perceived competence to enact the modeled performances. Unlike learning by doing, observational learning does not require enactment of the modeling activities during learning. The complexity of the learning, however, is restricted by the cognitive competence and enactment skills of the learner.

Transfer of learning
Transfer of learning research can be loosely framed as the study of the dependency of human conduct, learning or performance on prior experience. The notion was originally introduced as transfer of practice by Edward Thorndike and Robert S. Woodworth (1901)[1]. They explored how individuals would transfer learning in one context to another context that shared similar characteristics—or more formally how "improvement in one mental function" could influence another related one. Their theory implied that transfer of learning depends on the proportion to which the learning task and the transfer task are similar, or where "identical elements are concerned in the influencing and influenced function", now known as 'identical element theory'. Transfer research has since attracted much attention in numerous domains, producing a wealth of empirical findings and theoretical interpretations. However, there remains considerable controversy about how transfer of learning should be conceptualized and explained, what its probability occurrence is, what its relation is to learning in general, or whether, indeed, it may be said to exist at all (e.g., Detterman, 1993; Helfenstein, 2005).

Transfer of learning should not be confused with knowledge transfer, as the former concerns intra-individual, constructivist perspective, and the latter, an inter-individual or inter-organizational perspective.

Most discussions of transfer to date can be developed from a common operational definition, describing it as the process and the effective extent to which past experiences (also referred to as the transfer source) affect learning and performance in a current novel situation (the transfer target) (Ellis, 1965; Woodworth, 1938). This, however, is usually also where the general consensus between various research approaches ends.

Indeed, there are a wide variety of viewpoints and theoretical frameworks apparent in the literature. For review purposes these are categorized as follows:
• a taxonomical approach to transfer research that usually intends to categorize transfer into different types;
• an application domain-driven approach by focusing on developments and contributions of different disciplines that have traditionally been interested in transfer;
• the examination of the psychological scope of transfer models with respect to the psychological functions or faculties that are being regarded; and
• a concept-driven evaluation, which reveals underlying relationships and differences between theoretical and empirical traditions.

Transfer taxonomies
Of the various attempts to delineate transfer, typological and taxonomic approaches belong to the more common ones (see, e.g., Barnett & Ceci, 2002; Butterfield, 1988; Detterman, 1993; Gagné, 1977; Reeves & Weisberg, 1994; Salomon & Perkins, 1989; Singley & Anderson, 1989). Taxonomies are concerned with distinguishing different types of transfer, and are as such less involved with labeling the actual vehicle of transfer, i.e., what is the explanatory mental unit of transfer that is carried over. Hence, a key problem with many transfer taxonomy is that they offer an excessive number of labels for different types of transfer without really engaging in a discussion of the underlying concepts that would justify their distinction, i.e., similarity and the nature of transferred information. This makes it very difficult to appreciate the internal validity of the models.

Here is a table, presenting different types of transfer, as adapted from Schunk (2004, p. 220).

<table>
<thead>
<tr>
<th>Type</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near</td>
<td>Overlap between situations, original and transfer contexts are similar</td>
</tr>
<tr>
<td>Far</td>
<td>Little overlap between situations, original and transfer settings are dissimilar</td>
</tr>
<tr>
<td>Positive</td>
<td>What is learned in one context enhances learning in a different setting (+)</td>
</tr>
<tr>
<td>Negative</td>
<td>What is learned in one context hinders or delays learning in a different setting (+)</td>
</tr>
<tr>
<td>Vertical</td>
<td>Knowledge of a previous topic is essential to acquire new knowledge (++)</td>
</tr>
<tr>
<td>Horizontal</td>
<td>Knowledge of a previous topic is not essential but helpful to learn a new topic (++)</td>
</tr>
<tr>
<td>Literal</td>
<td>Intact knowledge transfers to new task</td>
</tr>
<tr>
<td>Figural</td>
<td>Use some aspect of general knowledge to think or learn about a problem</td>
</tr>
<tr>
<td>Low Road</td>
<td>Transfer of well-established skills in almost automatic fashion</td>
</tr>
<tr>
<td>High Road</td>
<td>Transfer involves abstraction so conscious formulations of connections between contexts</td>
</tr>
<tr>
<td>High Road / Forward Reaching</td>
<td>Abstracting situations from a learning context to a potential transfer context</td>
</tr>
<tr>
<td>High Road / Backward Reaching</td>
<td>Abstracting in the transfer context features of a previous situation where new skills and knowledge were learned</td>
</tr>
</tbody>
</table>


Apart from the effect-based distinction between negative and positive transfer, taxonomies have largely been constructed along two, mostly tacit, dimensions. One concerns the predicted relationship between the primary and secondary learning situation in terms of categorical overlap of
features and knowledge specificity constraints. The other concerns some general assumptions about how transfer relationships are established, in terms of mental effort and cognitive process.

**The effect-perspective: positive vs. negative transfer**
Starting by looking at the effect side of transfer, i.e., in terms of the common performance criteria, speed and accuracy, transfer theories distinguish between two broad classes of transfer that underlie all other classifications: negative and positive transfer. Negative transfer refers to the impairment of current learning and performance due to the application of non-adaptive or inappropriate information or behaviour. Negative transfer is therefore a type of interference effect of prior experience causing a slow-down in learning, completion or solving of a new task when compared to the performance of a hypothetical control group with no respective prior experience. Positive transfer, in contrast, emphasizes the beneficial effects of prior experience on current thinking and action. It is important to understand the positive and negative effects of transfer are not mutually exclusive, and therefore real life transfer effects are probably mostly a mixture of both.

**The situation-perspective: specific vs. general, near vs. far transfer**
The situation-driven perspective on transfer taxonomies is concerned with describing the relation between transfer source (i.e., the prior experience) and transfer target (i.e., the novel situation). In other words, the notion of novelty of the target situation per se is worthless without specifying the degree of novelty in relation to something that existed before. Butterfield and Nelson (1991), for example, distinguish between within-task, across-task, and inventive transfer. A similar classification approach reappears in many situation-driven transfer taxonomies (e.g., similar vs. different situations; example-to-principle and vice versa; simple-to-complex and vice versa) and can be noted as distinctions made along the specific-versus-general dimension. Mayer and Wittrock (1996, pp. 49ff.), for their part, discuss transfer under the labels of general "transfer of general skill" (e.g., "Formal Discipline", e.g., Binet, 1899), "specific transfer of specific skill" (e.g., Thorndike’s, 1924a, b, "identical elements" theory), "specific transfer of general skill" (e.g., Gestaltists’ transfer theory, see origins with Judd, 1908), and “meta-cognitive control of general and specific skills" as a sort of combination of the previous three views (see, e.g., Brown, 1989). Haskell’s (2001) taxonomy proposes a more gradual scheme of similarity between tasks and situations. It distinguishes between non-specific transfer (i.e., the constructivist idea that all learning builds on present knowledge), application transfer (i.e., the retrieval and use of knowledge on a previously learned task), context transfer (actually meaning context-free transfer between similar tasks), near versus far transfer, and finally displacement or creative transfer (i.e., an inventive or analytic type of transfer that refers to the creation of a new solution during problem solving as a result of a synthesis of past and current learning experiences). Both, near and far transfer, are widely used terms in the literature. The former refers to transfer of learning when task and/or context change slightly but remain largely similar, the latter to the application of learning experiences to related but largely dissimilar problems.

**The process-perspective**
In fact, the specific-versus-general dimension applies not just to the focus on the relation between source and target (i.e., from where to where is transferred), but also to the question about the transfer process itself (i.e., what is transferred and how). Reproductive versus productive transfer (see Robertson, 2001) are good examples of this type of distinction. Whereas reproductive transfer refers to the simple application of knowledge to a novel task, productive transfer implies adaptation, i.e., mutation and enhancement, of retained information. A similar dichotomous distinction is the one between knowledge transfer and problem-solving transfer (Mayer & Wittrock, 1996). Knowledge transfer takes place when knowing something after
learning task ‘A’ facilitates or interferes with the learning process or performance in task ‘B’. Knowledge used is referred to by many different terms such as declarative or procedural types (Anderson, 1976), but it means for our purposes that there are representational elements that suit ‘A’ and ‘B’. Problem solving transfer, on the other hand, is described as somewhat more "fluid knowledge" transfer, so that experience in solving a problem ‘A’ helps finding a solution to problem ‘B’. This can mean that the two problems share little in terms of specific declarative knowledge entities or procedures, but call for a similar approach, or solution search strategies (e.g., heuristics and problem solving methods).

The issues discussed in problem-solving transfer literature are also closely related to the concepts of strategic and theoretic transfer (Haskell, 2001, p. 31), and cognitive research on analogical reasoning, rule-based thinking and meta-cognition. Indeed, far transfer can be considered as the prototypical type of transfer, and it is closely related to the study of analogical reasoning (see also Barnett & Ceci, 2002, for a taxonomy of far transfer). Within the problem-solving literature the distinction between specific and general methods is made mostly with reference to Newell and Simon’s (1972) strong versus weak problem solving methods (Chi, Glaser & Farr, 1988; Ericsson & Smith, 1991; Singley & Anderson, 1989; Sternberg & Frensch, 1991).

Another concern that is frequently addressed in transfer taxonomies is the question of conscious effort. High-road vs. low-road transfer (Mayer & Wittrock, 1996; Salomon & Perkins, 1989) expresses a distinction between such instances of transfer where active retrieval, mapping and inference processes take place, as opposed to those instances that occur rather spontaneously or automatically. Hence, low-road transfer concerns frequently employed mental representations and automated, proceduralized knowledge, and occurs preferably in near transfer settings. In contrast, high-road transfer is more conception-driven and requires cognitive and meta-cognitive effort.

Traditional fields of transfer research

Obviously, there are a nearly unlimited number of research fields that share some applied interest into the study of transfer, as it pertains to learning in general. Three fields that contributed in most substantial ways to the progress of transfer research, both from a conception and empirical point of view, are the fields of education science, linguistics, and human-computer interaction (HCI). In fact, most transfer research has been conducted in reference to one of these applied settings, rather than in basic cognitive psychological laboratory conditions.

**Education science: "teaching for transfer"

Due to their core concern with learning, educational science and practice are the classic fields of interest regarding transfer research, and probably the prime target for the application of theories. In fact, transfer of learning represents much of the very basis of the educational purpose itself. What is learned inside one classroom about a certain subject should aid in the attainment of related goals in other classroom settings, and beyond that it should be applicable to the student’s developmental tasks outside the school. Indeed, the need for transfer becomes more accentuated. This is because the world educators teach in today is different from the world they themselves experienced as students, and differs equally from the one their students will have to cope with in future.

By nature of their applied interest, educationalists’ main concern has been less with the question of how transfer takes place, and much more with under what conditions, or, that it happens at all. Obviously, the basic conviction that student’s learning and achievement levels depend primarily on learning and achievement prerequisites, has constituted a central part in educational learning theories for quite some time (Gage & Berliner, 1983; Glaser, 1984). The major focus in educational transfer studies has therefore been on what kind of initial learning enables subsequent transfer: teaching for transfer. Research on learning and transfer has identified key characteristics with implications for educational practice.
From Formal Discipline to meta-cognition

Educational transfer paradigms have been changing quite radically over the last one hundred years. According to the doctrinaire beliefs of the Formal Discipline (Binet, 1899) transfer was initially viewed as a kind of global spread of capabilities accomplished by training basic mental faculties (e.g., logic, attention, memory) in the exercise of suitable subjects like Latin or Geometry. With the turn of the 20th century, learning, and therefore also transfer of learning, was increasingly captured in behavioral and empiricist terms, as in the Connectionist and Associationist theories of Thorndike (e.g., 1932), Guthrie (e.g., 1935), Hull (e.g., 1943), and Skinner (e.g., 1938). Thorndike (1923, 1924a and b) attacked the Formal Discipline empirically and theoretically and introduced the theory of “identical elements”, which is probably still today the most influential conception about transfer (Thorndike, 1906; Thorndike & Woodworth, 1901a, b and c). Thorndike’s belief that transfer of learning occurs when learning source and learning target share common stimulus-response elements, prompted calls for a hierarchical curricular structure in education. “Lower” and specific skills should be learned before more complex skills, which were presumed to consist largely of configuration of basic skills. This small-to-large learning also referred to as part-to-whole or vertical transfer has been popular with theories of learning hierarchies (Gagné, 1968).

It has later been challenged from conceptualistic point of views, which argue that learning is not just an accumulation of pieces of knowledge (i.e., rote memorization), but rather a process and product of active construction of cognitive knowledge structures (Bruner, 1986; Bruner, Goodnow & Austin, 1956). Knowledge, from a constructivist perspective, was no more believed to be a simple transfer by generalization to all kinds of situations and tasks that contain similar components (i.e., stimulus-response patterns; see also Logan, 1988; Meyers & Fisk, 1987; Osgood, 1949; Pavlov, 1927).

The critical issue, subsequently, was the identification of similarities in general principles and concepts behind the facades of two dissimilar problems, i.e., transfer by insight. This idea became popular in the Gestaltists’ view on transfer (e.g., Katona, 1940), and, in combination with growing interest in learners as self activated problem-solvers (Bruner, 1986), encouraged the search for abstract problem-solving methods and mental schemata, which serve as analogy enhancing transfer-bridges between different task situations. Emerging from these developments a new theme started to dominate educationalists’ research in transfer: meta-cognition (Brown, 1978; Brown & Campione, 1981; Campione & Brown, 1987; Flavell, 1976). In contrast to classical knowledge forms like declarative and procedural knowledge, different types of meta-knowledge and meta-cognitive skills such as strategic knowledge, heuristics, self-monitoring skills and self-regulation became quickly the royal road to learning and transfer. Characterized as self-conscious management and organization of acquired knowledge (Brown, 1987) it is evident that meta-cognitive awareness of task features, problem structures, and solution methods makes relations between different situations cognitively salient: Only an individual who learns from learning, learns for future learning. Soini (1999) developed on the same core ideas an examination of the preconditions for active transfer. Her emphasis is on the active and self-reflected management of knowledge to increase its accessibility. To some researchers, meta-cognition and transfer have become so entangled that the argument was generated that only the measurement of positive transfer effects truly supports inferences that meta-cognitive learning has taken place (e.g. MacLeod, Butler & Syer, 1996).

The generality predicament: return to the specificity view

Ever since the introduction of the meta-knowledge theme in education science, transfer discussions have been oscillating between the position taken by those representing the meta-cognitive view, and those who stress that generic knowledge forms alone do not allow an effective transfer of
learning: When knowledge stays "on the tip of the tongue", just knowing that one knows a solution to a problem, without being able to transfer specific declarative knowledge (i.e., know-what) or automated procedural knowledge (i.e., know-how), does not suffice. Specific teaching of the cognitive and behavioural requisites for transfer marked in principle a return to the identical element view, and can be summarized with Dettermann’s (1993) conclusion that transfer does not substantially go beyond the restricted boundaries of what has been specifically taught and learned. It, thus, appears that the basic transfer paradigms in educational psychology keep replicating themselves. And fundamental promotion of transfer itself is seen to be achievable through sensibilization of students by creating a general culture and "a spirit of transfer" inside the classroom on the one hand, and by allowing concrete learning from transfer models on the other (Haskell, 2001).

Learning and transfer: implications for educational practice

A modern view of transfer in the context of educational practice shows little need to distinguish between the general and specific paradigms, recognizing the role of both identical elements and metacognition. In this view, the work of Bransford, Brown and Cocking (1999) identified four key characteristics of learning as applied to transfer. They are 1) the necessity of initial learning, 2) the importance of abstract and contextual knowledge, 3) the conception of learning as an active and dynamic process and 4) the notion that all learning is transfer.

First, the necessity of initial learning for transfer specifies that mere exposure or memorization is not learning; there must be understanding. Learning as understanding takes time, such that expertise with deep, organized knowledge improves transfer. Teaching that emphasizes how to use knowledge or that improves motivation should enhance transfer.

Second, while knowledge anchored in context is important for initial learning, it is also inflexible without some level of abstraction that goes beyond the context. Practices to improve transfer include having students specify connections across multiple contexts or having them develop general solutions and strategies that would apply beyond a single-context case. Third, learning should be considered an active and dynamic process, not a static product. Instead of one-shot tests that follow learning tasks, students can improve transfer by engaging in assessments that extend beyond current abilities. Improving transfer in this way requires instructor prompts to assist students—such as dynamic assessments—or student development of metacognitive skills without prompting.

Finally, the fourth characteristic defines all learning as transfer. New learning builds on previous learning, which implies that teachers can facilitate transfer by activating what students know and by making their thinking visible. This includes addressing student misconceptions and recognizing cultural behaviors that students bring to learning situations.

A student-learning centered view of transfer embodies these four characteristics. With this conception, teachers can help students transfer learning not just between contexts in academics, but also to common home, work or community environments.

Inter-language transfer

Another traditional field of applied research is inter-language transfer. Here the central questions were (a) how does learning one language L1 (or more generally: language[m]) facilitate or interfere (Weinreich, 1953) with the acquisition of and proficiency in a second language L2 (language[m]), and (b) how does the training and use of L2, in turn, affect L1. Several variations of this conception of inter-language transfer can be found in the literature, also referred to as mother tongue influence or cross language interference (Corder, 1983, 1994; Faerch & Kasper, 1987; Jiang & Kuehn, 2001; Odlin, 1989; O’Malley and Chamot, 1990). What makes inter-language transfer a complex but at
the same time very valuable research matter is the fact that language knowledge skills continuously develop. This is so for L1 as well as for L2, when only bilingualism is considered, while alternately at least one of them is also continuously in use. This has led to the development of very different models of how languages are mentally represented and managed, with L1 and L2 seen (a) as two independent or autonomous mental systems (e.g. Genesee, 1989; Grosjean, 1989), (b) as being represented in a single unified system (e.g. Redlinger & Park, 1980; Swain, 1977), and (c) as rooting in a common underlying, multi-lingual conceptual base (CUCB; see Kecskes & Papp, 2000).

**Human-Computer Interaction: "designing for transfer"**

A third research area that has produced a variety of transfer models and empirical results can be located within the field of Human-Computer Interaction (HCI). Indeed, with the start of the user age in the 1980s, HCI and all kinds of virtual environments have in many ways become something like psychological micro-worlds for cognitive research. This is naturally also reflected in the study of transfer. Developments in favour of cognitive approaches to transfer research were especially accelerated by rapid changes in modern lifestyles, resulting in a virtual upsurge of cognitive demands in interaction with technology. Thus the call was on clearly domain-focused cognitive models to study the way users learn and perform when interacting with information technological systems (Card, Moran & Newell, 1980a and b, 1983; Olson & Olson, 1990; Payne & Green, 1986; Polson, 1987, 1988).

**Transfer based on the user complexity theory**

Thorough investigations of cognitive skills involved in HCI tasks have their origins with the research on text editing (e.g., Kieras & Polson, 1982, 1985; Singley & Anderson, 1985). The offsprings of this type of research were computational cognitive models and architectures of various degrees of sophistication, suitable for all kinds of man-machine interaction studies, as well as studies outside of the HCI domain (see the section of cognitive transfer). The original examples for these have become Kieras and Polson’s (1985) user complexity theory (later rephrased as cognitive complexity theory) and the GOMS family (i.e., Goals, Operators, Methods, Selection rules) based on the Model Human Processor framework (Card et al., 1980a and b, 1983; John & Kieras, 1996a and b). All of these models have their roots in the basic principles of production systems and can be comprehended with the help of ends-means-selections and IF-THEN-rules, combined with the necessary declarative and procedural knowledge (Anderson, 1995; Newell & Simon, 1972).

The crucial perspective for transfer became that of technology design. By applying cognitive models scientists and practitioners aimed at minimizing the amount and complexity of (new) knowledge necessary to understand and perform tasks on a device, without trading off too much utility value (Polson & Lewis, 1990). A key responsibility was hereby given to skill and knowledge transfer. And because the cognitive complexity theory is in fact a psychological theory of transfer applied to HCI (Bovair, Kieras, & Polson, 1990; Polson & Kieras, 1985), the central question was, how these models, united under the GOMS-umbrella, can be used to explain and predict transfer of learning. The basic transfer-relevant assumptions of the emerging models were that production rules are cognitive units, that they are all equally difficult to learn, and that learned rules can be transferred to a new task without any cost. Because learning time for any task is seen as a function of the number of new rules that the user must learn, total learning time is directly reduced by inclusion of productions the user is already familiar with. Hence, the basic message of the cognitive complexity theory is to conceptualize and induce transfer from one system to another by function of shared production rules is, which is a new interpretation of Thorndike’s (1923, 1924a and b)

A practical implication of the procedural communality principle has been formulated by Lewis and Riemann (1993), who suggest something like "transfer of design" on the side of the industry: "You should find existing interfaces that work for users and then build ideas from those interfaces into your systems as much as practically and legally possible."

**Emergence of holistic views of use**

Discouraged by the confined character of the GOMS-related transfer models many research groups began to import and advance new concepts such as schemata principles and general methods; a general development encouraged by the emerging cognitive approach to transfer that was also witnessed by other applied fields. Bhavnani and John (2000) analyzed different computer applications and strived to identify such user strategies (i.e., general methods to perform a certain task) which generalize across three distinct computer domains (word processor, spreadsheet, and CAD). Their conclusive argument is that "strategy-conducive systems could facilitate the transfer of knowledge" (p. 338). Other research groups' authors that assessed the questions about how people learn in interaction with information systems, evaluated the usefulness of metaphors and how these should be taken into consideration when designing for exploratory environments (e.g. Baecker, Grudin, Buxton, & Greenberg, 1995; Carroll & Mack, 1985, Condon, 1999).

As researchers became increasingly interested in the quality of a user’s knowledge representation (e.g., Gott, Hall, Pokorny, Dibble, & Glaser, 1993), mental models and adaptive expertise, as knowledge and skills which generalizes across different contexts of complex problem-solving tasks, became of paramount concern (Gentner & Stevens, 1983; Gott, 1989; Kieras & Bovair, 1984). In contrast to the knowledge of strategies (Bhavnani & John, 2000), the accentuation shifted hereby towards strategic knowledge (Gott et al., 1993). Gott et al. demonstrated that surface similarities between different technical domains alone did not essentially facilitate transfer of learning because they limited the user’s flexibility in the adaptation process. In accord with the ideas of schema-based and meta-cognitive transfer, the authors further formulated that "robust performance is one in which procedural steps are not just naked, rule-based actions, but instead are supported by explanations that perform like theories to enable adaptiveness" (p. 260).

Gott et al. (1993) finally note that mental models might be powerful instruments to analyze similarities between tasks as represented within a formulized cognitive architecture. However, they do not explain what particular similarities and dissimilarities are sufficiently salient from the individual’s mental point of view to affect transfer of learning; nor can they predict motivational or emotional conditions of transfer that are essential requisites for every learning process.

**Psychological scope of transfer research**

As transfer pertains to the dependency of an individual’s experience and behaviour on prior experience and behaviour, its research must involve all aspects of psychological functioning, ranging from physical activities, cognitive processes (e.g., thinking), emotion and connation, to its social and environmental dimensions. Although the cognitive connotation of skill has largely emerged as the dominant conception, is not truly possible to appreciate the real meaning of skill
without linking it to its motor or behavioural origins (Adams, 1987; Pear, 1927, 1948), and without extending its scope to include socio-emotional dimensions.

**Cognitive transfer**

The greatest bulk of theoretical and empirical research published in recent decades has been done with reference to transfer of cognitive skills and knowledge, for example with regard to problem-solving and analogical reasoning (Gentner & Gentner, 1983; Gick & Holyoak, 1980, 1983; Holland, Holyoak, Nisbett, & Thagard, 1986; Robertson, 2001). The cognitive shift in psychology showed a great impact on the evolvement of new and refined concepts, methods, theories, and empirical data in transfer research, and it put the investigation of the phenomenon back on the general research agenda after a clear decline in relevant scientific publications between 1960 and the 80ies (Cormier & Hagman, 1987; Haskell, 2001).

Cognition-oriented theories reinforced a series of key research frameworks to the study of transfer, including production systems, analogical reasoning (Gentner & Gentner, 1983; Gick & Holyoak, 1980; Holland et al., 1986), mental models, schema, heuristics, and meta-cognition (Brown, 1978; Flavell, 1976; Gentner & Stevens, 1983; Gott, 1989; Kieras & Bovair, 1984). Specifically, research on transfer has profited from three main drivers within the study of human cognition: these are analogy, the computational metaphor, and the intensified interests with the nature and quality of mental representations.

**Metaphor and analogy**

**Metaphor** refers to the use of a word or phrase to denote an object or concept not in a literary sense, but rather by suggesting an enhancement or replacement of the understanding and interpretation of the targeted object with the metaphor. The object we are indicating by a metaphor is holistically mapped onto the metaphor – and essentials of the metaphor’s content are therefore transferred to the representation of the denoted object. Indeed, the term metaphor comes from the Greek word "metapherein", meaning “to transfer” (see Ortony, 1991, for a overview).

In contrast to metaphor, the concepts of similarity and **analogy** are actually less inherently linked to the mental nature of transfer because they refer only to the circumstance of the relation between two representations. Here, object P is "seen" to be like Q (according to the Latin word "similis", meaning "like") in certain aspects; and by inferring that there might be other similar states between P and Q to be found, P can be used as an analog for Q. Transfer by analogy is not understood in the holistic way as is the case with metaphorical substitution of meaning, but rather in a channeled fashion due to aspectual (perceived or inferred) resemblance between P and Q.

Nevertheless, research on analogy, in all its nuances, proved to be a most influential to the conceptualization of cognitive transfer. Indeed, many cognitive scientists, as well as road leading philosophers, consider analogy to be one if not the core principle of human thinking and thought (e.g., Forbus, 2001; Hesse, 1966; Hofstadter, 2001). According to these views transfer has to be placed within the framework of analogy, rather than the other way around. Although research into analogy frequently penetrates traditional cognitive boundaries, for instance by involving emotionality and social cognition (see Thagard et al., 2002), it is usually associated with analogical reasoning and problem solving; both of which are closely related to the issue of transfer (Robertson, 2001).

**Computational models**

The nearly unifying cognitive metaphor is known as the information-processing approach (Eysenck, 2000; Kuhn, 1970; Lachman, Lachman & Butterfield, 1979), and with the understanding of the learning individual inspired by the **General Problem Solver** (GPS; Newell, Shaw & Simon, 1958 and 1960; Newell & Simon, 1963, 1972). Cognitive research brought forth a variety of
computational models and methods to study and simulate knowledge acquisition, retention, and use (e.g. Anderson, 1983, 1985, 1993; Anzai & Simon, 1979; Atwood & Polson, 1976; Hayes & Simon, 1974 and 1977; Simon & Hayes, 1976). This also provided a new framework for transfer theory development, particularly Singley and Anderson’s (1985, 1989) cognitive account of Thorndike’s identical element theory. Hereby, emphasis is put on the classic knowledge form distinction between declarative and procedural knowledge (Anderson, 1995) as well as between weak problem solving methods (i.e., generalized, domain-independent knowledge and skills) and strong problem solving methods (i.e., domain specific knowledge and skills) (Anderson, 1987, Klahr, 1985; Larkin, 1985; Newell, 1980; Newell & Simon, 1972; Simon & Simon, 1978). Anderson (1995) criticized preceding research on analogical transfer for its dominant focus on traits of the source and target in terms of declarative knowledge, instead of performance orientated processing aspects. He points out for skill acquisition that declarative memory plays only initially a significant role and is in the course of practice quickly replaced by procedural memory; encoded and strengthened in the form use specific production rules (also called the effect of \textit{Einstellung}; Luchins, 1942). The performance benefits from already compiled production rules are believed to be automatic, errorless, independent of each other, and largely independent of contextual variations of tasks within the same knowledge domain. Hence, the transfer distance between the performances in two tasks, or the solutions to two problems, is assumed to decrease proportionally to the number of share specific procedures. This procedural "proportionality-relationship" (Allport, 1937) is in effect the most straightforward interpretation of the Greek term of analogy, meaning proportion, and has in ideal cases of procedure-to-procedure transfer settings, been shown to make relatively good predictions (see also Moran, 1983; Polson & Kieras, 1985; Singley & Anderson, 1985, 1989). Anderson's assessment echoed the fact that research on human learning and problem-solving started to put increasing emphasis on issues like cognitive skills and mental operators, which found implementations in a variety of cognitive architectures such as Soar (i.e., State, Operator, And Result; Laird, Newell & Rosenbloom, 1987; Laird, Rosenbloom & Newell, 1984; Newell, 1990; Rieman et al., 1994), CE+ (Polson, Lewis, Rieman, & Wharton, 1992; Wharton, Rieman, Lewis & Polson, 1994), and the development of several versions of Anderson’s ACT theory (Adaptive Control of Thought; e.g., \textbf{ACT-R}, see Anderson, 1982, 1983, 1993, 1996; Anderson & Lebiere, 1998). In recent decades, cognitive scientists have developed numerous computational models of analogy such as the Structure Mapping Engine (SME) and the "model of similarity-based retrieval" (MAC/FAC; Forbus, Ferguson, & Gentner, 1994; Gentner & Forbus, 1991), Analogical Coherence Models (Holyoak & Thagard, 1989, 1995) Learning and Inference with Schemas and Analogies (LISA; Holyoak & Hummel, 2001) to name just a few (see Gentner, Holyoak & Kokinov, 2001, for an overview). Within LISA’s cognitive architecture, for instance, analogical mapping and retrieval functions are based on the premise that structural units in long-term memory (i.e., propositions, sub-propositions, objects and predicates) of source and target are represented by a collection of shared activated semantic units (Holyoak & Hummel, 2001; Hummel & Holyoak, 1997).

**Motor transfer**

Senso-motor skills are an essential ingredient in learning and performance in most tasks and can be categorized into continuous (e.g., tracking), discrete, or procedural movements (see Magill, 2004; Schmidt & Wrisberg, 2004, for recent basic overviews). Proceduralized motor skills have recently become the most referred to because they are consistent with the models of cognitive architectures and because they are seen as relevant to nearly all physical interactions with the environment; as is the case in transfer situations as well.
Open-loop and closed-loop processes
Before the birth of the proceduralization concept, theories of motor learning have been influenced by the open-loop versus closed-loop system distinction (Adams, 1971; Schmidt, 1975). The original formulation of the closed-loop view on motor performance and learning build on the momentum of internal feedback from executed movements, which allow for error detection and adjustment of actions through the process of contrasting perceptual traces against memory representations (Adams, 1971). Motor learning was accordingly seen as dependent on repetition, accuracy, refinement, and synchronization of a series of called-up movement units (i.e., open-loop structures) that are regulated by closed-loop structures.
In response to this view a different open-loop perspective emerged, namely the one of motor programs (Schmidt, 1975). The learning of motor skills was hereby seen in terms of the build-up, modification, and strengthening of schematic relations among movement parameters and outcomes. This learning results in the construction “generalized motor programs” (i.e., a sequence or class of automated actions) that are triggered by associative stimuli, habit strengths, and re-enforcers, and can be executed without delay (Anderson, 1995; Schmidt, 1975, 1988).
Both theories have their origin with Thorndike’s “Law of Effect”, because the formation of motor behaviour is essentially dependent on knowledge of the outcome of the action taken. This is regardless of whether the essence of motor skills is seen with specific movements or parameters in a schematic motor program (Adams, 1971; Bartlett, 1947a and b; Schmidt, 1988). Another, classic theme that was revived in the literature on transfer of motor skill is the part-to-whole transfer of training (Adams, 1987, p. 51ff.; Thorndike, 1924a and b). It emerged, because it is nearly unconceivable to learn a highly complex motor task as a complete entity. Much like in curriculum research, positive generalization of skill units into coherent task situations has been very limited. Particularly it was found that initial whole-task performances after part-task training remains seriously impaired due to difficulties in the time-sharing of the activities. In consequence whole task training remains generally superior to the part-task-whole-task transfer approach of learning (Adams, 1987; Adams & Hufford, 1962; Briggs & Brodgen, 1954).
Finally, motor research provided some evidence for context- and task-independent savings in learning effort on a new task that seems to be explainable by heightened plasticity and functional reorganisation in the senso-motor neural network system. This is naturally in line with the formal discipline argument.

Socio-emotional dimensions of transfer
Motor and cognitive transfer are in many respects inseparable from issues of emotion and motivation, just as cognitive research in general must embrace affective dimensions of experience and behaviour (Barnes & Thagard, 1996; Thagard & Shelley, 2001). This basic awareness has a long tradition in psychology and, of course, in the philosophical works of Aristoteles, Descartes, and Hume, but has to date not been sufficiently regarded in cognitive research (Damasio, 1994; Leventhal & Scherer, 1987; Mandler, 1975; Oatley & Johnson-Laird, 1987; Rapaport, 1950; Scherer, 1995).
Naturally, emotions and especially motivation have always been closely linked to learning in educational psychology, but their role was generally conceptualized as more of an assistant or moderating nature, i.e., in facilitating versus hindering cognition (Bruner, 1960; Gudjons, 1999; Pea, 1987, 1988; Pintrich, Marx, & Boyle, 1993; Salomon & Perkins, 1989; Thorndike, 1932). Approaches that focus on the same kind of relation between affect and transfer belong to the group that study main effects of affective beliefs on cognition in general, and in particular on transfer-relevant moderation and mediation effects of "will" on "skill" (see also Bong, 2002; Gist, Stevens, & Bavetta, 1991; Mathieu, Martineau, & Tannenbaum, 1993; Saks, 1995). In short: “Knowing how
to solve problems and believing that you know how to solve problems are often dissonant” (Jonassen, 2000, p. 14).

**Transfer of emotions**

Emotional transfer must, however, be regarded as a distinct aspect or type of transfer itself, i.e., one where the experiential relation between two situations is of affective nature (e.g., affective connotations and skills). It occurs wherever previously experienced feelings and attitudes toward a situation, object, or task are re-evoked in a current confrontation with related "symbols" (see Hobson & Patrick, 1995). The preferred emotional transfer model to date has been the one of analogical inference, e.g., if you like product X, and product Y is similar to X, then you will probably like Y. Thagard and Shelley (2001) criticized the simplicity of analogical inference based on mere comparison of objects and properties and proposed a more complex model that accounts for structures of analogies, e.g., by including relations and causality structures. Their emotional coherence theory implemented this idea in the form of the HOTCO model (standing for “hot coherence”) by drawing on assumptions made in preceding models, including explanatory coherence (ECHO), conceptual coherence (IMP), analogical coherence (ACME), and deliberative coherence (DECO) (see Thagard, 2000).

Conceptual foundation of transfer research

The cognitive shift in psychology encouraged the research of mental forms and processes engaged in learning and transfer rather than the simple modification of overt reproductional behaviour; a change in viewpoint that the early Gestalt psychologists and constructivists such as Köhler, Wertheimer, or Piaget had already propagated for a couple of decades. The investigation of cognitive dimensions in transfer became quickly the major driver of research across applied domains and cognitive transfer emerged in many ways as the quintessential view of transfer in general.

**Mental representations and transfer: Common element-based vs. schema-based approaches**

The majority of mental processes studied in research on human cognition have one thing in common: They all pertain in one way or another to the construction of mental representations. This is true, for instance, for perceiving, learning, problem-solving, reasoning and thinking, and recalling, as much as it is true for the phenomenon of transfer.

Although research on mental representation has been utterly manifold, two main traditions can be discerned. Some researchers have regarded mental representations in terms of abstract schemata, frames, patterns or mental models (Bartlett, 1932; Chase & Simon, 1973; Gentner & Stevens, 1984; Johnson-Laird, 1983; Johnson-Laird & Byrne, 1990; Minsky, 1975), while others have paid attention to semantic information and propositional nature of mental representations (Anderson, 1976, 1983, 1994; Collins & Quillian, 1968; Medin & Ribs, 2005; Medin & Smith, 1984; Minsky, 1968; Rosch, 1978). These differential conceptualizations have in general been driven by distinct psychological paradigms adopted, such as *Associationism* and *Connectionism*, *Behaviorism*, *Gestaltism*, and *Cognitivism*.

**GOMS** and ACT-based procedural transfer theses are a good example of modern explanations fitting the atomistic and mechanistic nature of the Connectionist paradigm, i.e., by seeing transfer as an effect of commonality in semantic conditions-action-goal structures, mainly instantiated as IF-THEN production rule associations overlap. This view on transfer clearly replaced Behaviorist explanatory concepts of stimuli and response with more sophisticated mental concepts that serve as units of transfer. The cognitive architecture background also added important processing capabilities and some degree of flexibility concerning the identicality constraint (e.g., declarative-
to-procedural, and declarative-to-declarative transfer); it did however not essentially defy the common underlying common element-based thought model of transfer.

Both the original habitual response-based idea of common element transfer as well as the modern production rule compilation and knowledge encapsulation account are in their core assumptions refuted by Gestaltists’ theories. Koffka’s (1925) scrutiny of Thorndike’s (1911, 1913) and Köhler’s (1917) arguments and findings revealed that explanations of learning and transfer based on the notions of association and automation fall short of explicating the nature of mental activity even for simple problem solving tasks. Novel explanatory concepts were needed to account for “learning by understanding” (Katona, 1940) and problem solving transfer (Mayer & Wittrock, 1996). These were found with reference to the organization and structure of knowledge (Clement & Gentner, 1991; Gentner & Gentner, 1983; Gentner & Toupin, 1986), abstraction and general principle inferences (Bourne, Ekstrand, & Dominowski, 1971, p. 104ff.; Judd, 1908, 1939; Simon & Hayes, 1976), the goal- and meaning-directedness of thinking and its holistic nature (Bühler, 1907, 1908a; Holyoak, 1985; Humphrey, 1924; Selz, 1913, 1922), and functional relations (Duncker, 1935; Köhler, 1917). Because this tradition of investigating transfer is based on Gestaltist ideas, we could summarize them under the header of schema-based theories of transfer.

In accord with the traditions regarding research on mental representation, we can conclude on two mainstream explanatory models for transfer to date: One is the model of common element-based transfer, rooting in Thorndikean ideas, which explains transfer as confined to elementary correspondences between a primary and a secondary learning situation, e.g., procedures, and their automated effect (e.g., Allport, 1937; Singley & Anderson, 1985, 1989; Thorndike, 1924a, b). The other model emerging from the Gestalt tradition can be labeled schema-based or analogical transfer, emphasizing elementary loosened structural or principle-rule-based coherence between transfer source and target (e.g., Duncker, 1935; Gentner, 1983; Gentner & Gentner, 1983; Gick & Holyoak, 1980, 1983; Köhler, 1917/1957; Reed, 1993). They continued Judd’s (1908) line of work resulting in further accentuation of “insightful” transfer, using terms like knowledge structures and schemata, solution principles, and functionality (Katona, 1940; Wertheimer, 1945/1959).

The problem is that, as far as transfer of learning in both traditions refers to one and the same phenomenon, there can not be a situation with two incompatible theoretical frameworks standing side-by-side. Conceptual resolution in some form is clearly imperative. Several efforts have been made in recent years to review and revive transfer research, and to resolve controversies but empirical justification is still in early stages.

### The similarity predicament

The notion of similarity has been particularly problematic for transfer research for a number of reasons. The main problem is that similarity implies dissimilarity, i.e., although two instances may in parts be identical, they are after all also different.

First, similarity has been the cause for debate about how to distinguish transfer of learning from learning or problem solving. The distinction of transfer (of learning) from learning is usually done with reference to a cut-off point on the similarity dimensions, by which the relation between a current and a past situation is estimated. The more similar two situations are rated, the more probable it becomes that any witnessed improvement in performance is due to learning rather than to transfer. The same logic is true in the other direction of the transfer-learning dimension. The discussion on the dissimilarity-similarity distinction has the ambivalent character of being conducted in reference to a dimensional or polar conception and dichotomous model interchangeably. Hence, learning is usually implicitly awarded its own place at the periphery of transfer taxonomies that are based on near-far distinctions. And this raises the question whether it would not be sounder to concentrate more intensively on the common cognitive bases of learning
and transfer, than on some conceptual distinction between them. For instance, while Butterfield and Nelson's (1991) categorization is intuitively appealing, it also conveys some typical problems and challenges. For instance, if transfer is to a task or situation, which is so similar to a previously experienced one that it actually can be considered as the same task (i.e., within-task transfer), then how do we distinguish transfer from learning in general? The corresponding deliberation is that learning refers to mental processes involved in the course of a repeated confrontation with a certain type of task or situation, of which the single accounts can never be identical. Butterfield and Nelson have themselves not been blind to this argument, but they still refrain from equating learning and transfer as proposed by Salomon and Perkins (1989, p. 115). Across-task transfer, according to Butterfield and Nelson’s (1991) model refers to the application of a learned principle in a new task situation which is superficially different, yet functionally equivalent to the prior one. Inventive transfer, finally, is used to describe incidences where learners can not make use of the same solution principles previously learned, but have to develop a new solution on the grounds of similarities and critical differences of source and target task. Understandably, Butterfield and Nelson pose the question to whether this should be rather characterized as problem-solving than transfer.

Second, transfer theories are build on the premise of identical constituents between transfer source and target, while differences, are usually seen as cause of transfer failure. In spite of the manifold attempts to dissociate from one-to-one similarity concepts, the identicality constraint continued to produce most of the headaches to cognitive scientists, especially in the area of analogy research. Considering the diversity of transfer conditions, application domains, and contextual dependency of analogical thought, it is not surprising that few psychologists have conclusively put their fingers on what see as the essence of analogical relations. While the talk of "sameness" and "transpositional similarity" appeals to common sense, much about what similarity means precisely , how it is established mentally, and, therefore, what justifies analogical reasoning, remains unclear. Overall, similarity constraint factors have been identified with respect to predicates, objects and propositions, relational and structural isomorphism, procedural matches, in relation to purpose or goals of tasks or episodes under analogical consideration (see e.g., Robertson, 2001), as well as in relation to the level or type of mental engagement (see results from research on Transfer-appropriate processing (TAP); e.g., Cermak & Craik, 1979; Francis, Jameson, Augustini, & Chavez, 2000; Jacoby, 1983; Roediger & Blaxton, 1987; Schacter, Cooper, Delaney, Peterson & Tharan, 1991; Vriezen, Moscovitch, & Bellos, 1995). As noted, analogical transfer and analogical memory recall has been demonstrated with respect to similarity in superficial traits rather than in respect to relational analogy or structural correspondence (e.g., Kaiser, Jonides, & Alexander, 1986), and has been best attained in within-domain and near transfer settings; in spite of the claim that similarity between analogs fundamentally refers to the qualitative “alikeness” in the relations that hold within one common structure of mental objects, and not simply to the quantitative surface similarity of properties or features from which analogy is then inferred (Forbus, 2001; Gentner, 1982, 1983). Nevertheless, if transfer by analogy is not to stumble over the boundaries of identical matches - be these superficial attributes between target and retrieved source, elements of declarative knowledge, procedural memory content, relational aspects, or otherwise - then the question what similarity means in the context of dissimilarity should be resolved. The focus should be on explicating the sameness in mental representations and assessing their impact on transfer; and not so much on the question "how similar is similar enough to be considered as an analog?"

Psychological Basis of Learning
There are many models explaining the psychological basis of learning, some of them are given below, which explains the processes behind learning:

Information Processing Theory

Information processing theory is a generic term used to describe a group of theoretical perspectives concerning the sequence and execution of cognitive events, including the acquisition of knowledge and cognitive strategies. These theories specifically deal with how learners attend to environmental events, encode information and relate it to knowledge in memory, store new knowledge in memory, and retrieve it as needed (Schunk, 1991).

Acquisition of Information

A learner becomes aware of an object or event through the senses. According to Gestalt psychology, what the individual receives from the senses is perceived not as a random collection of objects, but as an organized whole. This process of perception consists of reorganizing individual objects or events of the figure (the portion one focuses on) and the ground (the background) and transforming these sensory perceptions into a meaningful whole. When a normal individual sees leaves, branches, trunk and roots, it is not perceived as a random collection of parts, but rather as an organized entity called a plant.

After an environmental stimulus is attended to and a pattern perceived, the input is put into short-term or working memory (WM). Working memory is limited in duration and capacity. It has been suggested that the capacity of working memory is seven items plus or minus 2 items, when the items are meaningful units such as words, letters, numbers, or common expressions (Miller, cited in Schunk, 1991). A seven digit phone number is within this capacity, yet a person distracted before dialing an unfamiliar number is likely to forget it. The capacity of working memory can be increased by combining information in a meaningful way (chunking), such as 555-1776 chunked to triple 5 plus the year of American Independence.

As information is put into the information processing system, it is encoded before it is stored in long-term memory (LTM), where it will be available for later recall. Elaboration expands information by adding to it or linking it to existing knowledge. Elaboration aids both encoding and recall. Transfer occurs when (procedural) knowledge is linked in LTM with different content. Thus, learning is influenced by earlier learning and “all learning is influenced by transfer” (McGeoch, cited in Hebb, 1949). Gestalt research has shown that well-organized material is easier to learn and recall (Katona, cited in Schunk, 1991). Other memory research has found that subjects will impose their own organization on material lacking organization, which improves recall (Klatzky, cited in Schunk, 1991). Methods of organization of information include the use of hierarchies, mnemonics, and mental imagery.

Mental models

Research indicates that information in LTM is represented in associative structures and is content addressable, rather than location addressable like the computer (Calfee, cited in Schunk, 1991). Recent work in neurophysiology supports this work (Gardner, 1983). Several constructs have been developed to improve learning by attempting to model the organization of information in the brain. One of these is the concept map, in which information is shown as a network or hierarchy, along with the relationships between the ideas (Hooper, 1989). A similar, but perhaps more powerful construct for information technology instruction is the mental model, which attempts to model and explain human understanding of objects and phenomenon. There are several distinctive claims that mental models promote: (a) beliefs predict behavior; (b) inferences can be made by ‘mental simulation’; (c) mental representations can be analogical (Payne, 1991).

Alberico (1990) suggests that mental models, which influence thought and behavior, are responsible for the way in which a person uses information systems. Mental models have been described as representations or metaphors that users adopt to guide their interactions and aid their
understanding of devices (Hanisch, 1991). The mental models of novices are often based on faulty assumptions and "superstitious" beliefs (Norman, cited in Alberico, 1990; Payne, 1991). The completeness of the mental model has been shown to be less important than the validity or correspondence between the user's representation and the actual response of the system (Hanisch, 1991; Jih, 1992; Payne, 1991). Negative user beliefs and attitudes may be formed when users' expectations do not match the actual system reactions.

Mental models have been found to facilitate learning, retention of procedures, and the invention of procedures for operating systems. Important characteristics of mental models are organization of knowledge with an integrated structure (internal coherence), validity, and integration with knowledge in other areas (Hanisch, 1991). Experts typically have a better organized knowledge base in their own domain, are able to distinguish between important and unimportant elements, and categorize this knowledge at a deeper level (semantically or principal-based) than novices. Further, it has been found that it is easier to assimilate an externally produced mental model than to induce a new one (Jih, 1992).

**Andragogical Model**

Much of the focus on learning and teaching methods has been based on work with children, who have different developmental characteristics than adult learners. Pedagogy, "the art and science of teaching children", is the model with which we have had the most experience. Andragogy, the "art and science of helping adults learn", is a model for adult education which addresses these different characteristics. Developmental psychologists found that there are developmental stages in adults, just as there are stages in childhood and adolescence. The transition from one of these predictable stages to another is one of the main triggers of readiness to learn (Erickson, Havighurst, Levinson, et al, cited in Knowles, 1984). Social psychologists also examined the role of environmental conditions such as population density, stress, social norms, social class, race, and group processes in learning (Barker, Lewin, and others, cited in Knowles, 1984) as well as how change can be made in the environment (Arends & Arends, Lippit, and others, cited in Knowles, 1984).

Knowles (1984) contrasts the pedagogical model with the andragogical model in five key areas: concept of the learner (and, conversely, the learner's self-concept), the role of the learner's experience, readiness to learn, orientation to learning, and motivation to learn.

**Pedagogical Model Assumptions**

The pedagogical model **assumes** that learners are passive, have no worthwhile experience, learn only when they must, are subject-centered, and externally motivated:

- **Concept of the learner** - The learner is a dependent person who submissively carries out the teacher's directions. The teacher is responsible for all decisions regarding the content, how and when it will be learned, and whether it has been learned.
- **Role of the learner's experience** - The learner has little experience that is of value as a resource for learning. The experience of the teacher and the producers of learning aids are what counts. Therefore the transmission technique, either lecture, reading, or audiovisual aids, is the centerpiece of pedagogical methods.
- **Readiness to learn** - Learners become ready to learn what they are told to they have to learn in order to pass to the next grade.
- **Orientation to learning** - Learners have a subject-centered orientation to learning, therefore curriculum is organized into content units.
- **Motivation to learn** - Learners are motivated by external forces, such as pressure from parents and teachers, competition for grades, and the consequences of failure.

**Andragogical model Assumptions**

In contrast, the andragogical model **assumes** learners are self-directing, are a rich learning resource, are ready to learn, are life-, task-, or problem-centered, and are internally motivated:
**Concept of the learner** - The learner is self-directing, except when they are in the classroom, when they tend to regress to the dependency role they experienced as child learners.

**Role of the learner's experience** - The learner has a greater volume and different quality of experiences than children and adolescents. This makes the learner a rich resource for other students. These differences in background result in a much more heterogeneous group and increase the need for individual learning plans. The greater experience of adults also has the potential negative consequence of preconceptions, prejudices, and habitual ways of thinking and acting. Finally, adults also derive much of their self-identity from their experience, so if this experience is devalued, the person feels devalued as well.

**Readiness to learn** - Adult learners are ready to learn when they feel the need to know or do something. The chief sources of readiness are developmental tasks associated with moving from one stage of development to another. However, any life change, such as birth of children, loss of a job, divorce, or death of a friend or relative, may trigger a readiness to learn.

**Orientation to learning** - Learners enter educational activities with a life-centered, task-centered, or problem-centered orientation. The implication is clearly that the activities must be organized around life situations rather than subject and it must be clear at the outset what relevance the activity has to the learner's life tasks or problems.

**Motivation to learn** - While adult learners respond to external motivators such as the possibility of a better job or an increase in salary, internal motivators such as self-esteem, recognition, better quality of life, greater self-confidence, or self-actualization, are much stronger.

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**Module 5**

**RETENTION AND RETRIEVAL PROCESS**

**Memory**

In psychology, memory is an organism's ability to store, retain, and recall information. Traditional studies of memory began in the fields of philosophy, including techniques of artificially enhancing the 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 4. 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 memory**

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±2 items (the title of his famous paper, "The magical number 7±2"). Modern estimates of the capacity of short-term memory are lower, typically on the order of 4-5 items, and we know that memory capacity can be increased through a process called chunking. For example, in recalling a 10-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 letters. 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 memory**

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.

Constructive memory

In psychology, Constructive memory is the spontaneous narrative report of events that never happened. It consists of the creation of false memories, perceptions, or beliefs about the self or the environment usually as a result of neurological or psychological dysfunction.

Any discussion of constructive memory must acknowledge the pioneering ideas of Bartlett (1932), who rejected the notion that memory involves a passive replay of a past experience via the awakening of a literal copy of experience. Although Bartlett did not advocate the extreme position sometimes ascribed to him that memory is always inaccurate (Ost & Costall 2002), he clearly rejected the importance of reproductive memory: ‘the first notion to get rid of is that memory is primarily or literally reduplicative, or reproductive. In a world of constantly changing environment, literal recall is extraordinarily unimportant. If we consider evidence rather than supposition, memory appears to be far more decisively an affair of construction rather than one of mere reproduction’ (Bartlett 1932). Bartlett emphasized the dependence of remembering on schemas, which he defined as ‘an active organization of past reactions, or of past experiences’. Though usually adaptive for the organism, the fact that remembering relies heavily on construction via a schema also has a down side: condensation, elaboration and invention are common features or ordinary remembering, and these all very often involve the mingling of materials belonging originally to different ‘schemata’.

Bartlett’s (1932) ideas have influenced countless modern attempts to conceive of memory as a constructive rather than a reproductive process. For example, Schacter et al. (1998a) described a ‘constructive memory framework’ that links ideas about memory construction from cognitive psychology with various brain systems. Schacter et al. noted evidence supporting the idea that representations of new experiences should be conceptualized as patterns of features in which different features represent different facets of encoded experience, including outputs of perceptual systems that analyse specific physical attributes of incoming information and interpretation of these attributes by conceptual or semantic systems analogous to Bartlett’s schemas. In this view, constituent features of a memory are distributed widely across different parts of the brain, such that no single location contains a literal trace or engram that corresponds to a specific experience. Retrieval of a past experience involves a process of pattern completion in which the remembered pieces together some subset of distributed features that comprise a particular past experience, including perceptual and conceptual/interpretive elements.
Since a constructive memory system is prone to error, it must solve many problems to produce sufficiently accurate representations of past experience. For example, the disparate features that constitute an episode must be linked or bound together at encoding; failure to adequately bind together appropriate features can result in the common phenomenon of source memory failure, where people retrieve fragments of an episode but do not recollect, or misrecollect, how or when the fragments were acquired, resulting in various kinds of memory illusions and distortions (e.g. Johnson et al. 1993; Schacter 1999). Furthermore, bound episodes must be kept separate from one another in memory: if episodes overlap extensively with one another, individuals may recall the general similarities or gist (Brainerd & Reyna 2005) common to many episodes, but fail to remember distinctive item-specific information that distinguishes one episode from another, resulting in the kinds of gist-based distortions that Bartlett (1932) and many others have reported. Similarly, retrieval cues can potentially match stored experiences other than the sought-after episode, thus resulting in inaccurate memories that blend elements of different experiences (McClelland 1995), so retrieval often involves a preliminary stage in which the remembered forms a more refined description of the characteristics of the episode to be retrieved (Burgess & Shallice 1996; Norman & Schacter 1996). Breakdowns in this process of formulating a retrieval description as a result of damage to the frontal cortex and other regions can sometimes produce striking memory errors, including confabulations regarding events that never happened (e.g. Burgess & Shallice 1996; Dab et al. 1999; Ciaramelli et al. 2006; Gilboa et al. 2006).

During the past decade, research in cognitive neuroscience has made use of neuroimaging and neuropsychological approaches to address questions concerning memory errors and distortions that bear on constructive aspects of memory (for a review, see Schacter & Slotnick 2004). We do not attempt an exhaustive review here, but instead focus on two lines of research that are most relevant to our broader claims regarding a possible functional basis for constructive aspects of memory. First, we will consider research concerning false recognition in patients with memory disorders that provides evidence indicating that false recognition – rather than reflecting the operation of a malfunctioning or flawed memory system – is sometimes a marker of a healthy memory system, such that damage to the system can reduce, rather than increase, the incidence of this memory error. Second, we consider neuroimaging studies that provide insight into the extent to which accurate and inaccurate memories depend on the same underlying brain regions. A growing body of evidence indicates that there is indeed extensive overlap in the brain regions that support true and false memories, at least when false memories are based on what we refer to as general similarity or gist information.

Forgetting

Forgetting (retention loss) refers to apparent loss of information already encoded and stored in an individual's long term memory. It is a spontaneous or gradual process in which old memories are unable to be recalled from memory storage. It is subject to delicately balanced optimization that ensures that relevant memories are recalled. Forgetting can be reduced by repetition and/or more elaborate cognitive processing of information. Reviewing information in ways that involve active retrieval seems to slow the rate of forgetting.

Decay theory

Decay theory proposes that memory fades due to the mere passage of time. Information is therefore less available for later retrieval as time passes and memory, as well as memory strength, wears away. When we learn something new, a neurochemical “memory trace” is created. However, over time this trace slowly disintegrates. Actively rehearsing information is believed to be a major factor counteracting this temporal decline. It is widely believed that neurons die off gradually as we age, yet some older memories can be stronger than most recent memories. Thus, decay theory mostly
affects the short-term memory system, meaning that older memories (in long-term memory) are often more resistant to shocks or physical attacks on the brain. It is also thought that the passage of time alone cannot cause forgetting, and that Decay Theory must also take into account some processes that occur as more time passes.

History

The term decay theory was first coined by Edward Thorndike in his book “The Psychology of Learning” in 1914. This simply states that if a person does not access and use the memory representation they have formed the memory trace will fade or decay over time. This theory was based on the early memory work by Hermann Ebbinghaus in the late 1800s. The decay theory proposed by Thorndike was heavily criticized by McGeoch and his interference theory. This led to the abandoning of the decay theory, until the late 1950s when studies by John Brown and the Petersons showed evidence of time based decay by filling the retention period by counting backwards in threes from a given number. This led to what is known as the Brown-Peterson Paradigm. The theory was again challenged, this time a paper by Keppel and Underwood who attributed the findings to proactive interference. Studies in the 1970s by Reitman tried reviving the decay theory by accounting for certain confounds criticized by Keppel and Underwood. Roediger quickly found problems with these studies and their methods. Harris made an attempt to make a case for decay theory by using tones instead of word lists and his results are congruent making a case for decay theory. In addition, McKone used implicit memory tasks as opposed to explicit tasks to address the confound problems. They provided evidence for decay theory, however, the results also interacted with interference effects. One of the biggest criticisms of decay theory is that it can’t be explained as a mechanism and that is the direction that the research is headed.

Inconsistencies

Recall probability over number of intervening items, accounting for time, if decay theory accounts for forgetting.
Recall probability over number of intervening items, accounting for time, if interference theory accounts for forgetting. Researchers disagree about whether memories fade as a function of the mere passage of time (as in decay theory) or as a function of interfering succeeding events (as in interference theory). Often, evidence tends to favour interference related decay over temporal decay, yet this varies depending on the specific memory system taken into account.

**Short-Term Memory**

Within the short-term memory system, evidence favours an interference theory of forgetting, based on various researchers’ manipulation of the amount of time between a participant’s retention and recall stages finding little to no effect on how many items they are able to remember. Looking solely at verbal short-term memory within studies that control against participants’ use of rehearsal processes, a very small temporal decay effect coupled with a much larger interference decay effect can be found. No evidence for temporal decay in verbal short-term memory has been found in recent studies of serial recall tasks. Regarding the word-length effect in short-term memory, which states that lists of longer word are harder to recall than lists of short words, researchers argue that interference plays a larger role due to articulation duration being confounded with other word characteristics.

**Working Memory**

Both theories are equally argued in working memory. One situation in which this shows considerable debate is within the complex-span task of working memory, whereas a complex task is alternated with the encoding of to-be-remembered items. It is either argued that the amount of time taken to perform this task or the amount of interference this task involves cause decay. A time-based resource-sharing model has also been proposed, stating that temporal decay occurs once attention is switched away from whatever information is to be remembered, and occupied by processing of the information. This theory gives more credit to the active rehearsal of information, as refreshing items to be remembered focuses attention back on the information to be remembered in order for it to be better processed and stored in memory. As processing and maintenance are both crucial components of working memory, both of these processes need to be taken into account when determining which theory of forgetting is most valid. Research also suggests that information or an event’s salience, or importance, may play a key role. Working memory may decay in proportion to information or an event’s salience. This means that if something is more meaningful to an individual, that individual may be less likely to forget it quickly.

**System Interaction**

These inconsistencies may be found due to the difficulty with conducting experiments that focus solely on the passage of time as a cause of decay, ruling out alternative explanations. However, a close look at the literature regarding decay theory will reveal inconsistencies across several studies and researchers, making it difficult to pinpoint precisely which indeed plays the larger role within the various systems of memory. It could be argued that both temporal decay and interference play an equally important role in forgetting, along with motivated forgetting and retrieval failure theory.

**Future Directions of Decay Theory**

Revisions in Decay Theory are being made in research today. The theory is simple and intuitive, but also problematic. Decay theory has long been rejected as a mechanism of long term forgetting. Now, its place in short term forgetting is being questioned. The simplicity of the theory works against it in that supporting evidence always leaves room for alternative explanations. Researchers have had much difficulty creating experiments that can pinpoint decay as a definitive mechanism of
Hybrid Theories
The future of decay theory, according to Nairne (2002), should be the development of hybrid theories that incorporate elements of the standard model while also assuming that retrieval cues play an important role in short term memory. By broadening the view of this theory, it will become possible to account for the inconsistencies and problems that have been found with decay to date.

Neuronal Evidence
Another direction of future research is to tie decay theory to sound neurological evidence. As most current evidence for decay leaves room for alternate explanations, studies indicating a neural basis for the idea of decay will give the theory new solid support. Jonides et al. (2007) found neural evidence for decay in tests demonstrating a general decline in activation in posterior regions over a delay period. Though this decline was not found to be strongly related to performance, this evidence is a starting point in making these connections between decay and neural imaging. A model proposed to support decay with neurological evidence places importance on the firing patterns of neurons over time. The neuronal firing patterns that make up the target representation fall out of synchrony over time unless they are reset. The process of resetting the firing patterns can be looked at as rehearsal, and in absence of rehearsal, forgetting occurs. This proposed model needs to be tested further to gain support, and bring firm neurological evidence to the decay theory.

Interference theory
Interference Theory states that interference occurs when the learning of something new causes forgetting of older material on the basis of competition between the two. There are 3 main kinds of Interference Theory: Proactive, Retroactive and Output. The main assumption of Interference Theory is that the stored memory is intact but unable to be retrieved due to competition created by newly acquired information.

The History of Interference Theory
Bergström, a German psychologist, is credited as conducting the first study regarding interference in 1892. His experiment was similar to the Stroop task and consisted of subjects to sort two decks of card with words into two piles. When the location was changed for the second pile sorting was slower showing that the first sorting rules interfered with the learning of the new sorting rules. German psychologists continued in the field with Georg Elias Müller and Pilzeker in 1900 studying Retroactive Interference. To the confusion of Americans at a later date Georg Elias Müller used associative hemming (inhibition) as a blanket term for retroactive and proactive inhibition. The next major progression came from an American psychologist by the name of Benton J. Underwood in 1915. Underwood found that the more lists that were learned, the less the last-learned list was retained after 24 hours. These results were controversial because of the well known effect of the learning theory at the time. In 1924, James J. Jenkins and Dallenback showed that everyday experiences can interfere with memory with an experiment that resulted in retention being better over a period of sleep than over the same amount of time devoted to activity. The United States again made headway in 1932 with John A. McGeoch suggesting that decay theory should be replaced by an Interference Theory. The most recent major paradigm shift came when Underwood proposed that proactive inhibition is more important or meaningful than retroactive inhibition in accounting for forgetting.

Proactive Interference
Proactive Interference is the “forgetting [of information] due to interference from the traces of events or learning that occurred prior to the materials to be remembered”.

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Proactive and Retroactive Interference

Proactive Interference occurs when in any given context, past memories inhibit an individual’s full potential to retain new memories. It has been hypothesized that forgetting from working memory would be non-existent if not for proactive interference. A real life example of Proactive Interference is if a person had the same credit card number for a number of years and memorized that number over time. Then if the credit card was compromised, and a new card dispensed to the client, the person would then have great difficulty memorizing the new credit card number as the old credit card number is so ingrained in their minds. The competition between the new and old credit card numbers cause Proactive Interference.

Brain Structures

The leading experimental technique for studying Proactive Interference in the brain is the “Recent-Probes” Task, in which participants must commit a given set of items to memory and they are asked to recall a specific item which is indicated by a probe. Using the “Recent-Probes” Task, the brain mechanisms involved in the resolution of Proactive Interference have been identified as the ventrolateral prefrontal cortex and the left anterior prefrontal cortex. These influential areas of the brain have been identified through functional magnetic resonance imaging (fMRI).

Retroactive Interference impedes the retrieval and performance of previously learnt information due to newly acquired and practiced information. An example of Retroactive Interference would be if one was to memorize a phone number and then after a few moments memorize another phone number, practicing the second phone number more. When the recall of the first phone number is needed, the recollection will be poor because the last phone number was the item practiced the most. This Retroactive Interference is found because as the second phone number was practiced more, the retention for the first phone number decreases.

Brain Structures

Retroactive Interference has been localized to the left anterior ventral prefrontal cortex by magnetoencephalography (MEG) studies investigating Retroactive Interference and working memory in elderly adults. The study found that adults 55–67 years of age showed less magnetic activity in their prefrontal cortices than the control group. Executive control mechanisms are located in the frontal cortex and deficits in working memory show changes in the functioning of this brain area.

Output Interference occurs when the initial act of recalling specific information interferes with the retrieval of the original information. Output Interference occurs if one had created a list of items that were to be purchased at a grocery store, which had been forgotten home. The act of
remembering a couple items on that list decreases the probability of remembering the other items on that list.

**Retrieval Failure Theory**

Retrieval failure theory proposes that forgetting occurs because of breakdown in retrieval. Inconsistency between how we encode and retrieval cues negatively affects recall. This can be explained by the encoding specificity principle. The encoding specificity principle states that the value of a retrieval cue depends on how well it corresponds to the original memory code. Transfer appropriate processing is an example of encoding specificity. This process occurs when the initial processing of information is similar to the type of processing required by the subsequent measure of retention (retrieve the months of the year alphabetically).

Retrieval Failure can occur for at least four reasons. Interference Theory which states that we forget not because memories are lost from storage but because other information gets in the way of what we want to remember. Decay Theory states that when something new is learned, a neurochemical memory trace is formed, but over time this chemical trail tends to disintegrate; the term for the phenomenon of memories fading with the passage of time is transience. Motivated forgetting, which occurs when people want to forget something is common when a memory becomes painful or anxiety laden, as in the case of emotional traumas such as rape and physical abuse. Amnesia the physiologically based loss of memory; can be anterograde, affecting the retention of new information or events; retrograde, affecting memories of the past but not new events; or both. (King 2008)

**Motivated forgetting** is a debated concept referring to a psychological defence mechanism in which people forget unwanted memories, either consciously or unconsciously. There are times when memories are reminders of unpleasant experiences that make people angry, sad, anxious, ashamed or afraid. Motivated forgetting is a method in which people protect themselves by blocking the recall of these anxiety-arousing memories. For example, if every time you see something or someone that reminds you of an unpleasant event, your mind will tend to steer towards topics which are unrelated to the event; this could induce forgetting without being generated by an intention to forget, making it a motivated action. There are two main classes of motivated forgetting which include: repression and suppression. Repression is an unconscious act, while suppression a conscious form of excluding thoughts and memories from awareness.

**History**

Neurologist Jean-Martin Charcot was the first to do research into *hysteria* as a psychological disorder in the late 19th century. Sigmund Freud, Joseph Breuer, and Pierre Janet continued with the research that Charcot began on hysteria. These three psychologists determined that hysteria was an intense emotional reaction to some form of severe psychological disturbance, and they proposed that incest and other sexual traumas were the most likely cause of hysteria. The treatment that Freud, Breuer, and Pierre agreed upon was named the ‘‘talking cure’’ and was a method of encouraging patients to recover and discuss their painful memories. During this time, Janet created the term *dissociation* which is referred to as a lack of integration amongst various memories. He used dissociation to describe the way in which traumatizing memories are stored separately from other memories.

The publication of Freud’s famous paper, “The Aetiology of Hysteria” in 1896 lead to much controversy regarding the topic of these traumatic memories. Freud stated that *neuroses* were caused by repressed sexual memories, which suggested that incest and sexual abuse must be common throughout upper and middle class Europe. The psychological community did not accept Freud’s ideas, and years past without further research on the topic.
It was during World War I and World War II that interest in memory disturbances was peaked again. During this time, many cases of memory loss appeared among war veterans, especially those who had experienced shell shock. Hypnosis and drugs became popular for the treatment of hysteria during the war. The term post traumatic stress disorder (PTSD) was introduced upon the appearance of similar cases of memory disturbances from veterans of the Korean War. Forgetting, or the inability to recall a portion of a traumatic event, was considered a key factor for the diagnosis of PTSD.

Ann Burgess and Lynda Holmstrom looked into trauma related memory loss in rape victims during the 1970s. This began a large outpouring of stories related to childhood sexual abuse. It took until 1980 to determine that memory loss due to all severe traumas was the same set of processes.

The idea of motivated forgetting began with the philosopher Friedrich Nietzsche in 1994. Nietzsche and Sigmund Freud had similar views on the idea of repression of memories as a form of self-preservation. Nietzsche wrote that man must forget in order to move forward. He stated that this process is active, in that we forget specific events as a defense mechanism.

The False Memory Syndrome Foundation (FMSF) was created in 1992 as a response to the large number of memories claimed to be recovered. The FMSF was created to oppose the idea that memories could be recovered using specific techniques; instead, its members believed that the "memories" were actually confabulations created through the inappropriate use of techniques such as hypnosis.

Theories

There are many theories which are related to the complicated process of motivated forgetting. Due to the vast amount of theories which are related to the ways in which humans are able to forget, it can be assumed the human mind is a very complicated process in regards to memory and forgetting.

The main theory, the Motivated Forgetting Theory, suggests that people forget things because they either do not want to remember them or for another particular reason. Painful and disturbing memories are made unconscious and very difficult to retrieve, but still remain in storage. Retrieval Suppression is one way in which we are able to stop the retrieval of unpleasant memories using cognitive control. This theory was tested by Anderson and Green using the Think/No-Think paradigm.

The Decay theory is another theory of forgetting which refers to the loss of memory over time. When information enters memory, neurons are activated. These memories are retained as long as the neurons remain active. Activation can be maintained through rehearsal or frequent recall. If activation is not maintained, the memory trace fades and decays. This usually occurs in short term memory. The decay theory is a controversial topic amongst modern psychologists. Bahrick and Hall disagree with the decay theory. They have claimed that people can remember algebra they learnt from school even years later. A refresher course brought their skill back to a high standard relatively quick. These findings suggest that there may be more to the theory of trace decay in human memory.

Another theory of motivated forgetting is Interference Theory, which is believed to cause memory loss. Researchers believed that subsequent learning can interfere with a person’s memory in their everyday life. This theory was tested by giving participants ten nonsense syllables. Some of the participants then slept after viewing the syllables, while the other participants carried on their day as usual. The results of this experiment showed that people who stayed awake had a poor recall of the syllables, while the sleeping participants remembered the syllables better. This could have occurred due to the fact that the sleeping subjects had no interference during the experiment, while the other subjects did. There are two types of interference; proactive interference and retroactive interference. Proactive interference occurs when you are unable to learn a new task due to the
interference of an old task that has already been learned. Research has been done to show that
students who study similar subjects at the same time often experience interference. Retroactive
interference occurs when you forget a previously learnt task due to the learning of a new task.
The Gestalt Theory of Forgetting, created by Gestalt Psychology, suggests that memories are
forgotten through distortion. This is also called False Memory Syndrome. This theory states that
when memories lack detail, other information is put in to make the memory a whole. This leads to
the incorrect recall of memories.

**Directed forgetting**

Suppression encompasses the term directed forgetting, also known as intentional forgetting. This
term refers to forgetting which is initiated by a conscious goal to forget. Intentional forgetting is
important at the individual level: suppressing an unpleasant memory of a trauma or a loss that is
particularly painful. It is also important at a more interpersonal level in which a judge orders that
inappropriately presented information must be ignored or forgotten by a jury.

The Directed Forgetting Paradigm is a psychological term meaning that information can be
forgotten upon instruction. There are two methods of the directed forgetting paradigm; item method
and list method. In both methods, the participants are instructed to forget some items, the to-be-
forgotten items and the to-be-remembered items.

In the item method of directed forgetting, participants are presented with a series of random to-be-
remembered and to-be-forgotten items. After each item an instruction is given to the participant to
either remember it, or forget it. After the study phase, when participants are told to remember or to
forget subsets of the items, the participants are given a test of all the words presented. The
participants were unaware that they would be tested on the to-be-forgotten items. The recall for the
to-be-forgotten words are often significantly impaired compared to the to-be-remembered words.

The directed forgetting effect has also been demonstrated on recognition tests. For this reason
researchers believe that the item method affects episodic encoding.

In the list method procedure, the instructions to forget are given only after half of the list has been
presented. These instructions are given once in the middle of the list, and once at the end of the list.
The participants are told that the first list they had to study was just a practice list, and to focus their
attention on the upcoming list. After the participants have conducted the study phase for the first
list, a second list is presented. A final test is then given, sometimes for only the first list and other
times for both lists. The participants are asked to remember all the words they studied. When
participants are told they are able to forget the first list, they remember less in this list and
remember more in the second list. List method directed forgetting demonstrates the ability to
intentionally reduce memory retrieval. To support this theory, researchers did an experiment in
which they asked participants to record in a journal 2 unique events that happened to them each day
over a 5 day period. After these 5 days the participants were asked to either remember or forget the
events on these days. They were then asked to repeat the process for another 5 days, after which
they were told to remember all the events in both weeks, regardless of earlier instructions. The
participants that were part of the forget group had worse recall for the first week compared to the
second week.

There are two theories that can explain directed forgetting: retrieval inhibition hypothesis and
context shift hypothesis. The Retrieval Inhibition Hypothesis states that the instruction to forget the
first list hinders memory of the list-one items. This hypothesis suggests that directed forgetting only
reduces the retrieval of the unwanted memories, not causing permanent damage. If we intentionally
forget items, they are difficult to recall but are recognized if the items are presented again. The
Context Shift Hypothesis suggests that the instructions to forget mentally separate the to-be-
forgotten items. They are put into a different context from the second list. The subject’s mental
context changes between the first and second list, but the context from the second list remains. This impairs the recall ability for the first list.

**Psychogenic amnesia**

Motivated forgetting encompasses the term psychogenic amnesia which refers to the inability to remember past experiences of personal information, due to psychological factors rather than biological dysfunction or brain damage.

Psychogenic amnesia is not part of Freud’s theoretical framework. The memories still exist buried deeply in the mind, but could be resurfaced at any time on their own or from being exposed to a trigger in the person’s surroundings. Psychogenic amnesia is generally found in cases where there is a profound and surprising forgetting of chunks of one’s personal life, whereas motivated forgetting includes more day-to-day examples in which people forget unpleasant memories in a way that would not call for clinical evaluation.

**Psychogenic fugue**

Psychogenic fugue is a form of psychogenic amnesia where people forget their personal history, including who they are, for a period of hours to days following a trauma. A history of depression as well as stress, anxiety or head injury could lead to fugue states. When the person recovers they are able to remember their personal history, but they have amnesia for the events that took place during the fugue state.

**Neurobiology**

Motivated forgetting occurs as a result of activity that occurs within the prefrontal cortex. This was discovered by testing subjects while taking a functional MRI of their brain. The prefrontal cortex is made up of the anterior cingulate cortex, the intraparietal sulcus, the dorsolateral prefrontal cortex, and the ventrolateral prefrontal cortex. These areas are also associated with stopping unwanted actions, which confirms the hypothesis that the suppression of unwanted memories and actions follow a similar inhibitory process. These regions are also known to have executive functions within the brain.

The anterior cingulate cortex has functions linked to motivation and emotion. The intraparietal sulcus possesses functions that include coordination between perception and motor activities, visual attention, symbolic numerical processing, visuospatial working memory, and determining the intent in the actions of other organisms. The dorsolateral prefrontal cortex plans complex cognitive activities and processes decision making.

The other key brain structure involved in motivated forgetting is the hippocampus, which is responsible for the formation and recollection of memories. When the process of motivated forgetting is engaged, meaning that we actively attempt to suppress our unwanted memories, the prefrontal cortex exhibits higher activity than baseline, while suppressing hippocampal activity at the same time. It has been proposed that the executive areas which control motivation and decision-making lessen the functioning of the hippocampus in order to stop the recollection of the selected memories that the subject has been motivated to forget.

**Examples**

**War**

Motivated forgetting has been a crucial aspect of psychological study relating to such traumatizing experiences as rape, torture, war, natural disasters, and homicide. Some of the earliest documented cases of memory suppression and repression relate to veterans of the second world war. The number of cases of motivated forgetting was high during war times, mainly due to factors associated with the difficulties of trench life, injury, and shell shock. At the time that many of these cases were documented, there were limited medical resources to deal with many of these
soldier’s mental well-being. There was also a lesser understanding of the aspects of memory suppression and repression.

**Case of a soldier (1917)**

The repression of memories was the prescribed treatment by many doctors and psychiatrists, and was deemed effective for the management of these memories. Unfortunately, many soldier's traumas were much too vivid and intense to be dealt with in this manner, as described in the journal of Dr. Rivers. One soldier, who entered the hospital after losing consciousness due to a shell explosion, is described as having a generally pleasant demeanor. This was disrupted by his sudden onsets of depression occurring approximately every 10 days. This intense depression, leading to suicidal feelings, rendered him unfit to return to war. It soon became apparent that these symptoms were due to the patients repressed thoughts and apprehensions about returning to war. Dr. Smith suggested that this patient face his thoughts and allow himself to deal with his feelings and anxieties. Although this caused the soldier to take on a significantly less cheery state, he only experienced one more minor bout of depression.

**Abuse**

Many cases of motivated forgetting have been reported in regards to recovered memories of childhood abuse. Many cases of abuse, particularly those performed by relatives or figures of authority, can lead to memory suppression and repression of varying amounts of time. One study indicates that 31% of abuse victims were aware of at least some forgetting of their abuse and a collaboration of seven studies has shown that one eighth to one quarter of abuse victims have periods of complete unawareness (amnesia) of the incident or series of events. There are many factors associated with forgetting abuse including: younger age at onset, threats/intense emotions, more types of abuse, and increased number of abusers. Cued recovery has been shown in 90% of cases, usually with one specific event triggering the memory. For example, the return of incest memories have been shown to be brought on by television programs about incest, the death of the perpetrator, the abuse of the subject’s own child, and seeing the site of abuse. In a study by Herman and Schatzow, confirming evidence was found for the same proportion of individuals with continuous memories of abuse as those individuals who had recovered memories. 74% of cases from each group were confirmed. Cases of Mary de Vries and Claudia show examples of confirmed recovered memories of sexual abuse.

**Legal controversy**

Motivated forgetting and repressed memories have become a very controversial issue within the court system. Courts are currently dealing with historical cases, in particular a relatively new phenomenon known as historic child sexual abuse (HCSA). HCSA refers to allegations of child abuse having occurred several years prior to the time at which they are being prosecuted. Unlike most American states, Canada, the United Kingdom, Australia and New Zealand have no statute of limitation to limit the prosecution of historical offenses. Therefore, legal decision-makers in each case need to evaluate the credibility of allegations that may go back many years. It is nearly impossible to provide evidence for many of these historical abuse cases. It is therefore extremely important to consider the credibility of the witness and accused in making a decision regarding guiltiness of the defendant.

One of the main arguments against the credibility of historical allegations, involving the retrieval of repressed memories, is found in false memory syndrome. False memory syndrome claims that through therapy and the use of suggestive techniques clients mistakenly come to believe that they were sexually abused as children.
In the United States, the Statute of Limitations requires that legal action be taken within three to five years of the incident of interest. Exceptions are made for minors, where the child has until they reach eighteen years of age. There are many factors related to the age at which child abuse cases may be presented. These include bribes, threats, dependency on the abuser, and ignorance of the child to their state of harm. All of these factors may lead a person who has been harmed to require more time to present their case. As well, as seen in the case below of Jane Doe and Jane Roe, time may be required if memories of the abuse have been repressed or suppressed. As of 1981, the statute was adjusted to make exceptions for those individuals who were not consciously aware that their situation was harmful. This rule was called the discovery rule. This rule is to be used by the court as deemed necessary by the Judge of that case.

Amnesia

Amnesia is a condition in which memory is disturbed or lost. Memory in this context refers either to stored memories or to the process of committing something to memory. The causes of amnesia have traditionally been divided into the "organic" or the "functional". Organic causes include damage to the brain, through physical injury, neurological disease or the use of certain (generally sedative) drugs. Functional causes are psychological factors, such as mental disorder, post-traumatic stress or, in psychoanalytic terms, defense mechanisms. Amnesia may also appear as spontaneous episodes, in the case of transient global amnesia.

Forms of amnesia

- **In anterograde amnesia**, the ability to memorize new things is impaired or lost. A person may find themselves constantly forgetting information, people or events after a few seconds or minutes, because the data does not transfer successfully from their conscious short-term memory into permanent long-term memory (or possibly vice versa)

- **In retrograde amnesia**, a person's pre-existing memories are lost to conscious recollection, beyond an ordinary degree of forgetfulness. The person may be able to memorize new things that occur after the onset of amnesia (unlike in anterograde amnesia), but is unable to recall some or all of their life or identity prior to the onset

It should be noted, however, that there are different types of memory, for example procedural memory (i.e. automated skills) and declarative memory (personal episodes or abstract facts), and often only one type is impaired. For example, a person may forget the details of personal identity, but still retain a learned skill such as the ability to play the piano.

In addition, the terms are used to categorize patterns of symptoms rather than to indicate a particular cause (etiology). Both categories of amnesia can occur together in the same patient, and commonly result from drug effects or damage to the brain regions most closely associated with episodic memory: the medial temporal lobes and especially the hippocampus.

An example of mixed retrograde and anterograde amnesia may be a motorcyclist unable to recall driving his motorbike prior to his head injury (retrograde amnesia), nor can he recall the hospital ward where he is told he had conversations with family over the next two days (anterograde amnesia).

- The effects of amnesia can last long after the condition has passed. Some sufferers claim that their amnesia changes from a neurological condition to also being a psychological condition, whereby they lose confidence and faith in their own memory and accounts of past events.

- Another effect of some forms of amnesia may be impaired ability to imagine future events. A 2006 study showed that future experiences imagined by amnesiacs with bilaterally
damaged hippocampus lacked spatial coherence, and the authors speculated that the hippocampus may be responsible for binding different elements of experience together when re-experiencing the past or imagining the future.

Types and causes of amnesia

- **Post-traumatic amnesia** is generally due to a head injury (e.g. a fall, a knock on the head). Traumatic amnesia is often transient, but may be permanent of either anterograde, retrograde, or mixed type. The extent of the period covered by the amnesia is related to the degree of injury and may give an indication of the prognosis for recovery of other functions. Mild trauma, such as a car accident that results in no more than mild whiplash, might cause the occupant of a car to have no memory of the moments just before the accident due to a brief interruption in the short/long-term memory transfer mechanism. The sufferer may also lose knowledge of who people are, they may remember events, but will not remember faces of them.

- **Dissociative amnesia** results from a psychological cause as opposed to direct damage to the brain caused by head injury, physical trauma or disease, which is known as organic amnesia. Dissociative amnesia can include:
  - **Repressed memory** refers to the inability to recall information, usually about stressful or traumatic events in persons' lives, such as a violent attack or rape. The memory is stored in long term memory, but access to it is impaired because of psychological defense mechanisms. Persons retain the capacity to learn new information and there may be some later partial or complete recovery of memory. This contrasts with e.g. anterograde amnesia caused by amnesticics such as benzodiazepines or alcohol, where an experience was prevented from being transferred from temporary to permanent memory storage: it will never be recovered, because it was never stored in the first place. Formerly known as "Psychogenic Amnesia".
  - **Dissociative Fugue** (formerly Psychogenic Fugue) is also known as fugue state. It is caused by psychological trauma and is usually temporary, unresolved and therefore may return. The Merck Manual defines it as "one or more episodes of amnesia in which the inability to recall some or all of one's past and either the loss of one's identity or the formation of a new identity occur with sudden, unexpected, purposeful travel away from home." While popular in fiction, it is extremely rare.
  - **Posthypnotic amnesia** is where events during hypnosis are forgotten, or where past memories are unable to be recalled.

- **Lacunar amnesia** is the loss of memory about one specific event.

- **Childhood amnesia** (also known as infantile amnesia) is the common inability to remember events from one's own childhood. Sigmund Freud notoriously attributed this to sexual repression, while modern scientific approaches generally attribute it to aspects of brain development or developmental psychology, including language development

- **Transient global amnesia** is a well-described medical and clinical phenomenon. This form of amnesia is distinct in that abnormalities in the hippocampus can sometimes be visualized using a special form of magnetic resonance imaging of the brain known as diffusion-weighted imaging (DWI). Symptoms typically last for less than a day and there is often no clear precipitating factor nor any other neurological deficits. The cause of this syndrome is
not clear, hypotheses include transient reduced blood flow, possible seizure or an atypical type of migraine. Patients are typically amnestic of events more than a few minutes in the past, though immediate recall is usually preserved.

- **Source amnesia** is a memory disorder in which someone can recall certain information, but they do not know where or how they obtained the information.
- **Memory distrust syndrome** is a term invented by the psychologist Gisli Gudjonsson to describe a situation where someone is unable to trust their own memory.
- **Blackout phenomenon** can be caused by excessive short-term alcohol consumption, with the amnesia being of the anterograde type.
- **Korsakoff's syndrome** can result from long-term alcoholism or malnutrition. It is caused by brain damage due to a vitamin B₁ deficiency and will be progressive if alcohol intake and nutrition pattern are not modified. Other neurological problems are likely to be present in combination with this type of Amnesia. Korsakoff's syndrome is also known to be connected with confabulation.
- **Drug-induced amnesia** is intentionally caused by injection of an amnesiac drug to help a patient forget surgery or medical procedures, particularly those not performed under full anesthesia, or likely to be particularly traumatic. Such drugs are also referred to as "premedicants". Most commonly a 2'-halogenated benzodiazepine such as midazolam or flunitrazepam is the drug of choice, although other strongly amnestic drugs such as propofol or scopolamine may also be used for this application. Memories of the short time frame in which the procedure was performed are permanently lost or at least substantially reduced, but once the drug wears off, memory is no longer affected.
- **Electroconvulsive therapy** in which seizures are electrically induced in patients for therapeutic effect can have acute effects including both retrograde and anterograde amnesia.
- **Prosopamnesia** is the inability to remember faces, even in the presence of intact facial recognition capabilities. Both acquired and inborn cases have been documented.

**Situation-Specific amnesia** can arise in a variety of circumstances (e.g., committing an offence, child sexual abuse) resulting in PTSD. It has been claimed that it involves a narrowing of consciousness with attention focused on central perceptual details and/or that the emotional or traumatic events are processed differently from ordinary memories

Techniques to Improve Retention and Retrieval process
There are several methods that can be employed to improve one’s memory skills. Recall that the decay theory states that as time passes with a memory trace not being used, it becomes increasingly difficult for that pattern of neural activity to become reactivated, or in other words to retrieve that memory. The key is that information must be retrieved and rehearsed or it will eventually be lost. In remembering new information, the brain goes through three stages: registration, retention, and retrieval. It is only in the retention process that one is able to influence the retention rate if the information is properly organized in your brain. This can be done using these techniques:

1. Recall using cues. Connecting a piece of unfamiliar information with, say, a visual cue can help in remembering that piece of information much more easily.

2. Use the **Rule of 7**. Your brain can only store approximately seven items simultaneously in short-term memory. Lists and categories should therefore contain no more than seven items.
3. Teach it. This is another way to speed up the process of learning new information.

4. Use mnemonic devices and acronyms. This is a preferable method to memorize lists and increase chances of long-term memory storage.

General techniques to improve memory
In addition to exercising your brain, there are some basic things you can do to improve your ability to retain and retrieve memories:

1. **Pay attention.** You can’t remember something if you never learned it, and you can’t learn something — that is, encode it into your brain — if you don’t pay enough attention to it. It takes about eight seconds of intent focus to process a piece of information through your hippocampus and into the appropriate memory center. So, no multitasking when you need to concentrate! If you distract easily, try to receive information in a quiet place where you won’t be interrupted.

2. **Tailor information acquisition to your learning style.** Most people are visual learners; they learn best by reading or otherwise seeing what it is they have to know. But some are auditory learners who learn better by listening. They might benefit by recording information they need and listening to it until they remember it.

3. **Involve as many senses as possible.** Even if you’re a visual learner, read out loud what you want to remember. If you can recite it rhythmically, even better. Try to relate information to colors, textures, smells and tastes. The physical act of rewriting information can help imprint it onto your brain.

4. **Relate information to what you already know.** Connect new data to information you already remember, whether it’s new material that builds on previous knowledge, or something as simple as an address of someone who lives on a street where you already know someone.

5. **Organize information.** Write things down in address books and datebooks and on calendars; take notes on more complex material and reorganize the notes into categories later. Use both words and pictures in learning information.

6. **Understand and be able to interpret complex material.** For more complex material, focus on understanding basic ideas rather than memorizing isolated details. Be able to explain it to someone else in your own words.

7. **Rehearse information frequently and “over-learn”.** Review what you’ve learned the same day you learn it, and at intervals thereafter. What researchers call “spaced rehearsal” is more effective than “cramming.” If you’re able to “over-learn” information so that recalling it becomes second nature, so much the better.

8. **Be motivated and keep a positive attitude.** Tell yourself that you want to learn what you need to remember, and that you can learn and remember it. Telling yourself you have a bad memory actually hampers the ability of your brain to remember, while positive mental feedback sets up an expectation of success.
Mnemonic devices to improve memory

Mnemonics (the initial “m” is silent) are clues of any kind that help us remember something, usually by causing us to associate the information we want to remember with a visual image, a sentence, or a word.

Common types of mnemonic devices include:

1. **Visual images** - a microphone to remember the name “Mike,” a rose for “Rosie.” Use positive, pleasant images, because the brain often blocks out unpleasant ones, and make them vivid, colorful, and three-dimensional — they’ll be easier to remember.

2. **Sentences** in which the first letter of each word is part of or represents the initial of what you want to remember. Millions of musicians, for example, first memorized the lines of the treble staff with the sentence “Every good boy does fine” (or “deserves favor”), representing the notes E, G, B, D, and F. Medical students often learn groups of nerves, bones, and other anatomical features using nonsense sentences.

3. **Acronyms**, which are initials that creates pronounceable words. The spaces between the lines on the treble staff, for example, are F, A, C, and E: FACE.

4. **Rhymes and alliteration**: remember learning “30 days hath September, April, June, and November”? A hefty guy named Robert can be remembered as “Big Bob” and a smiley co-worker as “Perky Pat” (though it might be best to keep such names to yourself).

5. **Jokes** or even off-color associations using facts, figures, and names you need to recall, because funny or peculiar things are easier to remember than mundane images.

6. **“Chunking” information**: that is, arranging a long list in smaller units or categories that are easier to remember. If you can reel off your Social Security number without looking at it, that’s probably because it’s arranged in groups of 3, 2, and 4 digits, not a string of 9.

7. **“Method of loci”**: This is an ancient and effective way of remembering a lot of material, such as a speech. You associate each part of what you have to remember with a landmark in a route you know well, such as your commute to work.

Healthy habits to improve memory

Treating your body well can enhance your ability to process and recall information.

**Healthy Habits that Improve Memory**

**Regular exercise**

- Increases oxygen to your brain.
- Reduces the risk for disorders that lead to memory loss, such as diabetes and cardiovascular disease.
- May enhance the effects of helpful brain chemicals and protect brain cells.

**Managing stress**

- Cortisol, the stress hormone, can damage the hippocampus if the stress is unrelieved.
- Stress makes it difficult to concentrate.
Good sleep habits

- Sleep is necessary for memory consolidation.
- Sleep disorders like insomnia and sleep apnea leave you tired and unable to concentrate during the day.

Not smoking

- Smoking heightens the risk of vascular disorders that can cause stroke and constrict arteries that deliver oxygen to the brain.

References:


