Innovation Trend Report

Neuroscience Impact

Brain and Business

INTESA SANPAOLO INNOVATION CENTER

IMT SCHOOL FOR ADVANCED STUDIES LUCCA

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Frida Polli, CEO and Co-Founder of the startup Pymetrics.

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Foreword

Innovation is the engine of change and neuroscience is the subject where innovation runs exponentially.
For our country and for our bank, a good and forward-looking economic system is a priority.

We deeply believe in innovation as a key lever for the competitive development of the Italian productive system and so the mission of Intesa Sanpaolo Innovation Center is exploring business models of the future to discover new assets and skills that support the long-term competitiveness of the Group and its customers as we become the driving force of the New Italian Economy, to seize new opportunities and face the challenges of tomorrow, looking at cutting-edge technologies.

A commitment to the growth of our Group and the development and training of future generations is crucial for Intesa Sanpaolo Innovation Center.

In this scenario, Intesa Sanpaolo Innovation Center has taken up the challenge of exploring the field of scientific research by the creation of laboratories and competence centers dedicated, in cooperation with international excellence researchers in their own field to generate the know-how and develop new assets and new businesses.

"Intesa Sanpaolo Innovation Center Lab" wants to create a new cooperative working model between industry and research to guarantee the competitiveness of the group and for its customers not yet covered by big players or startups due to new market trend evolution and cutting-edge, exponential technologies.

Foreword

With deep passion, we study the neuroscience in Lucca, in our "Intesa Sanpaolo Innovation Center Lab Neuroscience" in cooperation with IMT School for Advanced Studies Lucca to generate the know-how in cooperation with national and international talents and develop new assets and new businesses, saving intellectual property of our studies and enhance research and Academy.

Our goal is to create an ecosystem in which scientists can work on real data and use cases to produce knowledge and intellectual property for the business. For us, innovation means progressing towards more prosperity, resiliency, better health, and social wellbeing. Innovation for good is our vision.

This book, that considers the complex mechanism of the human brain, wants to reaffirm the role of Intesa Sanpaolo Innovation Center as a strategic actor in the innovation ecosystem to support the progress and the evolution of future generations, towards responsible development models that reconnect business and society.

Maurizio Montagnese

Introduction

In the ancient days, knowledge was seen as a whole. There were no compartments, no disciplinary boundaries. Philosophers would think and talk spanning the whole range of natural phenomena.
The development of more and more sophisticated techniques has led to an ever deeper specialization. However, as scientists, we do know that what must be avoided is the fragmentation of scientific speculation, the acritical devotion to a technique or a methodology. In fact, science grows from cross-contamination, from the interaction of individuals who come from very diverse fields and backgrounds.

This is the model that we adopt at the IMT School. Since its institution in 2005, the School has distinguished itself thanks to its interdisciplinary nature, characterized by the complementarity and discourse between methodologies drawn from economics, engineering, computer science, applied mathematics, physics, archeology, art history and the analysis and management of cultural heritage. IMT researchers carry out cutting-edge research with the aim of generating and applying knowledge to solve problems of an economic, industrial, societal and cultural nature.
To this aim research at IMT is also carried out in close collaboration with the local territory through several initiatives and projects in a variety of areas, including tissue industry, healthcare industry, marine industry, Information and Communications Technology for smart cities and many others.

In this context of successful integration among distinct disciplines, the research field of cognitive and social neuroscience represents a very recent, but inevitable addition. Indeed, scientific advancements of the last decades made clear that any human behavior, from simple daily activities

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to the creation of a piece of art, to a decision made to achieve a particular economic advantage, could be truly understood only by cracking the complex code hidden in the structure and function of the human brain. This change of perspective is particularly evident in the social and economic fields. Indeed, it became clear, for instance, that companies and individuals that analyze the behavior of consumers and their needs, exploring the best solutions to make their customers happy, will never be able to fully reach their objectives without taking into account the complexity and multifaceted nature of the human mind. However, it is only in the most recent years that we have finally come to obtain the 'tools' needed to understand the roots of human behavior and the basis of differences that naturally exist among individuals. Indeed, the introduction and the advancements of so-called neuroimaging methodologies have allowed an unprecedented definition of the marvelous morphological and functional architecture of the human brain.
Today researchers are able to visualize the finer details of the encephalic structure, measure the thickness and the neuronal density in the different areas of the cerebral cortex, and identify the bundles of fibers that, like many thin electric cables, connect the various areas of the human brain. In addition, by using functional neuroimaging techniques such as functional magnetic resonance imaging (fMRI) or high-density electroencephalography (hd-EEG), they can even observe 'the brain in action', that is, what happens in our brain when we do any of our daily activities: to perceive a picture or a painting, to make a decision, or to inhibit an automatic impulse.

Thanks to these novel tools, we are finally becoming able to understand the processes that guide our decisions, as well as those that determine our moral

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judgment, our respect for ethical norms or our ability to control (or not to control) automatic impulses. We have realized, for instance, that the behavior of economic agents is the result of instinct and emotion on the one hand and of reason on the other. The former, which have remained almost unchanged in millions of years of evolution, makes us similar to other animals on Earth. The second, which represent the result of the unique development of the cerebral cortex, and especially of its anterior portion (the so-called 'prefrontal cortex'), is unmatched in the animal world. Both of these factors and their interactions are reflected in any human voluntary or involuntary behavior. Thus, individuals who make decisions in social and/or economic contexts do not behave as 'simple' rational beings, and unconscious processes partially (or totally) hidden to our conscious self clearly have a much greater relevance than previously thought.

Scientific advancements in the fields of neuroscience and psychology are progressively uncovering the mechanisms that drive the choices of individuals and communities, leading us toward a new science of behavior that integrates and complements all other fields of human knowledge. This book aims at presenting the most recent discoveries of neuroscience and their most important implications for our modern society, with particular regard to the social and economic impact. We will also cast a glance into the next few decades, to illustrate the possible and the practical consequences, the potential benefits for the society and the individuals of the future.

Pietro Pietrini

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Table of contents

A Reading Guide

Aim of the book

This volume is aimed at general readers interested in the subject as well as those who want a deeper insight in certain areas of business.
The authors have tried to aid readers throughout by writing clearly and simply, where possible using images and graphs: as readers will discover as they go along, the human brain is far more sensitive to visual stimulus than words expressing the same idea.
Furthermore, as readers may consult the material selectively, this Reading Guide provides all the information necessary for finding chapters of immediate interest, should sequential reading not be preferred.

Structure of the book

Ch. 1 – From Brain to Mind
Ch. 2 – Neural bases of human cognitive processes and behavior
Ch. 3 – Focus on: Health
Ch. 4 – Focus on: Arts & Creativity
Ch. 5 – Focus on: Learning & Training
Ch. 6 – Focus on: Legal & Ethics
Ch. 7 – Focus on: Marketing
Ch. 8 – Focus on: Finance & Investments
Ch. 9 – Focus on: Human Resources

Structure of Chapters

In every chapter reading is helped by tables summarizing leading topics and boxes highlighting the key issues.
In addition, some chapters feature interviews with experts in the world of science and research and reports on firms which zoom in on a particular theme of the chapter.
Finally, QR codes in the text link readers to the Internet, providing an in-depth look at the subjects that interest them most. Glossary and site/bibliography conclude and complete each chapter.

01 From Brain to Mind

The chapter opens with a brief summary of how human beings have come to see the brain as a whole – i.e.: as an organ – and the mind, as manifestation of existence and consciousness. Neurosciences came into existence as scientific disciplines towards the end of the XIX century and advance thanks to technological development.

The second part of the chapter describes how Cognitive Neurosciences have come along thanks to inventions such as: PET, (Positron Emission Tomography); MRS (Magnetic Resonance Spectroscopy); fMRI (Functional Magnetic Resonance Imaging). These technologies have made it possible to go from considering the brain a mere organ to analyzing the flows it generates and that pass through it.

The description of neurons, the analysis of synapses and brain activity connected to them are central to the chapter, which ends with a thorough analysis of the previously-mentioned innovations and a brief but in-depth mention of the ongoing dispute between Neuromaniacs and Neurosceptics.

At the end of chapter:
– information about the International Projects
– interview with Russel Poldrack, Professor of Psychology at Stanford University, CA, USA;
– interview with John Dylan-Haynes, Professor at the Bernstein Center for Computational Neuroscience Berlin, Germany.

02 Neural bases of human cognitive processes and behavior

This chapter looks at brain activity in detail:
It describes what happens to the brain when it receives no stimuli from the outside world and is at 'rest', which areas work the most in this state and what activities are carried out.

It illustrates how attention works and describes the difference between this and consciousness; it also highlights the correlation between "multitasking" at work and stress.

It describes the senses and how they influence one another.

It examines the mechanisms that allow memory and learning to take place, it considers various types of memory and its ability to "store" memories.

It explores the areas of the brain that control the movements which allow humans to interact with the outside world and looks at the link between perception and motor planning.

It describes the birth of "Neurolinguistics" and explains the connections between language and communication.

It analyses executive functions and cognitive processes as a whole, including "Decision Making", which make up the management system of the brain.

It describes the six emotions and illustrates the "Theory of mind" i.e.: the process which allows humans to recognize their emotions and those of others.

03 Focus on: Health

It determines that "Positive Psychology" is the field of investigation aimed at understanding how the individual "happiness" may be fostered, through voluntary changes in attitude and behavior.

It illustrates the benefits of sleep and how much rest we need according to our age, it analyses the positive effects of meditation on our individual behavior and on how we respond to others, it provides a list of useful apps for meditating, eating healthily, fitness and assessing and improving sleep.

It describes the continuous progress in "brain reading" thanks to fMRI and other technological instruments and the progresses in de-codifying brain processes by "rebuilding" them with ever more sophisticated algorithms.

It links brain-reading techniques with "Brain-Computer Interface" (BCI) which provides new communication channels between the brain and the devices that enable lesions or amputations to be mended.

It analyses the possibility of controlling objects from a distance, like drones or robotic arms using electroencephalographic techniques.

At the end of chapter:
– interview with Carlo Miniussi, Director of Center for Mind/Brain Sciences – CIMeC, University of Trento, Rovereto TN Italy;
– information about the startups: Paradromics, Neuron Guard, Mindmaze, Dreem.

04 Focus on: Arts & Creativity

This chapter defines Neuroaesthetics as the study of the neural reactions that help create and contemplate works of art and identifies neurological reactions that turn on emotions when an artist creates or a spectator/listener enjoys an artwork.

It describes how the "mirror neuron system" is part of the brain, being the mechanism that allows those looking or listening to "understand" the feelings, intentions and actions of the artist and be on the same wavelength as him/her.

It explains that the development of new technological instruments like portable electroencephalographs and Eye-tracking Systems, which track eye position and movements, will allow Neuroaesthetics to make significant progress. The combined use of both will in fact make it possible to study visitors and eventually create customized museums.

It tackles creativity, which involves various parts of the brain that work together and is favored by suitable surroundings – soft lights, muffled noises, mild temperatures and even a bit of untidiness.

It describes how difficult it is to measure the impact teaching has on creativity and warns that stress negatively affects creative abilities, which on the other hand are stimulated by rest.

At the end of chapter:
– interview with Zaira Cattaneo, Associate Professor in Psychobiology and Physiological Psychology, Department of Psychology, University of Milano-Bicocca, Milano, Italy;
– information about the startup: Emotiv;
– description of the experience of Gallerie di Italia of Intesa Sanpaolo: L'ultimo Caravaggio. Eredi e nuovi maestri.

05 Focus on: Learning & Training

It lists the definitions of intelligence according to:
– A. Binet, inventor of the first intelligence test to be used and the basis of the current IQ test;
– H. Gardner, father of the theory on multiple intelligences;
– R. Sternberg, one of the most authoritative researchers of intelligence and cognitive development.

It explains that efficiency is a characteristic of cerebral organization and is obtained when the various areas of the brain communicate effectively and with minimum waste of energy.

It defines "neuronal plasticity" as the typical ability of the human brain to adapt and reorganize when faced with changes in the environment. The structure of the brain develops and changes thanks to experience, improving efficiency in carrying out activities.

It explains how physical activity can improve brain activity and how both can slow down cognitive decline.

It discusses the issue of forming and keeping information and dismisses the theory of being able to learn while sleeping.

It hypothesizes that in future educators will be able to set out personalized learning paths based on the level of cognitive development of each student.

It pinpoints dyslexia and autism as the most widespread cognitive disorders and mentions the techniques used to cope with them.

It reveals that there are gender differences in the use of the various areas of the brain.

From the basic principle that "neurons that fire together, wire together", it analyses different techniques in stimulating cognitive potential.

At the end of chapter:
– interview with Nadia Bolognini, University of Milano Bicocca, Department of Psychology, & IRCCS Istituto Auxologico Italiano, Laboratory of Neuropsychology;
– information about the startup: Halo Neuroscience.

06 Focus on: Legal & Ethics

It describes the ethical debate surrounding the possibility that progress in neuroscience and the technology connected to it will soon offer scientists the chance to penetrate the deepest recesses of the human mind. The discussion obviously regards the legal sector as well: one wonders for example whether authorities will be able to use equipment to “read” the minds of witnesses.

It questions how in future the line will be drawn between a person’s right to privacy and that of authorities to know secret aspects of his/her mind, bearing in mind that humans can alter their own memories.

It mentions the current debate on the lawfulness of using “cognitive enhancers” or “smart drugs”, normally used to treat illnesses like Alzheimer’s or Parkinson’s which stimulate specific brain areas and if taken by “healthy” people in a certain context take them beyond their normal standards and significantly improve their performance.

It warns us that in future developments in knowledge of the brain will allow us to act upon the mechanisms that affect emotions, moods and empathy towards others.

It explains that there are three main factors in understanding human behavior: genetic profile, brain structure and environment.

At the end of chapter:
– interview with Dario Nardi, Author, speaker and expert in the fields of neuroscience and personality; he currently holds a position as senior lecturer at University of California (Los Angeles);
– interview with Nick Chater, Professor of Behavioral Science at Warwick Business School.

07 Focus on: Marketing

It starts by pointing out that our minds are forever working on making choices resulting from processes stemming from dual models.

It examines one of these dual models: the "planner doer model", describing characteristics and function when a decision is needed.

It points out the different brain areas involved in each phase of carrying out the "planner doer model" and how this model is comparable with other "dual processes".

It highlights the areas of the brain that preside over conscious and unconscious behavior and what happens in the brain when looking at a work of art or listening to music.

It defines "Neuromarketing" as: the application of neurosciences to marketing that analyses the cognitive and emotional reactions of consumers to marketing stimulus, indicating which graphs can come of this analysis and which characteristics they reveal about consumers.

It explains how marketers inspire consumers using the optimal mix of attention, arousal, motivation and brand recall in the right sequence; It explains that "Neuromarketing" includes the use of technological instruments to gauge reactions to specific products, packaging, advertising and other marketing elements.

It describes the role of visual stimuli in marketing activities.

It explains that EEG may be used as an indicator of advertising effectiveness and therefore for its ability to favorably affect consumer preferences and purchase behavior.

It describes how questionnaires are used to profile consumers.

It explains how the study goes from the single individual to collective behavior.

It explains how a significant quantity of information can be gleaned from consumer data, which when processed gives rise to precise information regarding habits and behavior.

At the end of chapter:
information about the startups:
Neuralya, Neural Sense, Sinetiq.

08 Focus on: Finance & Investments

It explains that Neurofinance is the result of applying a neural approach to finance, thus creating decision making models that can predict a wide range of behaviors in the field of economics.

It gives information on how the different areas of the brain are involved when weighing up different investments and their relevant risk factors.

It states that neuroscientific techniques can help researchers classify individual cognitive characteristics and "automatic" behavior mechanisms.

It reveals that men and women use different parts of the brain when deciding how to invest; the former tend to prefer "liquidity" while the latter would rather have a portfolio of stocks;

It illustrates the role of emotions when deciding on investments and states that they can't be overlooked in defining the behavior pattern of investors.

It identifies the development of the theory of decision-making as the main achievement of neuroscience applied to economy. Knowing why we make wrong or suboptimal decisions can help us develop the best tools in order to improve the effectiveness of the decision making processes.

At the end of chapter:
interview with Enrico Maria Cervellati, Associate Professor of Corporate Finance at the Department of Management Ca' Foscari University of Venice.

09 Focus on: Human Resources

Explains that Neuroscience applied to HR can foster better management.

It defines "Organizational Neuroscience" as the branch of neuroscience dedicated to exploring social-cognitive phenomena in organizations, which helps to better understand interaction between the brain and the work environment.

It illustrates how technological development helps understand behavior. In particular, being able to monitor eye movement (eye-tracking) and measure pupil dilation (pupillometry) can provide HR professionals with precious information regarding the cognitive difficulties inherent to a role within the organization.

It clarifies how the application of knowledge derived from the study of neuroscience can optimize and facilitate the development of trust and relationship in organizations.

It analyses the "SCARF Model" and provides hints as to how to apply it in HR.

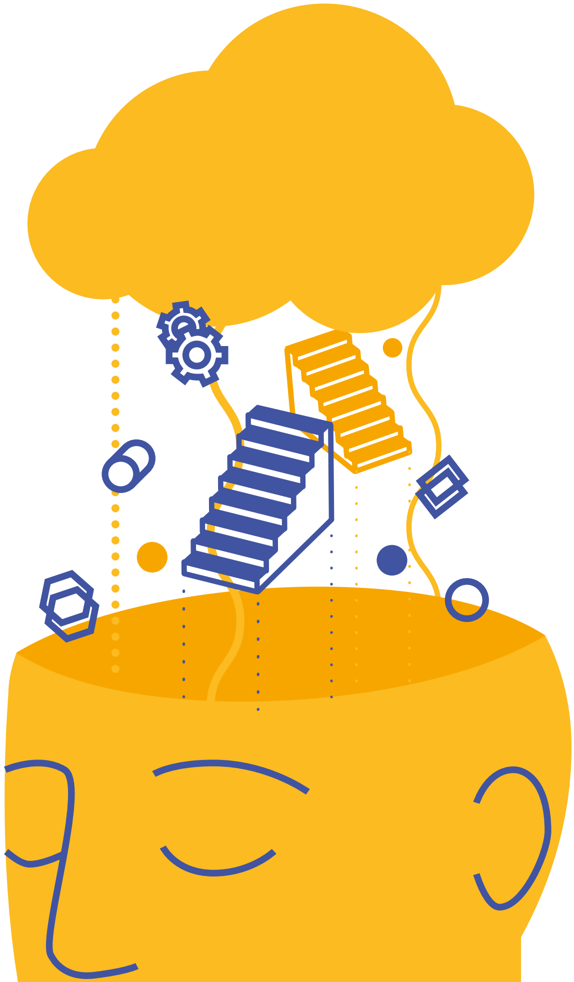
It explains how virtual games are useful in improving the results of selection and hiring processes.

It analyses which factors are essential in creating a cooperative atmosphere within an organization.

At the end of chapter:
– interview with Frida Polli, CEO and Co-Founder of the startup Pymetrics;
– information about the startup: pymetrics;
– description of the experience of Intesa Sanpaolo with pymetrics.

01

From Brain to Mind



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01 — SYNTHESIS

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The key for understanding the human brain is interdisciplinary work.

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Neuroscience is becoming one of the most popular field of research. However, with high popularity also comes high scientific responsibility.

Neurolove & Neurohate

The role of scientific research

Neuroscience was born when the mind was traced back to the brain: before, it was for philosophy, anthropology or even religion to explore the origin of our thoughts, experiences and emotions. Since the decades just prior to the scientific revolution, with little being known about the workings of the human body, to the dawn of the twentieth century, which has seen the rise of artificial intelligence, brain and mind have been considered either distinct or one and the same, with grading opinions as to whether or not one may influence the other.

In **Cartesian philosophy**, where the so-called 'mind-brain problem' originated in a specific formulation, the mind pertained to its own immaterial realm, clearly separated from the material brain. Cartesian dualism lived off the 'cogito ergo sum' motto, a frame of thought in which the mind and its perceptions are the only entities whose existence cannot be doubted: in Descartes' words, there is no way of being sure the material world exists outside of what our mind makes of it - a theme explored to the present day even by popular media such as cinema and literature. The Cartesian brain is pure matter, subjected to the control of the immaterial, though solely real mind.

The human brain represents the most complex puzzle on earth.

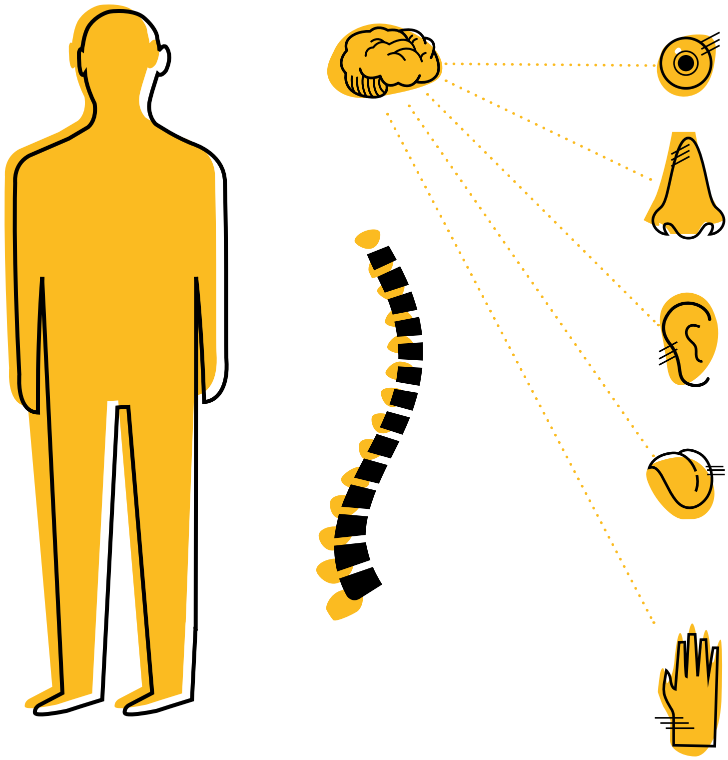
Mind-Body Problem
What is the relationship between our physical body and our mind?

Experimental Psychology
The study of behavior and mind through the application of the experimental method.

Cognitive Neuroscience
The discipline that investigates the neural correlates of psychological processes using neural imaging tools.

Three hundred years after Descartes, the dawn of experimental psychology and neuroscience has seen the fall of introspection, the first defining feature of psychology as a science, in favor of the exploration of animal and human behavior: in such view, the study of the mind sought to embrace all mental functions as a product of the brain, denying any dualism, and tracing it all back to molecules which do not even differ between man, dog or mouse.
For the first behaviorists, mind and brain are their own reciprocal reflection: as already Leibniz and, more recently, Wundt posited, the two entities act as the pre-established harmony of two separated clocks keeping the exact same time, as our mental life and neural structure determine one another.

→
The way we perceive the external world is determined by the five human senses: sight, smell, taste, touch and hearing



The brain is the tiny organ that governs our bodies from its topmost location in the head, close to the sensing apparatuses, the eyes, ears, mouth and nose, in command of our limbs, ready to receive the touch of our hands, sights and smells, words, music. The brain is where a conglomerate of physical structures, becomes the mind, a manifestation of existence and consciousness.

Interestingly, the cultural milieu and technological state of the art have always shaped the path of science investigating the brain and mind. Ancient and modern scientists have always tried to link the inner mechanisms of brain functioning to phenomena they knew or that were just discovered.

For instance, for Galen of Pergamon, in the early centuries of the Roman Empire, the workings of the Earth and the Universe were perceived as one with those governing the anatomy and physiology of life on the planet - i.e., based on fluid dynamics: thus, in Galen's view, while blood flew through the arterial system, the heart instilled it with the vital spirit, and the brain with the psychic spirit, allowing all superior mental functions to be performed. And even referring to the Roman mastery of hydraulic engineering, Galen was labelling brain structures as ‘canal’, ‘aqueduct’ or ‘cistern’.

Much later on, after the Age of Exploration and geographical mapping, the Scientific Revolution of the Seventeenth century, and Enlightenment had imprinted society with newly found needs for an encyclopedic systemization of knowledge, Franz-Joseph Gall, a German physician, attempted the first comprehensive mapping of cerebral functions in humans by tracing every variation of details in the shape of the skull and linking it to behavior. Gall dedicated his life to assigning a nucleus of the brain to a specific function exactly as prominent members of the Enlightenment worked for decades to the first Encyclopedia: he mapped twenty-seven mental functions, nineteen of which he linked specifically to human beings. Despite his incorrect idea that the external shape of the skull could determine the internal working of the brain, justifying behavior and features of one’s personality, Gall fought for a reduction of the mind within the brain and its biology and chemistry, and was the first to systematically isolate cognitive functions in a comprehensive way.

Just right before the birth of modern Neuroscience, technology had a leap forward in new, exciting directions: first, the discovery of electricity and its applications in the physiology of the neuron, then the intuition that cognitive activity, such as processing emotions or making calculations, could be linked to an increase in cerebral blood flow, carried Neuroscience forward together with technology in the late Nineteenth century and early Twentieth. By 1859, Hermann van Helmholtz had measured the speed at which electricity

travels down an axon, the 'wiring' of neurons, Angelo Mosso thought of a special 'balance' to measure the increase in blood flow to the brain during cognitive activities, and Charles Scott Sherrington discovered how signal 'buzzes' from neuron to neuron, naming the synapse for the first time. The first Neuroscience-related Nobel Prize of the Twentieth century went to Camillo Golgi and Santiago Ramon-y-Cajal in 1906 for their discovery of how neurons are wired up together and organized in structured circuits. Shortly after, Adrian, Gasser and Erlanger were then able to amplify the synaptic signal by observing it as a light trace or the sound of an external speaker. From then on, every discovery made in Physics or Chemistry such as the discovery of certain organic compounds or the phenomenon of Magnetic Resonance, every technological advancement, such as the development of computers, had their neuroscientific applications: the discovery of chemical synapses and neurotransmitters; the possibility to briefly modify certain atomic properties in the water to look inside the brain and to see structure and function. Now, high-performing, predictive computational algorithms are being used to simulate the complexity of brain imaging data, and ultimately, cognition in itself.
Nowadays, we are in the era of internet and communication. Neuroimaging is now permeated by terms such as network and connectivity; cortical regions are represented as nodes or hubs; AI, machine learning, cloud computing are commonly applied to brain imaging data.

Anything man has ever said about the brain arises from the brain itself.

400s BC

Plato
The mind (or soul) cannot be identified with, or explained in terms of, the physical body.

1000s

Avicenna
The brain is the place where reason interacts with sensation. The self is not logically dependent on any physical thing (body).

1600s

Descartes
Two kinds of substance: matter, a substance that is spatially extended; mind, a substance that thinks (a 'res cogitans').

1800s

Flourens
Different portions of the brain control different aspects of behavior.

2000s

Modern Neuroscience
How does a brain give rise to a mind? Consciousness has become a hot topic for brain scientists.

Mind and Brain along the centuries

David Chalmers
TED talk:
"How do you explain consciousness?"

The Human Brain

1250 g Average weight

86 Bln Nerve cells

2% of total Body weight

1200 mm^3 Capacity

150,000 Km of white matter connections

Indeed, recent materialists view 'look for the mind' inside any sufficiently complex (even artificial) system that might reproduce the same mechanisms taking place in the nervous system. Yet, we are far from a full comprehension of such mechanisms: how consciousness arises, how we put labels on objects, perceptions, actions and we organize them in a complex semantic world, how we lie or believe, all still partially elude our understanding. Another important and still unanswered question concerns the role of free will: a full equivalence between brain and mind would imply that free will is just an illusion, and that knowing the physiological mechanisms that generate our conscious mind we could gain the ability to predict the behavior of any individual by knowing the structure and wiring of his/her brain.

Will the knowledge of brain structure and physiology allow prediction of behavior?

In this context, although behavior can now be explained in physical terms by Neuroscience through the action of electric signals propagating within and from the brain, of chemicals being exchanged to excite or inhibit function, sugars and oxygen being broken down into energy-releasing molecules to keep cells alive, we cannot yet grasp the complexity of the mind: we now know the cause-effect relationship between some manifestations of the mind, and the working of specific areas of the brain, and still we cannot reproduce complex behaviors in humans, as if the mind wanted to break free from our laboratories.

Attention and memory, learning, action and motor control, language for inner and social communication and conceptualization, emotions, and many psychiatric disorders have been linked to regions of the cerebral cortex, to connectivity across white matter pathways, or to sub-cortical structures - some of them so ancient in evolution, that we share them with ancestral forms of life, such as reptiles. Yet, the more we know, the more we realize how much we still need to understand. How complex the mind is, with respect to the numerous, yet finite number of connections within the brain, baffles anyone approaching the study of behavior. No computer today comes even close to reproducing the complexity of Man's thoughts, even though we know the functioning of electrical and chemical signal transduction and their effect on neurons. Indeed, there is a patch of dark, unexplored territory still calling for understanding, and there we shall be headed.

Henry Markram
TED talk:
"A brain in a supercomputer"

Could computers and robots become conscious?

NCC
The neural correlates of consciousness (NCC) constitute the minimal neuronal mechanisms jointly sufficient for any one specific conscious percept.

AC
Artificial consciousness may be created by emulating the NCC.

Turing Test
Will a machine be able to exhibit intelligent behavior equivalent to, or indistinguishable from, that of a human?

From physiology to cognitive neuro- science

«Those of us who entered neuroscience and psychiatry around the 1980s witnessed the birth and the rapid growth of an era: the in vivo metabolic and functional exploration of the human brain. Positron emission tomography (PET), magnetic resonance spectroscopy (MRS) and, more recently, functional magnetic resonance imaging (fMRI) have presented scientists from different fields with the unprecedented opportunity to investigate the biochemical bases of mental activities in the intact living human brain as well as in the presence of disease. Measures of regional cerebral glucose metabolism and blood flow obtained by PET (or blood flow-related phenomena by fMRI) represent reliable indices of neuronal/synaptic activity –the basis of whatever action, perception, thought, or feeling our brain may be capable of experiencing.»

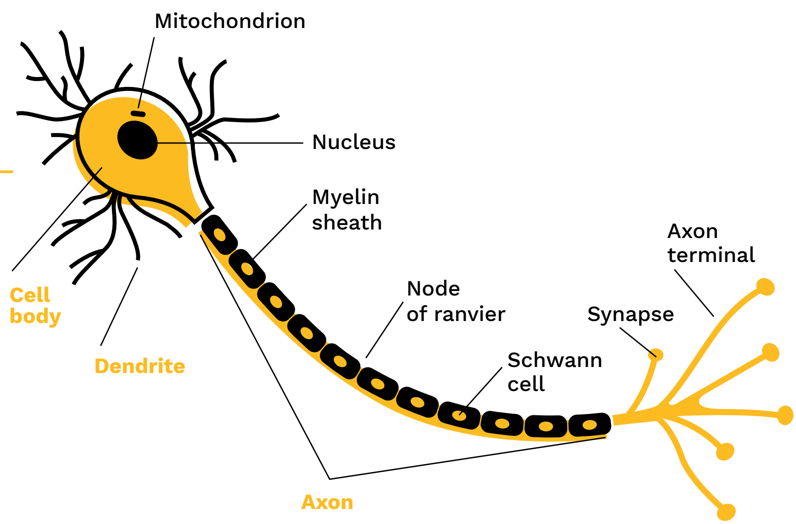
Pietrini P, *Towards a biochemistry of mind*, Am J Psychiatry 160:11, November 2003, 1907-1908.

The advent of methodologies that, for the first time, were able to 'open a window' on the human brain and to observe mental functioning, revolutionized neuroscience.

Before entering the world of neuroimaging to dissect the molecular aspects of brain function, let us try to introduce our main character and its basic physiological functioning.

The neuron and the synapsis

The human brain is made up of neurons that gather together to transmit signals over long distances and send messages to each other.



Khan Academy
Anatomy of a neuron
Human anatomy and physiology

Khan Academy
Sodium-potassium pump cells

But how many neurons do the human brain have?

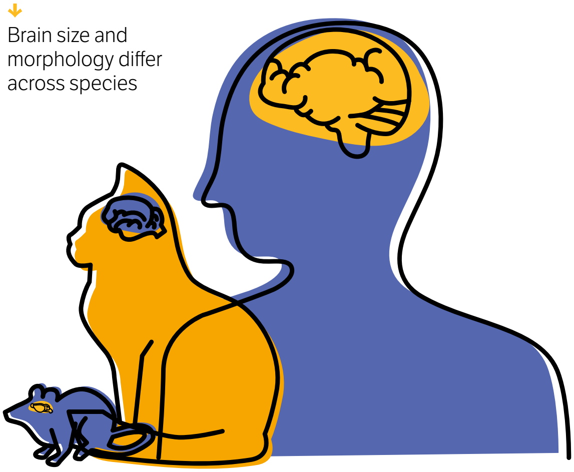
Are there really as many neurons in our brain as stars in the Milky Way? Likely, our brain is made up of about 80-90 billions (while the galaxy that contains our Solar System is estimated to comprehend up to 400 billion stars!), but we are still not sure of how many. In fact, similarly to the Milky

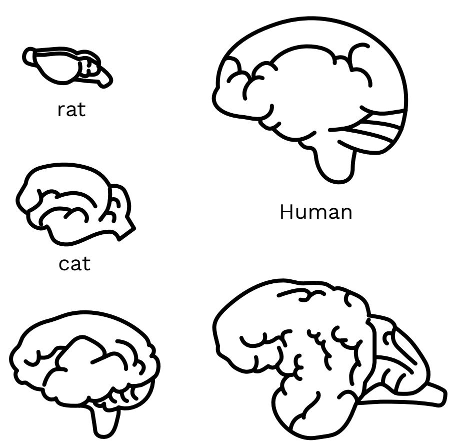
Way with stars of various sizes and brightness, the brain holds intertwined neurons of different sizes and shapes, and with a local density that varies from a brain structure to another (for instance, the cerebellum contains four times the neurons of the cerebral cortex). As a comparison, an African elephant has 250 billions, a gorilla 33 billions, a lion has 5 billions of neurons, a rat has 200 millions and a snail 11,000.

Snail 11,000	**Fruit Fly** 250,000	**Rat** 200 Mln
Cat 760 Mln	**Dog** 2.3 Bln	**Lion** 4.7 Bln
Gorilla 33.4 Bln	**Human** 86 Bln	**Elephant** 257 Bln

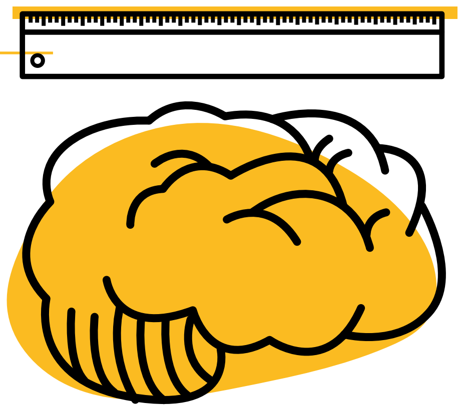
How many neurons are in a brain?

Brain size and morphology differ across species





Suzana Herculano
What is so special about the human brain?



Average brain width
140 mm

Average brain length
167 mm

Average brain height
93 mm

Furthermore, the overall amount of neurons changes with age. If just half of the neurons mammalian embryos generate will survive until birth, during the early years neurons grow (by two years old, your brain is about 80% of its adult size) and work more efficiently, thus pruning functionally inappropriate connections. The brain matures until late 20s and gets its larger volume between 30s-40s. Nonetheless, after its maturation, the human brain starts loosing 1 neuron per second. Drug abuse could increase this loss up to 4/second, and even up to 30,000/second when a stroke occurs!

At Birth
370 cm^3

1 Year of Age
960 cm^3

Young Adult
1,250 cm^3

Old Adult
1,100 cm^3

Changes in brain size

As electrically excitable cells, the neurons process and transmit information by electro-chemical signaling, called synapses. Each neuron may be connected to up to 10,000 other neurons, passing signals through over 1,000 trillion synaptic connections.

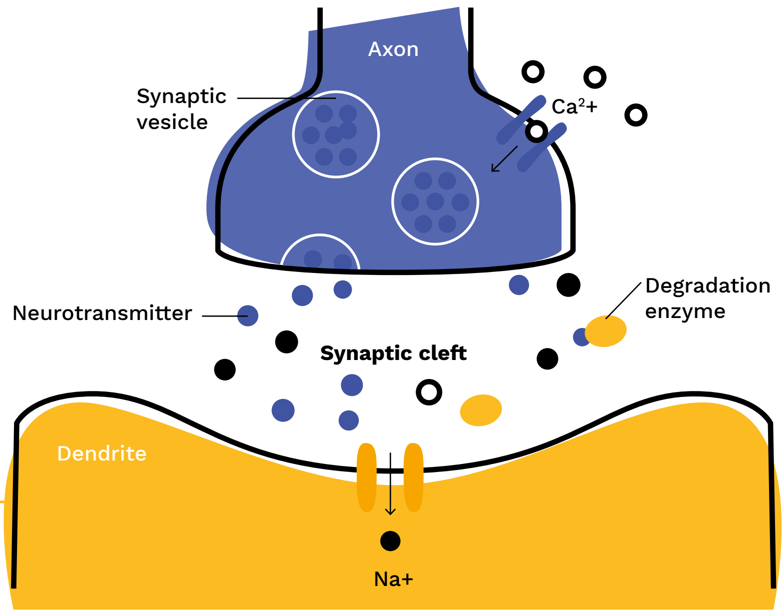
The connections between neurons – defined as neural networks - are not static and change over time. The more signals sent between two neurons, the stronger the connection grows, and so, with each new experience, the brain slightly re-wires its physical structure.

Similarly to the number of neurons, major synapse elimination occurs between early childhood and the onset of puberty during brain maturation. Specifically, when a neuron is 'excited', the voltage of its membrane changes significantly and an electrochemical pulse (action potential) is generated: neurons typically fire 5-50 times every second. This pulse travels rapidly along the soma till the axon, and is transferred across a synapse to the dendrites (less typically also to the soma or axon) of a neighboring neuron.

Neurons communicate with each other using both electrical and chemical signals.

These interactions among neurons are actually electro-chemical, as each axon terminal releases thousands of neurotransmitter molecules: neurotransmitters are chemical messengers, which relay, amplify and modulate signals between neurons and other cells.

→
Chemical synapse



Khan Academy
Neuronal synapses
Human anatomy
and physiology

When an action potential occurs, neurotransmitters of various types are released at the synapsis and bind to receptors of the receiving neuron. Neurotransmitters do not simply excite or inhibit, but may also act more complex functions upon the connected neurons: to set their 'mood', to regulate their ability to respond to stimuli, to modify their functional performance and their structural conformation, etc.

30 nanometers
Width of a synapse

VS

100,000 nanometers
Thickness of a sheet of paper

How long is an axon? The length can range from few micrometers to several centimeters.
Synaptic communication is so fundamental that more than 70% of the neuronal energy is spent for supporting this function. But how does the neuron generate energy?

How neurons get their 'food'...
Even if it represents a complex machine, our brain relies on the simplest metabolic consume of just glucose and oxygen. No other nutrients could physiologically be processed to produce energy. However, the brain has not enough storage and strictly depends on blood flow to get an adequate supply of these nutrients. Consequently, even if the adult brain represents about 2% of a human adult weight, it gets up to 15% of each basal cardiac output, constantly devours 10% of the circulating glucose and about 20% of the blood oxygen.

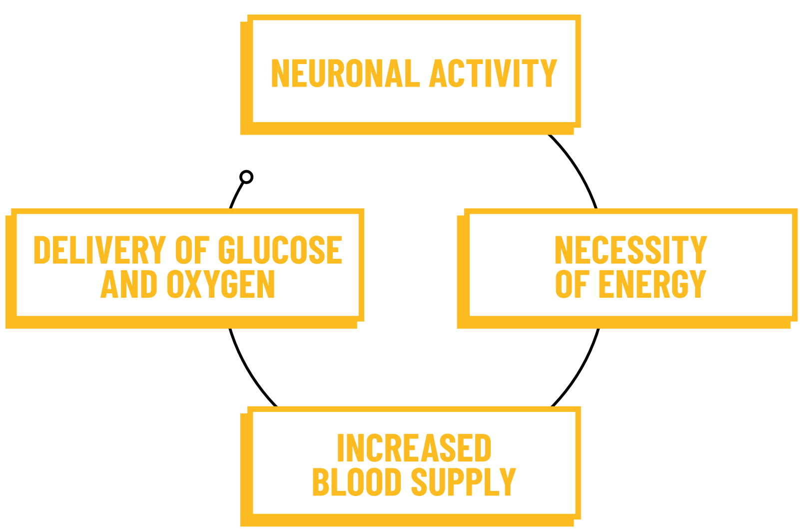
The brain demands 20% of our metabolic rate. This percentage can reach 75% in newborn babies.

Glucose is then oxidized to produce ATP, the fuel for the cellular engine to work. But blood supply of nutrients to the brain should never stop to meet metabolic demand: few seconds of decreased blood flow and the neurons start suffering. An example? When we stand up too quickly, without abundant blood supply, the brain breaks down, causing dizziness and stars before eyes. So, how can the brain provide sufficient blood supply to those neurons that work more?

In addition to neurons, the brain contains about an equal mass of glial cells, the most common types being astrocytes. Because they are so much smaller than neurons, there are up to 10 times as many in number.

Astrocytes perform an active role in brain communication and neuroplasticity, and also support, nourish and repair the neurons of the central nervous system. More importantly, they appear to have an important role in regulating the aperture of arteries to augment blood supply to those neurons whose synaptic activity increase.

More neuronal activity, more necessity of energy, more blood supply to provide with glucose and oxygen! This physiological mechanism is called "neurovascular coupling".

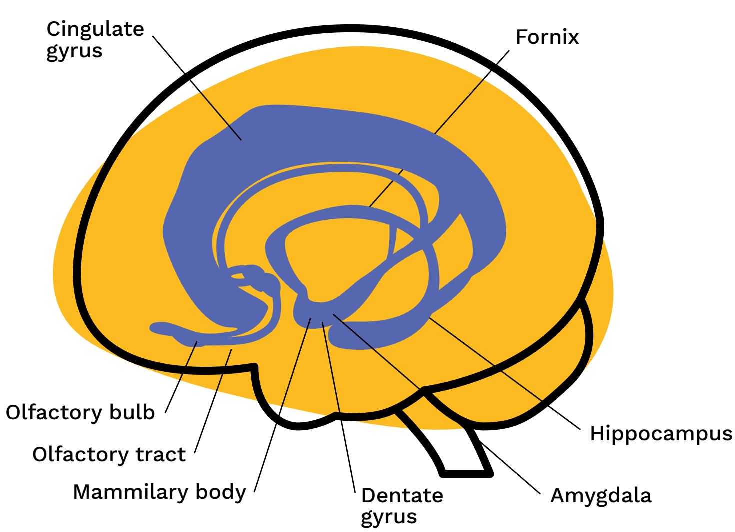


This coupling mechanism that relates blood vessels to neurons through astrocytes in an 'activated' brain region represent the physiological basis to neuroimaging methodologies that measure 'indirect' markers of synaptic activity, such as glucose consumption or changes in blood flow.

Orienting on brain's map

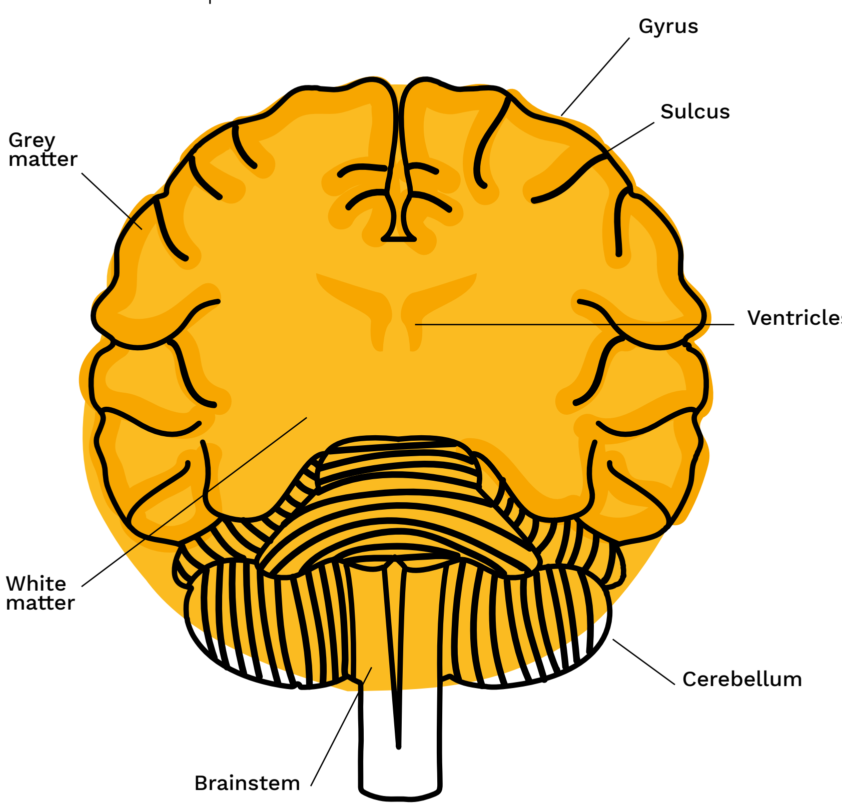
The brain, a 1,250 g wet organ, light grey on the outside and whitish pink on the inside, controls every single aspect of our life, during daytime and nighttime. A complex machine, with about 150,000 km of myelinated nerve fibers that make information to travel up to 120 m/s, mirrors the complexity of the world we live in and how we function within it.
The human brain is made up of different structures that subserve different functions and reflects its evolutionary history, since the first brain structure that appeared in worms over 500 million years ago.
In brief, the brainstem is the most primitive region. It consists of the medulla, pons and midbrain and sustains fundamental homeostatic functions (i.e., controls the reflexes and automatic functions, limb movements and visceral functions, such as digestion, urination).

→ The limbic system

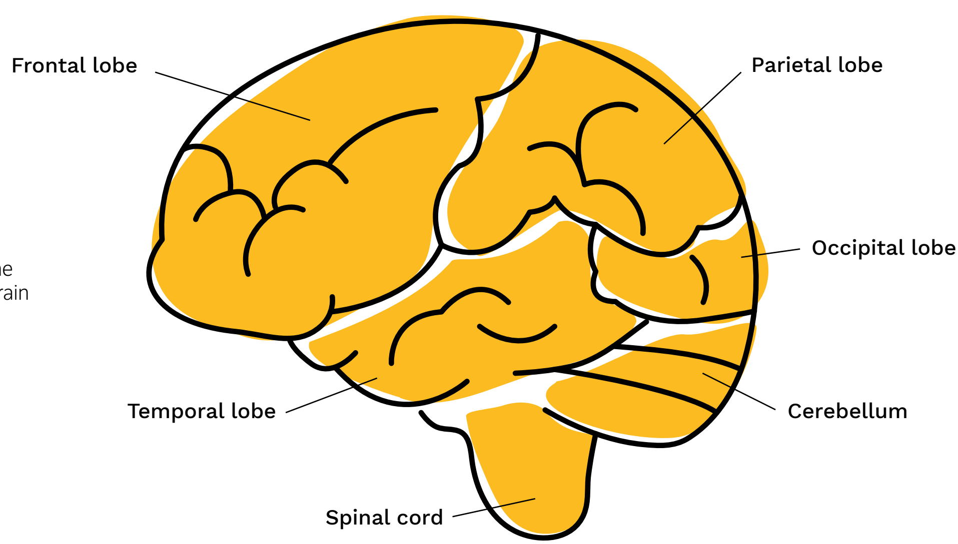


The hippocampus, amygdala, olfactory bulb, hypothalamus, basal ganglia and cingulate cortex form the limbic system that is responsible for the regulation of visceral functions, temperature and behavioral responses including emotional, feeding, sexual and fighting behaviors.
The cerebellum integrates information from the vestibular system to coordinate limb movements.

The cerebrum is the largest component of the human brain with a surface area of about 1.5-2 m^2. The most recognizable part consists of the cerebral cortex (i.e., the gray matter) that covers large fiber tracts (i.e. the white matter) and some deeper structures. To fit this surface area within the skull, the cortex is folded, forming folds (gyri) and grooves (sulci). Several large sulci divide the cerebral cortex into various lobes: the frontal lobe, parietal lobe, occipital lobe and temporal lobe.



Within each lobe, brain areas have different functions and that is why we refer to the brain as functionally segregated. For instance, as we will subsequently detail in Chapter 2, the brain contains regions that receive and interpret sensory information (e.g., occipital, parietal and temporal areas), initiate movement (e.g., frontal and parietal cortex, together with the basal ganglia), reason or experience emotions (e.g., frontal lobe, but also the amygdala and the hippocampus). Nonetheless, each part of the brain 'talks' to the rest of the brain and the processing of information occurs in a functionally integrated manner. Indeed, inside the cerebrum, the different lobes and the two halves of the brain communicate through long tracts of white matter fibers.



➔ Parts of the Human Brain

Khan Academy
Cerebral cortex
Organ Systems

Lobes and functions of the human brain

Frontal

Reasoning, planning, speech, movement, emotions, problem solving.

Parietal

Movement, orientation, recognition, perception.

Occipital

Processing of visual information.

Temporal

Perception and recognition of auditory stimuli, memory, and speech.

The cerebral cortex provides the biological substrate for human cognitive capacity that distinguishes us from other animal species. It is sufficient to look at the massive expansion in size and complexity of the human cortical surface, and mainly in its most anterior regions (i.e., prefrontal cortex) to understand how unique and distinctive could be its functioning and its potentiality... just think to our linguistic abilities, creativity, social interactions, higher-order thinking skills, such as metacognition (i.e., thinking about one's thinking). But let us not forget that this complexity requires longer periods of maturations, during which our brain may be vulnerable to insults, such as stress or abuse, and pathologies. We will talk about that later...

The raise of functional neuro-imaging

As humans, we have always being curious about how we perceive and interact with the surrounding world, yet the idea to systematically explore mental faculties has taken root during the first half of the 19th century, with the advent of experimental psychology.

An experiment is a study of cause and effect: an independent variable (cause) is manipulated and the dependent variable (effect) is measured, while extraneous variables are controlled.

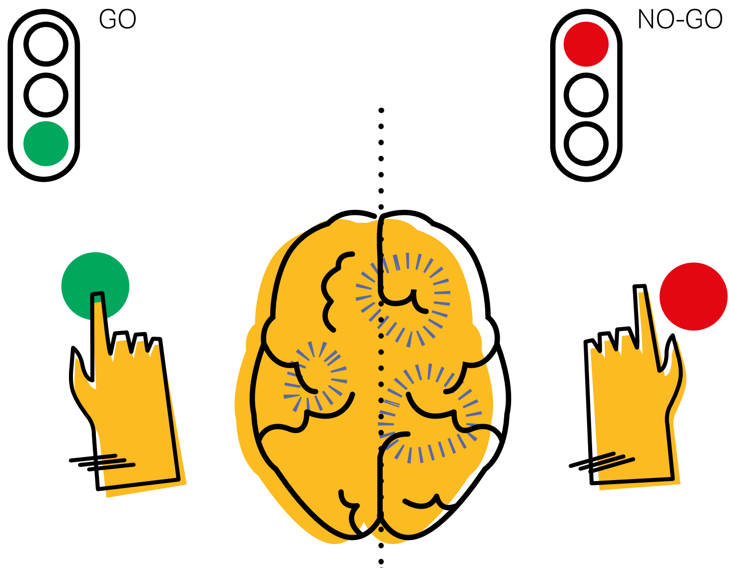
Researchers such as Ernst Weber or Gustav Fechner postulated that the quantification of specific aspects of human behaviors could be used to infer the underlying mental computations involved in the analysis of the environment. For instance, by using a very simple experiment where subjects are instructed to press a button whenever a bright light is presented, one can measure the delay between the stimulus (i.e., bright light) onset and subject's response (i.e., button press), to estimate how rapidly individuals react to sudden events.

Deductive reasoning
Process of reasoning from one or more premises to reach a logically certain conclusion.

Experimental approach
Procedure carried out to support, refute, or validate a hypothesis using the scientific method.

However, if we now introduce a simple variant, by asking subjects to press a button whenever a green light is presented and withhold the response every time a red light appears, we would gather much more information than we would expect from a still very simple experiment. The number of erroneous responses (i.e., button press when the red light is presented) is indeed informative of how efficiently one can control impulsive behaviors, such as reacting to sudden events; in addition, the difference between first and second experiment reaction times represents a proxy of attentional processes involved in stimulus selection. Over the last 150 years, this approach provided fundamental, but indirect, insights regarding mental faculties in living humans.

Nancy Kanwisher
TED talk:
"A neural portrait
of the human mind"



During the second half of '900 advancements in the medical field paved the way for the raise of neuroimaging, by providing the extraordinary possibility to examine the human body from the inside in a non-invasive manner. Year by year, pneumoencephalography, computed tomography (CT), positron emission tomography (PET) and magnetic resonance imaging (MRI) offered increasingly sophisticated and detailed images of human bodies, with the brain making no exception in this regard.

Year	Technique	What is measured?	Information
1924	EEG	Electrical activity	Changes in neural activity
1961	PET	Consumption of radioactive glucose	Metabolic processes in the brain
1967	CT	X-ray Images	Brain anatomy
1968	MEG	Magnetic fields produced by neurons	Changes in neural activity
1972	MRI	Response of tissues to magnetic field	Brain anatomy or changes in regional blood flow (functional MRI)

Neuroscientists have taken advantage of these novel tools to directly investigate what happens in the brain when subjects are engaged in different cognitive or perceptual tasks.

→
Scanner for magnetic resonance imaging

This produced a paradigm shift in the study of the human mind, as the focus moved progressively from the observed behavior to its own source. Thus, neuroscientists started to use the new available techniques to evaluate the effects of distinct experimental conditions on both behavior and brain activity, and the direct comparison of these different experimentally-induced states, in which only one or few variables were manipulated, allowed to isolate the specific brain substrates of different behaviors or subjective experiences.

Activation Analysis
The study of changes in brain activation associated with particular stimuli or behaviors.

Connectivity Analysis
The study of 'communication' between brain regions, used to explore how different parts of the brain share information.

Indeed, accumulating evidence indicates that distinct aspects of human cognition, such as memory, emotions, attention or language, depend on the activity of specific brain regions and, in light of this, many research groups are currently collaborating to create a brain map of mental faculties. Thanks to this approach we are aware now that evolutionary-relevant stimuli, such as faces, are processed in a specific brain module, the fusiform face area, or that a small nucleus, the amygdala, is responsible for our ability to detect and cope with fearful situations. More recently, information gathered through neuroimaging techniques has reached a unique level of complexity: machine-learning methods demonstrated how complex behaviors are accurately predicted on the basis of brain hemodynamic activity, and network (connectivity) analysis revealed that consciousness relies on the dynamic interplay between brain areas.

Allen Brain Atlas:
www.brain-map.org
The Allen Atlas is a project which seek to combine genomics with neuroanatomy by creating gene expression maps for the mouse and human brain.

Although, gathered evidence seem to suggest that we, as humans, are to a large extent deterministic, other researches stress that even subtle variations in environmental factors can produce unpredictable changes in the human brain, ultimately shaping our own behavior. In fact, neuroscientific studies are often conducted in the rigorous but artificial setting of neuroscience laboratories, and functional neuroimaging investigations make no exception in this sense. Conditions reproduced in the laboratory, however, do not resemble experiences of the daily life and the high predictability of human behaviors observed in the experimental setting are hardly exported in more complex and dynamic situations, such as real-world ones. A compelling example in this regard comes from the fact that even though the 95% of the structure of our brain is determined by genes, external factors substantially modulate the chances to develop a specific pathology or can even simply condition our preferences. Nonetheless, in the next years, progresses in computer sciences, physics, bioengineering and medicine will contribute to improve the ability of neuroimaging tools to capture the fine grain organization of the brain, ultimately leading to a better understanding of mechanisms and intimate characteristics of the human mind.

The key for understanding the human brain is interdisciplinary work. Modern neuroscience tries to bridge research fields to each other, tool development to experimental application, human neuroscience to non-human models.

Methodological approaches in neuro imaging

Neuroscientists can investigate brain functioning using different techniques, each one with specific advantages and disadvantages.

Some techniques, such as Electroencephalography (EEG) and Magnetoencephalography (MEG) are able to acquire electrical signals directly originating from neural networks, while other approaches such as Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI), only provide indirect measures of neural activity based changes in the metabolic rate of activated neurons. In this respect, different techniques may allow to study the human brain from distinct but complimentary perspectives.

Temporal resolution
Precision of a measurement with respect to time. High temporal resolution allows to determine the exact timing of very fast changes in brain activity.

Spatial resolution
Precision of a measurement with respect to space. High spatial resolution allows to determine the exact location of a change in brain activity. There is usually a trade-off between temporal and spatial resolution.

EEG and MEG

EEG is probably the oldest technique for the study of brain activity. Hans Berger, a German physiologist and psychiatrist, recorded the first human EEG in 1924. The first MEG recording has been performed more than forty years later, in 1968. Both EEG and MEG record the effects of electrical currents produced by 'activated' neurons, but while EEG directly detects such currents, MEG actually measures the magnetic fields that they produce. The electric potential or the magnetic field generated by a single neuron are far too small to be detected by EEG or MEG using sensors placed on the scalp. Therefore, the activity measured by researchers always reflects the summation of the synchronous activity of thousands or millions of neurons that have similar spatial orientation.

→ Scalp electro-encephalography

Both MEG and EEG have a very high temporal resolution. This means that both techniques are able to 'capture' rapid changes in brain activity, occurring within just few milliseconds. On the other hand, the spatial resolution of EEG and MEG is relatively low, in the order of several centimeters. Therefore, these methods do not allow for an accurate localization of the original sources of changes in brain activity. The situation is slightly worse for EEG because electric fields are commonly distorted while passing through the skull and scalp.

EEG & MEG: High Temporal resolution, Low Spatial Resolution

Researchers employ EEG or MEG when they want to measure changes in brain activity with a high temporal accuracy.

Of note, however, new tools and analytical techniques now allow to strongly improve the spatial resolution of EEG and MEG. The approach known as 'source modelling' uses complex mathematical and geometrical models to determine the exact source of the electrical or magnetic signal recorded at scalp level. Thanks to this new method the spatial error can be reduced below 1-2 centimeters, becoming similar to that of PET.

$3.0 Mln

Price of a high-end MEG system
(plus 200,000$ for annual maintenance)

$150,000

Price of a high-end EEG system with 257 scalp electrodes

PET

The PET technique measures emissions from radioactively labeled metabolically active chemicals that have been injected into the bloodstream. For the study of brain activity, a radioactive analogous of glucose is commonly used. This 'tracer' is then captured by activated neurons, in light of the tight relationship between neural activity and energy need

described in the Book Section *From Physiology to Cognitive Neuroscience*. However, different compounds other than glucose may be used to study other metabolic parameters (such as blood flow or oxygenation), neurotransmitters metabolism and receptor distribution, or to assess the presence of amyloid in dementia.
PET scans are characterized by a very low temporal resolution (tens of seconds to minutes) and an intermediate spatial resolution (centimeters). The necessity of radioactive tracers currently limits the applications of PET.

PET
Very low temporal resolution, intermediate spatial resolution, top chemical specificity.

Researchers employ PET scanning mainly for research and clinical uses (relative to brain disease -e.g., tumors, strokes, dementia) associated with relevant changes in brain metabolism.

$1-2 Mln
Price range for most PET/CT scanners

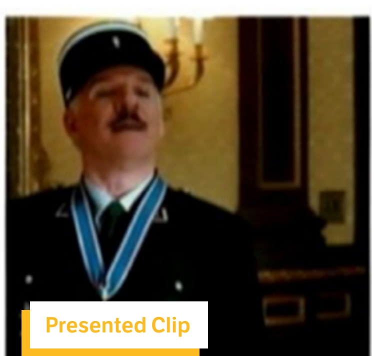
MRI and Functional MRI

MRI techniques use magnetic fields and radio waves to produce two- or three-dimensional brain images without the need of ionizing radiation or radioactive tracers. The so-called functional MRI (fMRI) allows to measure brain activity by detecting changes in regional blood flow. This technique relies on the fact that neuronal activation and cerebral blood flow are coupled.

fMRI: Low Temporal resolution, High Spatial Resolution

The fMRI technique allows obtaining every few seconds (usually 1 to 3) a complete image of the brain containing information about the status of blood flow in different areas. Compared to EEG or MEG, fMRI thus has a relatively low temporal resolution (seconds). Of note, changes in blood flow induced by changes in neuronal activity (neurovascular coupling), are also relatively slow. Therefore, fMRI can only provide an indirect and temporally blurred representation of variations in brain activity. On the other hand, fMRI can offer a spatial resolution of 2-4 millimeters, which allows to precisely identify the specific brain cortical areas that are involved in a particular task.
The level of accuracy and precision is so good that, if an image is presented for a sufficient time (and multiple times, to achieve an optimal signal-to-noise ratio), researchers can obtain a rough 'picture' of what an individual is seeing just by looking at the patterns of activity within his visual cortical area.

Mary Lou Jepsen
TED talk:
"Could future devices read images from our brains?"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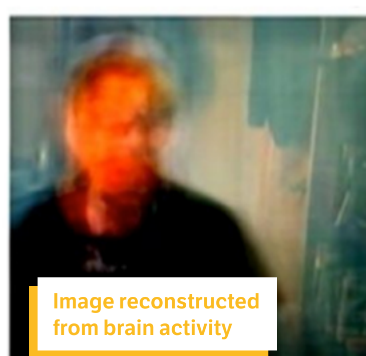


Image reconstructed from brain activity

Given its relatively good combination of temporal and spatial resolution fMRI is increasingly used for the study of the neural correlates of human consciousness and behavior.

$1-5 Mln

Price range for most MRI scanners used in research.

Those described above represent only a fraction of all the techniques that neuroscientists can employ to carry out their research on the brain structure and function.

In most cases, neuroscientists formulate a hypothesis based on theories or on previous evidence and subsequently design an experiment to prove or disprove their conjecture.
In this phase, the optimal methodological approach to answer the specific question being asked is also selected.
For instance, if the question is related to the identification of the specific area or group of areas involved in a particular brain function, then a method with high spatial resolution (e.g., fMRI) will be preferred. Vice versa, if the question involves the definition of the specific temporal sequence of brain areas being recruited, a high temporal resolution will be required (e.g., EEG or MEG).

A neuroscientific study always necessitates the definition of an experimental paradigm, where the variables of interest and the type and timing of the stimulations, are carefully defined to properly evoke neural activity which is concurrently measured by means of one (or, sometimes, more) acquisition techniques. Importantly, potential confounding factors, such as background noise or signal artifacts depending on physiological (e.g., heart-beats, respiration, head movements) or non-physiological (e.g., artificial electrical currents) sources, also have to be identified, and specific strategies have to be implemented to minimize their potential negative impact on the results.

Using statistical or machine learning approaches, neuro-scientists analyze the patterns of brain activity elicited during the experiment to test their scientific hypothesis and to uncover the neural underpinnings of the cognitive process of interest.

>23,000
scientific papers based on fMRI published in 2017

>4,000
scientific papers based on EEG published in 2017

>500
scientific papers based on MEG published in 2017

The future of neuroimaging

Technological advances will significantly improve the efficiency of both neuroimaging machines and mathematical algorithms used to extract information from the data. At present, for instance, most MRI laboratories use large magnets that generate a magnetic field of 3 Tesla (corresponding to ~320,000 times the strength of Earth's magnetic field). New technologies are now allowing to create magnets that can reach 17 Tesla (although currently only fields up to 7 Tesla are used on humans), and have the potential of generating images of the brain with an incredibly high (sub-millimetric) spatial resolution. New techniques have been also developed to improve the time resolution of fMRI that can now reach the order of few hundred milliseconds (i.e., one complete image of the brain can be acquired every 200-600 ms). Other techniques, such as EEG and MEG, are undergoing similar improvements. For instance, EEG caps with up to 500 electrodes (the current maximum is 256) are currently under development. These advances will allow to study the brain and its function with an unprecedented level of detail.

Moritz Helmstaedter
TED talk:
"Brain Mapping"

On a different perspective, new techniques are becoming available to directly 'stimulate' specific parts of the brain and thus probe their different functions. For instance, transcranial magnetic stimulation (TMS) uses large magnetic coils positioned just above the patients scalp to produce an electric current in the nearby neurons located in the brain through short magnetic pulses. Similarly, transcranial direct current stimulation (tDCS) is based on the direct application of a low-intensity electrical current that can reach brain areas directly below electrodes placed on the scalp. These techniques can however reach only brain areas that are located at short distance from the scalp surface. Researchers are working on the development of new techniques that may directly probe both superficial and deep brain areas with a high temporal and spatial precision. Such approaches will allow an unprecedented level of accuracy in the characterization of the function of different parts of the human brain.

Neurolove & Neurohate

Since its debut in the early 1990s, fMRI has had an ever-increasing popularity among neuroscientists, and nowadays around 30,000 papers are published each year with this technique. On the other hand, public reactions to neuroimaging findings exhibited high excitement as well as high concern. These 'extreme' reactions have been often favored by the media. Terms as Neuromania (or Neurolove) and Neuroskepticism (or Neurohate) have arisen: the former refers to an inflated enthusiasm for neuroscientific methodologies, seen as a way to overcome the mind-brain dichotomy; while the latter is related to a fear that fascination for neuroscience may potentially lead to cultural impoverishment.

Neuromania
The appeal to the brain, as revealed through the latest science, to explain all aspects of human behavior.

Neuroskepticism
Distrust on inferences that reach-out beyond the brain into society, politics, economics, etc.

Neuromaniacs strongly believe that neuroscience may offer a biological explanation to all aspects of mental function and behavior, and that most philosophical, ethical and social questions should be therefore investigated using neuroimaging techniques. Indeed, neuroscience is offering novel insight on long-standing, fundamental questions, such as...

What is the origin of consciousness? How do we make decisions? How are emotions generated? How are memories stored and retrieved? Why do we sleep and dream?

All these questions have fundamental implications for our modern society, and neuroscience may offer the key to answer most (if not all) of them.

Do we really use only 10% of our brain?
This is probably the most famous false myth about our brain. Most of our brain areas are active even when we are doing apparently nothing! The truth may rather be that we still know less than 10% of how our brain works.

This new enthusiasm (or hype?) for opportunities brought about by neuroscientific research led to the proliferation of interdisciplinary research fields, such as neuromarketing, neuroaesthetics, neuropolitics, neuroeducation, neuroethics, neurolinguistics and so on.

Neuroskeptics believes that Neuromania may lead us to think of our behavior and our society just in terms of the brain, the neurons and synapses.

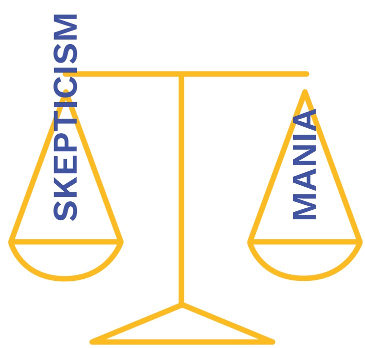
Neuroskeptic
discover.magazine.com
blog

Unfortunately, results of neuroscientific investigations are often presented by mass media using exaggerated – or even false – headlines and over-simplistic claims. Very often we observe a negative relationship between scientific relevance of a study and its actual impact on media: recently, for instance, a study correlating brain cortical thickness with the number of Facebook friends gained attention of reporters, and has been widely covered by news sites and social networks.

Some headlines (erroneously) suggested that measuring the size of the amygdala can provide information about the social skills of an individual. In a similar fashion, other recent headlines announced that neuroscientists have explained love just because they identified a region of the brain activated while seeing a loved person. This kind of claims is obviously exaggerated (i.e., not really supported by the experimental data) and may lead to wrong (and sometime even deceitful) 'uses' of the scientific results. Indeed, excessively strong or inconsistent claims brought about by the media and by some scientists inevitably led to a rapid growth in the skepticism toward neuroscience in a part of the general population.
Neuroskeptics tend to highlight the limitations of current neuroimaging techniques and of the procedures related to scientific publication. In this respect, for instance, a great attention has been caught a few years ago by a provocative experiment showing that a wrong use of neuroscientific approaches may lead to the observation of apparent brain activity even in a dead salmon. Methodological or statistical errors, and sometimes even fraud or scientific misconduct, can obviously undermine the reliability of neuroscientific studies. But these kind of problems affect all fields of research, and bad neuroscience is like any bad science. Importantly, like other fields of science, neuroscience can correct itself through replications of experiments and introduction of new technological or methodological advancements.
Neuroscientists are able to identify limitations and potential problems of a study, and this allow them to evaluate current claims and to plan and improve future research.
Even episodes of fraud or misconduct can be efficiently

identified and dismissed, when researchers worldwide try to replicate a published study and fail. This perspective is rarely understood by the general population who get to know neuroscientific findings only, or mainly, through news reported on the media or on the internet.

Neuroscience is becoming one of the most popular field of research. However, with high popularity also comes high scientific responsibility.



Beyond extreme neuromania or neuroskepticism, what is becoming clear is that neuroscience may at least help us to unveil some of the mysteries surrounding our brain and, thus, ourselves. In fact, the amount of knowledge already gathered in the last decades is astounding: we will try to present just a small portion of it in the next chapters. At the same time, much remains to be done and for this reason many countries are increasing their effort and investment on brain research. The 21th century is certainly one of great explorations: one toward the outer space, to understand the universe, and one toward the brain, to understand our inner self.

www.braininitiative.nih.gov

Brain Initiatives
NIH BRAIN Initiative

The White House BRAIN (Brain Research through Advancing Innovative Neurotechnologies) Initiative, represents a collaborative, public-private research initiative with the goal of supporting the development and application of innovative technologies that can create a dynamic understanding of brain function.
Inspired by the Human Genome Project, the BRAIN initiative aims at helping researchers uncover the physiological and pathological basis of brain functioning, potentially providing novel new strategies for the cure of of brain disorders, such as Alzheimer's and Parkinson's diseases, depression, and traumatic brain injury.

Established 2013

Where United States

Funding >€4.5 Bln

www.humanbrainproject.eu

Brain Initiatives
Human Brain Project

The Human Brain Project (HBP) is a large ten-year scientific research project that aims at accelerating the fields of neuroscience, computing and brain-related medicine. Specifically, the project aims at integrating programmes in fundamental neuroscience, advanced simulation and multi-scale modelling with the construction of an enabling Research Infrastructure.
The HBP is coordinated by the École Polytechnique Fédérale de Lausanne (EPFL) and is largely funded by the European Union.

Established 2013

Where

European Countries, Switzerland

Funding >€4.5 Bln

bluebrain.epfl.ch/

Brain Initiatives
Blue Brain Project

The Blue Brain represents a Swiss national brain initiative aiming at creating a digital reconstruction of the brain by reverse-engineering mammalian brain circuitry. Biologically-detailed digital reconstructions and simulations of the brain could be used to identify the fundamental principles of brain structure and function in health and disease. The Blue Brain initiative involves several sub-projects run by universities and independent laboratories both in Switzerland and in other European countries.

Established 2005

Where

Switzerland, European Countries

Funding >€70 Mln

brainminds.jp/en/

Brain Initiatives
Brain/MINDS

The Brain/MINDS (Brain Mapping by Integrated Neurotechnologies for Disease Studies) represents a Japanese brain initiative sponsored by the Ministry of Education, Culture, Sports, Science, and Technology of Japan.

The Brain/MINDS Project focuses on three areas:

- The study of the brain in a non-human primate (marmoset),
- Developing technologies for brain mapping,
- Human brain mapping.

Established 2014

Where Japan

Funding >€300 Mln

english.cas.cn/

Brain Initiatives
China Brain Project

The China Brain Project is a 15-year project, approved by the Chinese National People's Congress in 2016.
Similar to other brain initiatives, the China Brain Project aims at exploring the neural basis of cognitive function and at improving diagnosis and prevention of brain diseases.
Gathered information about brain functioning will be also used to guide information technology and artificial intelligence projects.

Established 2016

Where China

Funding n.a.

INTERVIEW

Russell Poldrack
Professor of Psychology at Stanford University, CA, USA
poldracklab.stanford.edu

What are your fields of interest and your most recent and relevant contributions to the understanding of the neural underpinnings of mental functioning?

My lab currently has two major lines of basic research. The first is to understand the organization of self-control in terms of both behavior and neural functioning. Self-control is studied across many different parts of psychology and neuroscience, using a broad range of methods including self-report surveys and cognitive tasks. Our research is examining how these different aspects of this construct relate to one another at the level of behavior and brain function, and how they relate to real-world outcomes that are often thought to relate to self-control. The second set of interests are centered around the nature of functional connectivity as measured using fMRI, and particularly around the dynamics of functional connectivity. Our previous work has shown that dynamic changes in network integration are related to cognitive function, and our ongoing work is characterizing this in more detail, with a particular focus on how different types of cognitive challenges may drive different types of network-level changes. My lab is also deeply involved in the development of methodology for the analysis and sharing of neuroimaging data. We lead the Neurovault and OpenNeuro data sharing projects, which both support the open sharing of data. We have also led the development of the Brain Imaging Data Structure (BIDS), which is a community format for the organization and sharing of data. We are currently developing a suite of tools for analysis of BIDS datasets including the MRIQC quality control tool and the fMRIPrep preprocessing workflow.

INTERVIEW

In your opinion, what are the big questions to be answered next in the field of cognitive neuroscience?

- How can we use neuroscience data to inform and potentially reform our theories of the structure of the mind?
- Previous neuroimaging research has largely focused on the acquisition of relatively small amounts of data from each individual, and recent moves towards "big data" have focused almost exclusively on the acquisition of larger numbers of subjects rather than more data per individual. However, we and others have recently shown that much more data is necessary in order to characterize individual brain function in a reliable way. How can we build a reliable cognitive neuroscience given these constraints?
- Network neuroscience is increasingly focused on characterization of brain function using graph - theoretic methods. However, we know that the brain is not a set of interchangeable nodes - each node does a specific computation, and routes through the brain's network are not fungible. How can we reconcile the network neuroscience perspective with a computational perspective?

What are the current limitations or pitfalls in cognitive neuroscience research?

- Insufficient attention to reliability of our fMRI measures and psychometric features of our behavioral tasks
- Use of limited sets of measures per individual, leading to a focus on relating activity to specific tasks rather than to more general processes that span across tasks - Lack of detailed cognitive/behavioral modeling in most studies

INTERVIEW

Which challenges and developments can we expect to see in cognitive neuroscience research?

- Much deeper phenotyping of individuals, both in time (many sessions) and in cognitive space (many tasks)
- Integration of data across many different tasks via data sharing
- Stronger integration of computational models into neuroimaging, beyond subfields where this has already been prevalent (such as vision research and neuroeconomics)

INTERVIEW

John Dylan-Haynes
Professor at the Bernstein Center for Computational Neuroscience Berlin, Germany

What are your fields of interest and your most recent and relevant contributions to the understanding of the neural underpinnings of mental functioning?

I work on cognitive and computational neuroimaging. That means I use behavioral experiments in brain scanners together with special mathematical analyses to understand how the mind is linked to brain processes. Our specific foci are on perception, working memory and intentions.

In your opinion, what are the big questions to be answered next in the field of cognitive neuroscience?

Mapping the exact relationship between thoughts and brain activity patterns. This is equivalent to research on reading out mental states from brain activity because if you understand how the thoughts are stored in the brain you should also be able to read them out.

What are the current limitations or pitfalls in cognitive neuroscience research?

The biggest problem is the limited resolution of non-invasive neuroimaging techniques. If we want to properly understand the human brain then we need to be able to record what all the neurons are doing. And currently that is not possible in healthy humans.

GLOSSARY
FROM BRAIN TO MIND 1

AC
Artificial consciousness may be created by emulating the NCC.

Activation Analysis
The study of changes in brain activation associated with particular stimuli or behaviors.

Allen Brain Atlas:
The Allen Atlas is a project which seek to combine genomics with neuroanatomy by creating gene expression maps for the mouse and human brain.

Cognitive Neuroscience
The discipline that investigates the neural correlates of psychological processes using neural imaging tools.

Connectivity Analysis
The study of 'communication' between brain regions, used to explore how different parts of the brain share information.

Deductive reasoning
Process of reasoning from one or more premises to reach a logically certain conclusion.

Experimental approach
Procedure carried out to support, refute, or validate a hypothesis using the scientific method.

Experimental Psychology
The study of behavior and mind through the application of the experimental method.

Mind-Body Problem
What is the relationship between our physical body and our mind?

Modern Neuroscience
How does a brain give rise to a mind? Consciousness has become a hot topic for brain scientists.

NCC
The neural correlates of consciousness (NCC) constitute the minimal neuronal mechanisms jointly sufficient for any one specific conscious percept.

Neuromania
The appeal to the brain, as revealed through the latest science, to explain all aspects of human behavior.

GLOSSARY
FROM BRAIN TO MIND

1

Neuroskepticism
Distrust on inferences that reach-out beyond the brain into society, politics, economics, etc.

PET
Very Low Temporal resolution, Intermediate Spatial Resolution.

Spatial resolution
Precision of a measurement with respect to space. High spatial resolution allows to determine the exact location of a change in brain activity.
There is usually a trade-off between temporal and spatial resolution.

Temporal resolution
Precision of a measurement with respect to time. High temporal resolution allows to determine the exact timing of very fast changes in brain activity.

Turing Test
Will a machine be able to exhibit intelligent behavior equivalent to, or indistinguishable from, that of a human?

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02

Neural bases of human cognitive processes and behavior

02 — SYNTHESIS

02 — SYNTHESIS

124

Motor control requires a cooperative interaction between the central nervous system and the musculoskeletal system.

Actions and motor control

132

Learning a new language leads to a functional and structural reorganization of the brain.

Language and communication

140

Decision-making belongs to complex cognitive processes, named “executive functions”, which form the management system of the brain.

Decision making and other executive functions

150

It is commonly assumed that humans can display six basic emotions: happiness, surprise, fear, anger, disgust and sadness.

The emotional and social brain

The brain at rest

Even when we are at rest (i.e., our brain does not receive any sensory input and is not involved in any specific task), the neurons display some activity and consume energy. Many scientists have long assumed that much of the brain activity occurring when an individual is at rest, may represent nothing more than random noise. However, in the last decades, neuroimaging experiments have clearly shown that a great deal (more than 90%!) of meaningful activity occurs in the brain when a person is apparently doing nothing at all. Indeed, initial experiments performed in 1990s, showed that when your mind is at rest -when, for instance, you are daydreaming quietly on a chair-, different parts of the brain are metabolically active and communicate with each other.

This group of interacting areas has been called 'default mode network' (or DMN), because it is supposed to represent the 'default' activity when we are not engaged in particular tasks.

Default Mode Network or DMN
Set of interacting brain areas that show a high level of activity during wakeful rest.

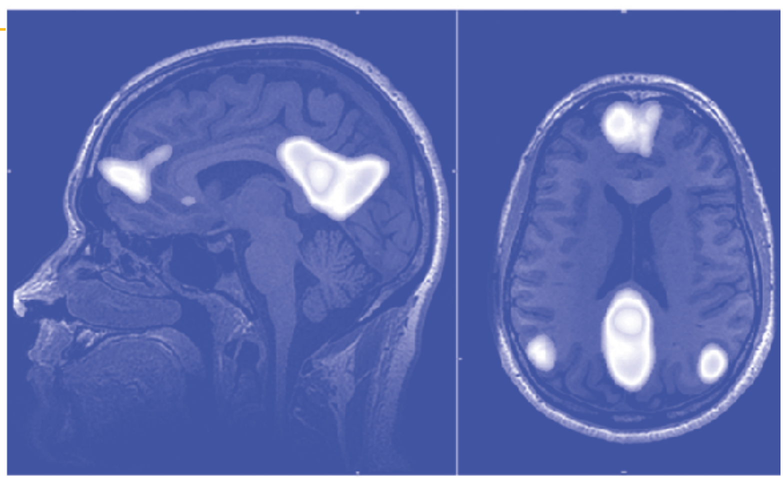
Task Positive Network or TPN:
Set of interacting brain areas that show high levels of activation during attention-demanding tasks in functional imaging studies.
These regions are 'anti-correlated' with DMN.

The default mode network (DMN) is a set of interacting brain regions that are more active when a person is not focused on the outside world.

The main fundamental hubs of the DMN include anterior (medial prefrontal cortex) and posterior (posterior cingulate cortex and precuneus) areas located on the medial face of the two brain hemispheres, and areas located posteriorly and laterally (right and left the angular gyri). These areas are commonly active when a person is not focused on the outside world, such as during mind-wandering, or when the individual is thinking about himself, thinking about others, remembering the past, or making plans for the future. When we focus our attention on a particular task, activity within the DMN decreases, while activity in other brain networks, such as those involved in attention control, increases. Such change is believed to represent a 'switch' of cognitive focus from internal to external processes (events, stimuli, interactions, etc.). Interestingly, several studies showed that our brain spontaneously switches between these two functional networks every 20-30 seconds (unless voluntary control or arousing stimuli intervene), with potential effects on our ability to perceive and integrate external stimuli.

The DMN has been hypothesized to be involved in the generation of spontaneous thoughts, mind-wandering and creativity.

Default Mode Network
A brief Introduction



→
Areas of the Default Mode Network

Neuroscientific research showed that activity in areas of the DMN is modulated by interventions such as acupuncture, drugs, meditation, sleep and sleep deprivation.

Moreover, alterations of the DMN are typically associated to disorders including Alzheimer's disease, autism, schizophrenia, depression, chronic pain and others.
Since assessment of activity in the DMN poses no cognitive demands for the subject (vs. psychological experiments based on behavioral tasks), measurements can be easily

performed using the so called 'resting-state' experimental paradigm (using functional magnetic resonance imaging, fMRI), even in impaired individuals.

Given these premises, researchers proposed a potential use of the resting-state paradigm for obtaining diagnostic and prognostic information about patients, for longitudinal studies of treatment effects, as well as for patient clustering in heterogeneous disease states.

Resting State Paradigm
This is an approach of functional brain imaging that is used to evaluate regional interactions that occur when a subject is not performing an explicit task.

Task-Based Paradigm
This is an investigation approach in which specific brain functions are probed using pre-defined tasks involving the passive or active processing of stimuli.

Of note, the DMN is not the only network that we can study using a resting-state paradigm. In fact, areas of the brain that have strong anatomical and functional connections, tend to continue communicating with each other even at rest, when we are not specifically 'using' those brain areas to complete a task. Therefore, using specific analytical approaches, researchers can investigate the properties of different brain networks, including the visual, motor, auditory, language-related and attention-related networks, without the need for complex stimulation paradigms or definition of specific tasks. Clearly, when we are just sitting on a chair, doing apparently nothing, there is much more going on than meets the eye.

Possible future development...

- Creation of large databases of resting-state brain activity patterns from healthy and clinical populations to foster future research and allow the mapping of inter-individual brain functional and anatomical differences.
- Use of resting-state brain activity indices as predictors for psychometric or behavioral characteristics of individuals.
- Use of resting state brain activity indices to aid diagnosis of pathological conditions.

The brain at rest: What is in the future?

Since alterations in 'resting-state' brain activity have been shown to occur in several pathological conditions, their identification could provide an important contribution to many aspects of clinical practice. The most evident advantage of resting-state measurements of brain activity is that they have no specific cognitive demands. Thus, contrarily to indices of brain activation obtained during psychological and behavioral experiments involving particular tasks or stimulation paradigms, resting-state measures can be easily obtained even in cognitively impaired persons and in children. In order to maximize the accuracy and reliability of information that can be derived from resting-state measurements, scientists around the globe are currently gathering their efforts to create large databases including data collected in both healthy individuals and clinical populations. These databases will allow a precise mapping of inter-individual brain functional and anatomical differences and will facilitate the identification of specific traits associated with a wide number of conditions. Thanks to these efforts, in a near future, doctors will be able to use results of resting-state neuroimaging exams to obtain information that will help them in the diagnosis, follow-up and prognosis of many psychiatric and neurological disorders, including Alzheimer's Disease, Parkinson's Disease, Autism, Depression, Bipolar Disorder, and many others. Several lines of investigation also provided evidences indicating that differences in resting-state brain activity may exist across healthy individuals and that such variability may reflect differences in personality traits and/or propensity to specific behaviors. In this light, resting-state measurements in conjunction with other indices, such as those obtained from psychometric questionnaires, will also allow predicting attitudes and future behaviors of particular populations sharing specific psychometric and/or demographic characteristics.

Attention and awareness

Attention is the behavioral and cognitive process of selectively focusing on a discrete aspect of information while ignoring all other sources of information. Different stimuli can either capture our attention involuntarily (exogenously) or we can voluntarily decide to direct our attention towards them (endogenously). As it is humanly impossible to process all stimuli equally well at the same time, we shift our attention to one task and decrease our attentional resources for processing irrelevant distractions. This 'selective attention' is what allow us to focus on our conversation partners at cocktail parties amongst many voices, loud music and clinking glasses. Interestingly, the unattended stimuli are not completely blocked, but only weakened. If a very important word to us, such as our own name, is mentioned in a different circle of conversation close to us, it may grab our attention. In the psychological literature, this is called the 'cocktail party effect'.

However, there are not many words that are as important to us as our own name, therefore, in most cases, selective attention limits the amount of information that our brain can process at any given time. As an example, you may decide to make a phone call while driving through busy traffic. The call might distract you from noticing a red traffic light, making you cross the junction and potentially cause a traffic accident.

This is a real-life example of what psychologists call 'inattentional blindness'. We fail to perceive an unexpected stimulus that is in plain sight just because the focus of attention is directed towards other aspects. You are so focused on your task (calling your friend) that you forget to watch the traffic closely. Similarly, researchers demonstrated that paying attention to a specific stimulus may determine a failure in detecting a second stimulus that is presented close in time to the first. This particular phenomenon is called 'attentional blink'.

Whodunnit?
Test your awareness

Some stimuli have the power to immediately capture our attention: for example hearing our own name, or seeing a face. Indeed, such stimuli clearly have a relevant social meaning and are thus given priority by our brain!

EyeTracking on Mona Lisa
Where did the people look at Da Vinci's famous painting

→ Eye-tracking heat-map

The relationship between attention and consciousness is at the same time very intimate, but also highly contested. When we attend to an object, we become conscious of its various features; when we shift our attention away from it, the object fades from consciousness (however, it is still unclear whether we can become conscious of an object without attending to it).

Understanding the role of attention in consciousness is fundamental for our comprehension of how our brain builds each of our conscious experiences.

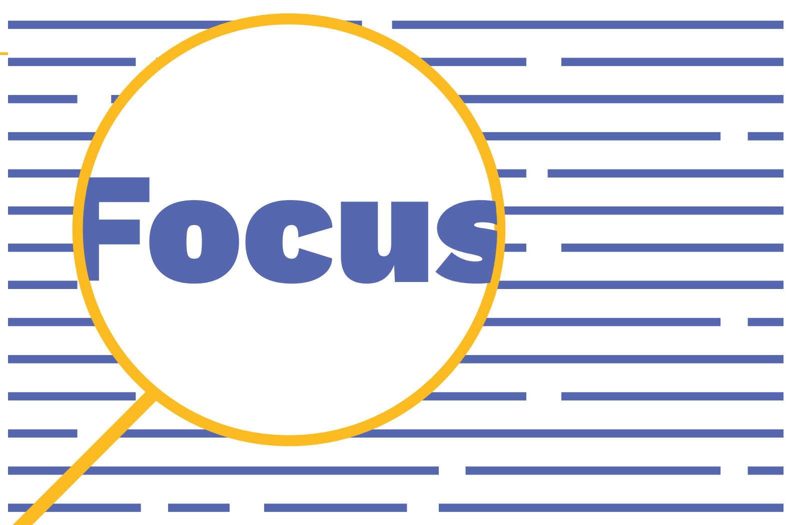
Since attention occurs simultaneously through multiple sensory modalities (i.e. visual, auditory, tactile), we can define attention as either modality-specific or shared across many different sensory processing pathways (i.e. 'cross-modal' attention). Neuroimaging studies have suggested that two brain networks connecting parietal (posterior) and frontal (anterior) brain areas may be responsible for general attentional processes: a more dorsal network is involved in top-down, voluntary deployment of attention, whereas a more ventral network is called into play during stimulus-driven (bottom-up) attentional shifts.

Exogenous orienting attention
Automatic shift of attention caused by an external stimulus.

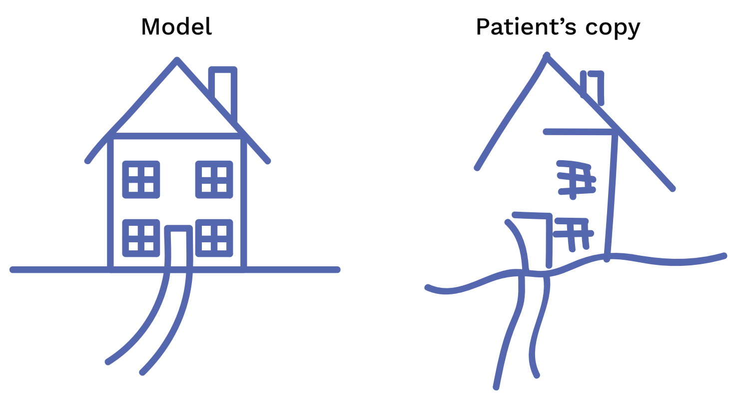
Endogenous orienting attention
Intentional allocation of attentional resources to a predetermined location or space.

Attention is crucial to interact with and understand the world around us.

Khan Academy
Divided attention, selective attention, inattentional blindness and change blindness



Brain lesions involving specific areas of the brain responsible for attentional processes can significantly change our way of perceiving the world. For instance, patients who develop the so-called ‘hemispatial neglect’ (usually after lesions affecting the right parietal cortex) typically show a deficit in attention and awareness that lead them to ignore the left side of their bodies and even the whole left side of their visual fields.



In the era of smartphones, many of us find themselves multitasking. It has been shown that dividing attention across different tasks impairs memory and cognitive performance and increases stress levels. However, people think they can (and some of them might actually) still selectively focus on the most relevant facts. All potential benefits of multitasking come at a cost. For instance, a recent study in a driving simulator has shown that talking on the phone whilst driving can bring you and others into dangerous situations by slowing down your reaction time significantly. In another recent study, students who generally spend less time simultaneously reading e-mails, surfing the web, talking on the phone and watching TV performed best in memory and task-switching tests. This does not only apply to students, but also employees. When people are limited to checking their email just three times per day, their stress levels decrease and their productivity increases.

The brain cannot fully focus on each individual task when multitasking, thus people take longer to complete each activity and are predisposed to error.

Khan Academy
The spotlight model of attention and our ability to multitask

«There is time enough for everything, in the course of the day, if you do but one thing at once; but there is not time enough in the year, if you will do two things at a time.»

Philip Stanhope, *4th Earl of Chesterfield*

Possible future development...

- Adaptation of devices of common use (e.g., smartphones) to minimize potential distraction and optimize multitasking.
- Creation of new tools/devices that may help our brain to maintain the focus of attention on specific aspects of interest.
- Identification of potential strategies to increase attentional skills in patients with pathological alterations of attention (e.g., ADHD, dementia, hemineglect, etc.).

Attention and awareness: What is in the future?

Attention and awareness are essential for most of our daily activities. However, in particular tasks, such as during car driving or when a surgeon is performing a delicate intervention, a temporary drop of attention may lead to terrible consequences.

The well-known risks related to lapses in vigilance and attention led researchers and industries to focus a growing effort on the development of novel techniques for real-time monitoring of vigilance states and cognitive resources in humans. In a near future, such methods will allow to monitor the state of an individual (e.g. a driver, a surgeon) and alert him/her when an increased risk for attention lapses is detected. Preliminary applications of these techniques are already available today: for instance, devices that measure levels of vigilance and attention are currently tested in modern cars with the aim of reducing the risk of accidents.

On a different perspective, knowledge obtained from the study of attention mechanisms will also allow developing tools aimed at increasing our ability to focus on specific aspects of interest. Common noise-cancelling headphones already represent a relatively simple example of such tools; they filter out sounds that may distract us from other activities, thus allowing us to better focus on what we listen in the headphones, or on what we perceive with our other senses. Indeed, when our brain is bombarded by many sources of information, it tends to spontaneously shift attention from one source to another, with a consequent loss in cognitive performance. Intelligent technologies in smartphone, computers, and other devices could be used to automatically recognize different contexts and conditions and to adapt the produced number of potential distractors (e.g., alarms, notifications, calls) in order to minimize undesired focus shifts and optimize multi-tasking. However, research showed that the ability to focus our attention could be also trained, and some 'gamified' approaches have been already suggested as an aid for this training process. Some devices, for instance, can measure brain activity (usually through an electroencephalogram) and inform the individual about his/her level of focus. The reaching of a specific type of brain electrical activity typically leads to the attainment of a particular goal in the game. This mechanism produces a reward for our brain, thus reinforcing and stabilizing newly acquired attitudes or behaviors. In the future, a more complete knowledge of attention mechanisms and the creation of more accurate brain reading devices will allow improving current strategies for attention training. Such technical and theoretical developments will not only be important for healthy individuals but also in patients with pathological alterations of attention, such as those with attention deficit hyperactivity disorder (ADHD), dementia, hemispatial neglect, and others.

How we perceive and represent the external world

Nature has endowed humans with five basic senses, touch, sight, hearing, smell and taste, which provide the possibility to detect environmental energies and infer characteristics of the surroundings. Scientists distinguish between the words sensation and perception. These terms are complementary but refer to different phenomena. The word sensation is used to describe how we are informed about the environment through the senses. It refers to the process of converting a stimulus into a neural signal. Once this information is sent to the brain our perception is built. Perception relates to how sensations are interpreted, integrated and ultimately to the way we make sense of the world around us. Perception occurs only in our minds.

The bases of sensations are receptors and they have a common fundamental mechanism across all different senses: the process of transduction of environmental energies, as lights or sounds, into electric discharges. Here is how the senses work.

Sensation
This term refers to how we are informed about the environment through touch, taste, sight, sound, and smell.

Perception
This term refers to how sensations are interpreted to make sense of the world around us.

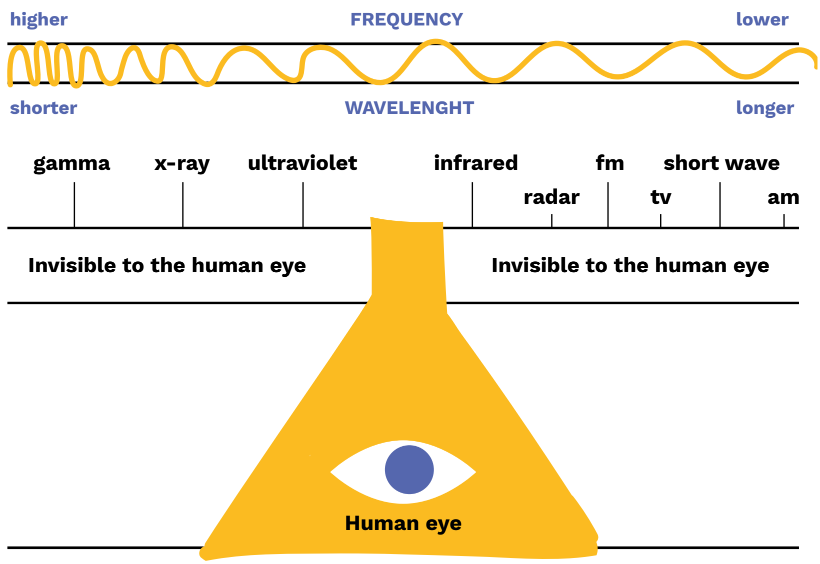
Sight
Sensory experiences depend on receptors characteristics. For instance, what we call light is only the narrow band of the electromagnetic spectrum that can be detected by the human eye. If snakes would talk, they would disagree with our definition of light. Indeed, thank to particular protein channels, some species, like vipers and pythons, at night can detect infrared radiation, and therefore 'see' the heat of a prey.

Two types of cells located in the retina, called "cones" and "rods", enable human light perception. While cones provide the possibility to see colors and details in central vision, rods are more responsible for peripheral vision and motion perception. Scientists have acknowledged that the eye is smarter than previously thought. Complex processing involved in seeing occurs already within the retinal neurons.

Khan Academy
Visual sensory information; Processing the Environment

This complexity partially explains why retinal prosthesis, alternatively called "the bionic eyes", represent today a very limited solution to blindness and only provide a bare sensation of light presence or absence.

The electro magnetic spectrum



The visible spectrum
The portion of the electromagnetic spectrum that is visible to the human eye. A typical human eye responds to wavelengths in the vicinity of 430–770 THz.

Poppy Crum
TED talk:
"Your reality might not be mine: Sensory Perception and Empathy"

The electromagnetic radiation that falls in the range of wavelengths and is visible to the human eye is called 'visible light' or simply 'light'. However, this is only a tiny portion of the electromagnetic spectrum!

BBC One
How moken children see with amazing clarity underwater - Inside the Human Body

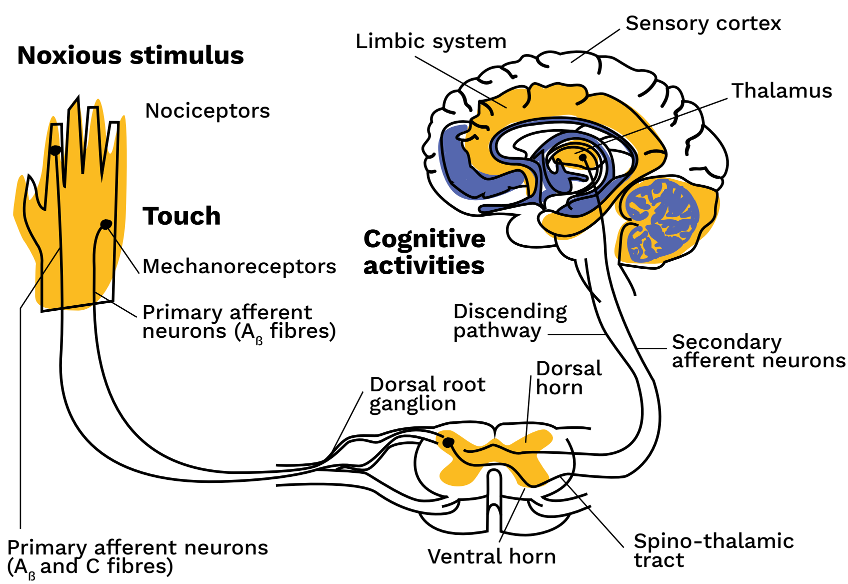
The study of vision has revealed that the eyes functioning adapts to environmental conditions. Children of the Moken people, small nomad tribes living on islands in the Andaman sea, spend long part of the day underwater to pick up food, as shells and clams. Studies on their visual abilities have shown that the Moken children have grater skills in seeing details underwater as compared to children born somewhere else.
A study by a Swedish University showed that these children are able to change the size of the pupil and the shape of the eye-lens in order to see clearly either under and above water.

Touch

Touch depends on multiple receptors on the skin which provide pressure, temperature, vibration and pain. It is the first sense that develops in humans. Touch does not solely inform about the environment. For instance, touch seems to have a remarkable role in functional brain development in infants. Today, massages are adopted as a therapy to promote better development in newborns at risk, like preterm babies (babies born prior to the due date). Tactile sensations seem to be more than feelings in adults as well. For instance, Dr. Ackerman at the MIT in Boston revealed in a study published on Science in 2010, that touch can influence how people think or make decisions. People were asked in different studies to take a number of decisions while having tactile experiences.

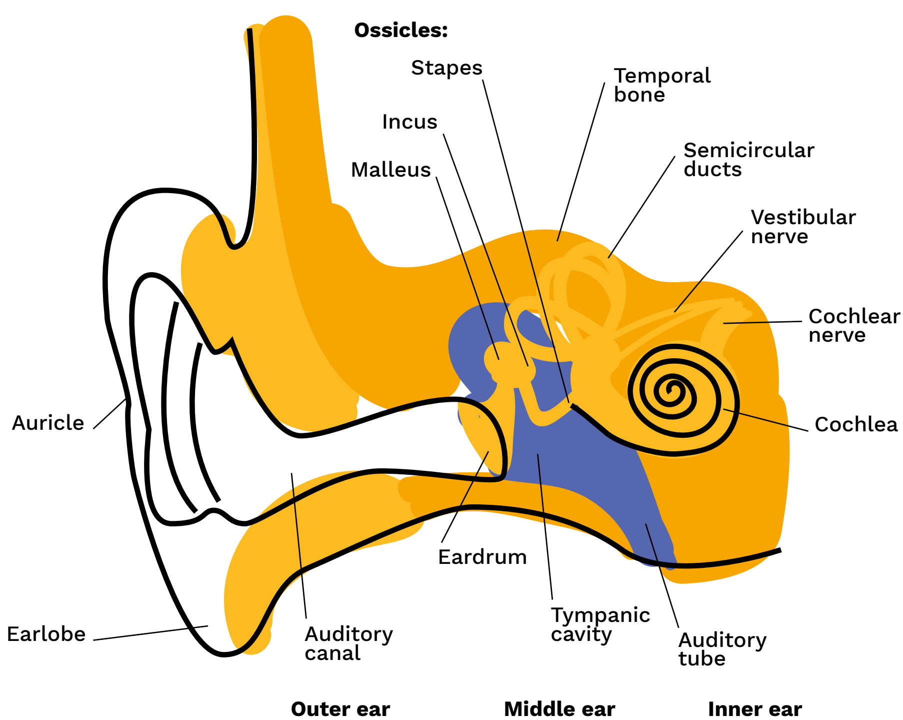
As an example, if a person held a heavy or a light clipboard, his/her judgments were influenced in different ways. Holding a heavy clipboard led to more serious rating of the work of a job candidate, or to be more incline to be active on social issues, such as pollution. Similarly, sitting on a soft or a hard chair was shown to influence negotiations.

→ Pathways from touch and pain receptors to the brain



Hearing
Sounds are waves travelling through the air. Such energy reaches the inner ear after having travelled into the external ear, through the eardrum and three tiny bones. Within the inner ear, the cochlea, a spiral-shaped receptor organ which is filled with liquid, possess tiny hair cells. They swing with vibrations and convert motion into electrical pulses. These are then sent to the brain by the auditory nerve. The inner ear does not only allow hearing. Humans have in the inner ear the vestibular complex as well, which allow the perception of balance and motion. A common cause of motion sickness is caused by a conflict between the visual and the vestibular systems, like when we read in a car, or sail on choppy waters. The eyes do not perceive the motion while the vestibular system does.

Anatomy of the Ear

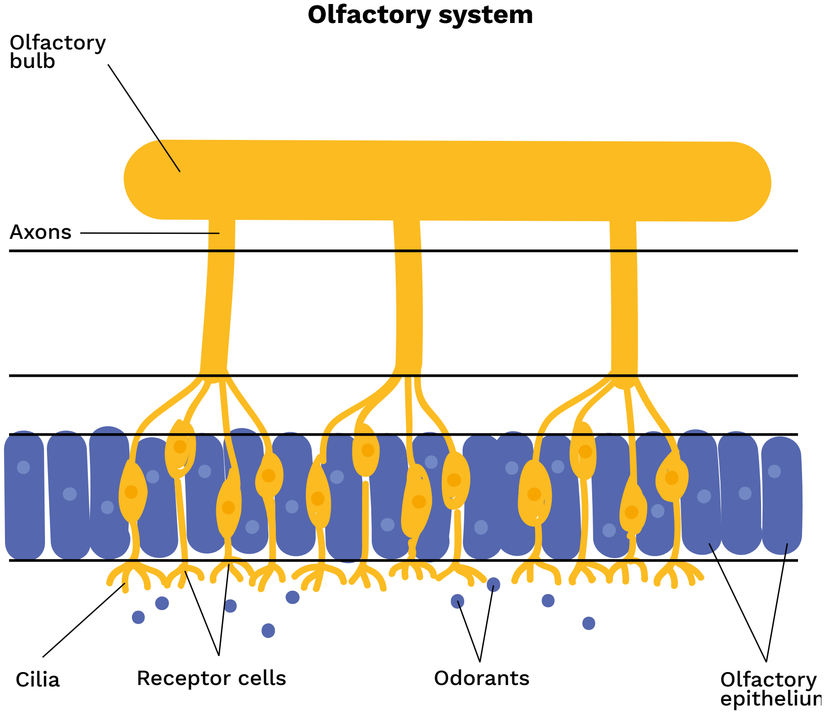


Smell

On the roof of the nasal cavity humans have the olfactory cleft, which contains about 400 smelling receptors. These are directly connected to the olfactory bulb and fossa, the parts of the brain which sense smells. A recent literature review by Dr. McGann published on the journal Science, has revealed that humans are just as good as dogs and rodents in the sense of smell and can discriminate about 1 trillion different odors.

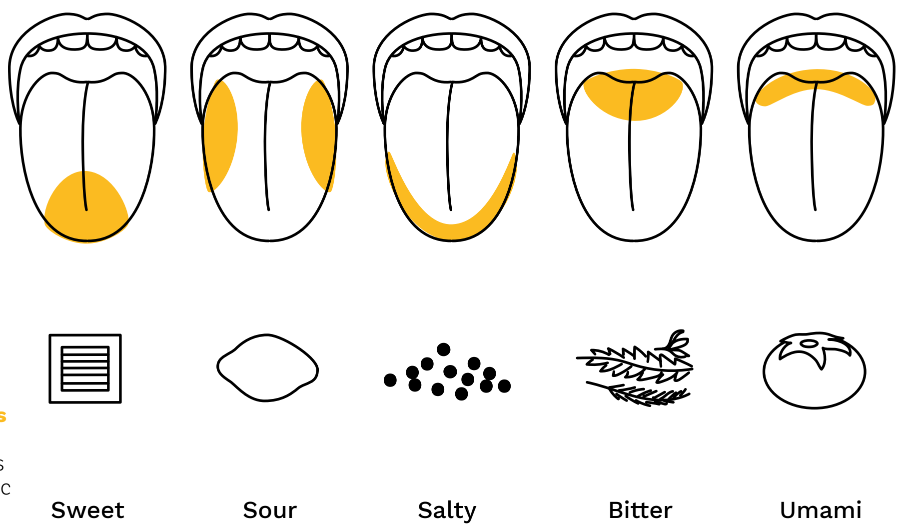
The old view that humans are bad smellers seem to have originated by the different behavior and number of smell receptors when comparing humans and other mammals.

Olfactory system



Taste

While the sense of taste has traditionally been divided into sweet, salty, sour and bitter, a fifth taste was discovered in recent years and termed umami or savory. This latter taste corresponds to glutamate, tomatoes or soy sauce for instance are rich in umami components. Most of the receptors which allow taste perception, taste buds, are on the tongue. All parts of the tongue can sense the five tastes and it is only a myth that the tongue is divided in specific flavor-zones.

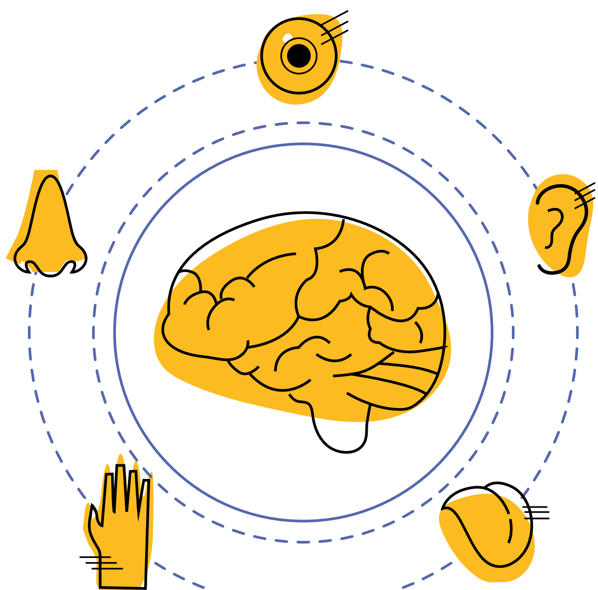


→ **The five tastes**
It is only a myth that the tongue is divided in specific flavor-zones!

The sixth sense, Proprioception

In addition to the traditional five senses humans have the sense of perceiving body parts position in space. Thank to this sense we can touch the tip of our nose with the eyes-closed. This sense is so closely linked to motion, that when we remain for enough time completely still, with the eyes closed, we tend to lose the knowledge about the precise location of our limbs.

Multisensory perception
The study of perception has traditionally been conducted by isolating the different senses, considering them as independent functions organized in pathways and modules for specific forms of analysis (e.g. what an object is vs. where an object is). Only recently, Cognitive Science and Neuroscience have started to address the questions about how information from different senses is integrated and how much the senses influence each other.



Human senses do not work in isolation. Today we know that senses heavily interact with each other. Multisensory research is the field of cognitive science that investigates such interactions or interplays.

It is well established that a sensory modality can dominate the others with respect to specific information processing. Sight for instance is the leading modality when considering space, while hearing dominates in the time domain. These dominances are the reasons of strong perceptive illusions, such as the 'ventriloquist', in which the voice of a speaker is captured by the moving mouth of a puppet. Similarly, while we watch a movie we feel that the voice originates from the mouth of the actor and not by the loudspeakers. The interaction between senses are also evident in more familiar contexts.

Does it taste white or red?

There is strong evidence that the color of food influences the taste perception, but this is not all. More surprisingly, multiple studies have shown that even wine experts change their description of the aroma of a white wine if the color is artificially changed to red with a flavorless colorant!

It might seem odd, but powerful models to study sensory systems are the sensory deprived (e.g. blind of deaf individuals) as well as individuals who experienced the restoration of a sense (e.g., cochlear implanted). Thank to them much has been understood about the function of brain areas devoted to sensory processing, as well as about their ability to adapt to different environmental conditions. It is remarkable how, in case of blindness, visual brain areas increase their responsiveness to tactile or auditory information. Indeed, for instance, the visual cortex of congenitally blind individuals is known to contribute in Braille reading.

Fundamental models for investigating how the brain processes and integrates sensory information are the lack of a sense or its restoration.

David Eagleman
Can we create new senses for humans?

The fundamental role of the brain in constructing a representation of the world appears clear when hallucinations, imagination or phantom percepts are studied. Brain activations are just enough to elicit seemingly real percepts.
Damages to small portions of the brain can lead to dramatic changes in what we see or hear, like the famous patient affected by visual agnosia described by the neurologist Oliver Sacks: "The man who mistook his wife for a hat".

Possible future development...

- Creation and use of validated, non-intrusive sensory substitution devices for people with sensory deficits.
- Use of neuroimaging-based indices to guide therapeutic or rehabilitative choices in patients with sensory deficits.
- Creation of new devices able to capture signals that are not normally perceived by our brain and integration in existing sensory and cognitive systems.

How we perceive and represent the external world: What is in the future?

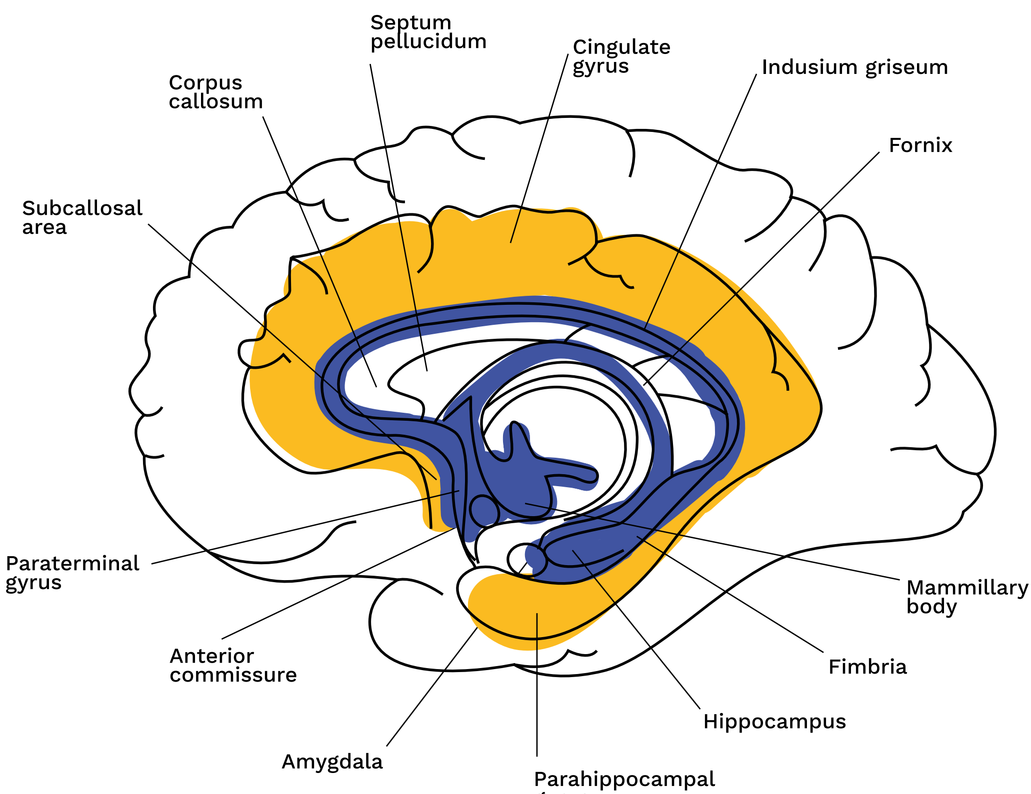
The study of sensory perception has led to fundamental advancements in our understanding of how our brain processes and integrates distinct sources of information to extrapolate abstract, sensory-independent concepts and ideas. It is now known that some parts of the brain dedicated to the processing of sensory information undergo specific changes during development and that these changes require a direct exposure to a particular sensory modality. Thus, for instance, individuals that are blind since birth (e.g., due to congenital cataract) and that recover sight in adulthood (e.g., through surgical intervention) may not be able to ever achieve a visual experience comparable to that of individuals who have seen since birth. A better knowledge of how the brain develops with or without distinct sensory experiences will lead in a near future to the identification of neuroimaging-based indices that will allow guiding therapeutic or rehabilitative choices in patients with sensory deficits. For instance, we may become able to evaluate the optimal age at which a sensory-recovery intervention could be performed and to predict the post-intervention quality of perceptual recovery. On a different perspective, researchers have been also able to demonstrate that areas involved in the extraction of abstract concepts do not require sensory experience to develop. Thus, the same concept can be correctly interpreted and represented by our brain regardless of the sensory modality through which information reaches it. Such knowledge has been instrumental for the creation of (still rudimental) 'sensory substitution device' for patients with sensory deficits; such devices are able to collect information from a lost sensory channel and transform it to make it available to one of the remaining sensory modalities. Applications of these approaches are still preliminary and often not well tolerated by their users, but future technological and theoretical advances will likely increase their social and clinical value. By taking advantage of the same technologies and devices, in a near future, all individuals could become able to "capture" signals that are not normally perceived by our brain, integrating them in existing sensory and cognitive systems. Thus, for instance, we could become able to "perceive" naturally and seamlessly thermal information as done by some animals, such as snakes, or to expand our senses, for instance by "seeing" portions of the electromagnetic spectrum that normally lie outside the limits of visible light. We can easily imagine a natural integration of these systems in currently developed devices for augmented reality (i.e., technological devices that provide a composite experience based on the superimposition of computer-generated information and the user's sensory experience).

How we remember and how we learn

The ability to learn and remember information about the world around us is essential for our interactions with other individuals or with objects, but also for our own sense of self. Indeed, if we could not remember past events, we could not learn or develop language, relationships, nor a personal identity. Remarkably, our brain has the ability to retain an enormous quantity of details, sometimes with ease, other times with enormous effort. What does our ability to remember the first day of school or the familiar smell of a particular place depend on?

Imagine waking up one day having lost the ability to learn novel information and remember it for more than a few minutes: every experience would be alone in itself. This is exactly what has happened to the famous patient H.M., who started suffering severe memory deficits after an experimental surgery was conducted on his brain with the aim of treating epilepsy. The portion of brain removed included a bilateral region called "hippocampus", and located in the middle temporal lobe.

The hippocampus plays an important role in the formation of new declarative memories that can be explicitly verbalized about experienced events.



Anterograde Amnesia
Loss of the ability to create new memories.

Retrograde Amnesia
Loss of memory-access to events that occurred in the past.

After the surgery, H.M. developed severe anterograde amnesia (he could not form new explicit memories) and a moderate retrograde amnesia (he could not remember many events occurred in the 11 years before surgery). Thus for instance he could do the same crossword puzzle again and again, if the words were erased, as if to him it were a new one each time. However, his ability to form long-term procedural (implicit) memories was intact. Thus, H.M. could, for instance, learn new motor skills, despite not being able to remember learning them. The unlucky case of H.M. has contributed enormously to our understanding of the anatomo-functional bases of memory and of its relation to other aspects of cognition and behavior.

Procedural memory
Memory of how to do certain things. It is also called implicit memory.

Declarative memory
Form of memory that involves conscious recollection of previously acquired knowledge. It is also called explicit memory.

Khan Academy
Information processing model: Sensory, working, and long term memory

Memory is defined as the ability to store information in our brains, while learning is the process that allows to acquire new knowledge.

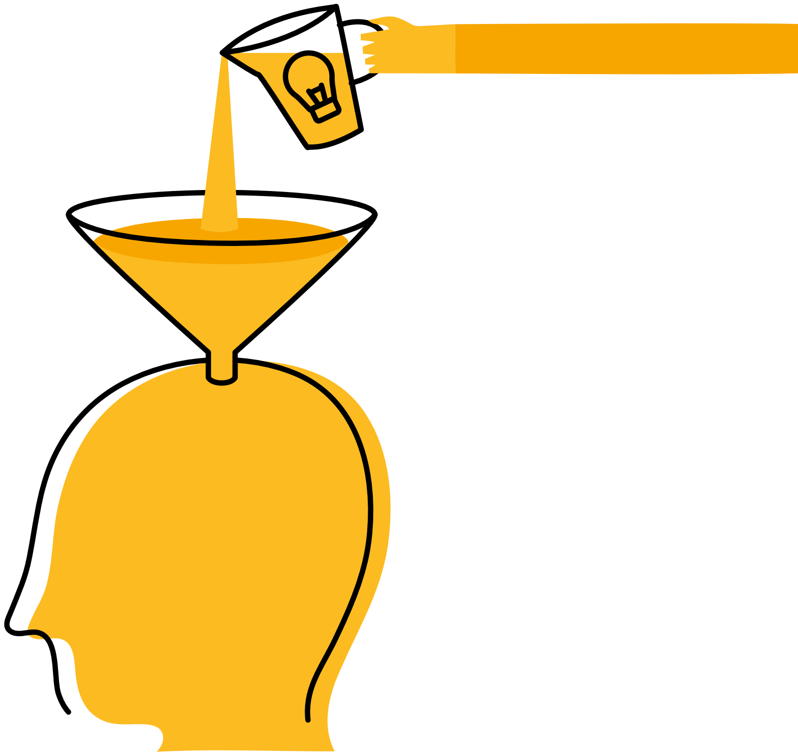
The study of memory functions has always attracted attention of researchers and is still a fundamental line of brain research. The approaches by which neural correlates of learning and memory are investigated in the neuroscience field are many: individual clinical cases (like the one of H.M.) are studied to determine what is and what is not lost in amnesia; neuroimaging techniques are employed to investigate in healthy subjects the anatomical and functional substrates of memory formation or recall; animal models are used to explore the cellular mechanisms underlying all aspects of memory and learning.

Long-term Memory
Form of memory in which informative knowledge is held indefinitely. Explicit and implicit forms of memory are types of long-term memory.

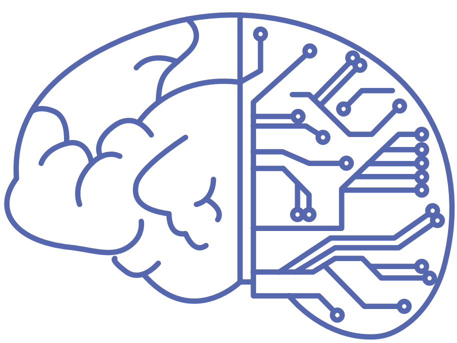
Short-term (Working) Memory
Cognitive system with a limited storage capacity that is responsible for temporarily holding information available for processing. It is important for the guidance of decision-making.

Catharine Young
How memories form and how we lose them

Traditionally, memory models distinguish between sensory memory, short-term memory and long-term memory, based on the time for which the information is retained.
The information retained for a significant length of time is called long-term memory and a functional division has been proposed, based on the characteristics of the stored information, between declarative (explicit) memory and procedural (implicit) memory. When you are trying to intentionally remember something (like a shopping list), this information is retrieved by your explicit memory. Instead, singing a familiar song, or driving a car, since you don't have to consciously recall how to perform these tasks, belong to the category of implicit memory.



Brain structures that support various memory processes differ depending on the type of information to be retained and on how the information is coded and recovered. The memory system includes the medial temporal lobe, which shapes and consolidates new memories, the prefrontal cortex, involved in coding and retrieving information, and other cortical and subcortical structures, that take part in various modes of learning. Different from amnesia is memory deterioration, that is observed with normal aging: it seems that there may be deficiencies in coding and recovery mechanisms, while the storage would not seem to be significantly compromised.



The human memory has been estimated to have a storage capacity of 1 petabyte, corresponding to 1,000 terabytes (the most common size of modern computer hard-disks). Just consider that 1 terabyte of data may contain up to 2 million photos or 500 hours of video!

In spite of the huge amount of the information that our brain can store, we may experience difficulties at storing or retrieving a particular piece of information (at any age). Indeed, while attention is certainly important for storing a particular information, the simple voluntary intention to store or retrieve an information is often insufficient. On the other hand, it is common observation that memories associated to a particularly strong emotional content (either positive or negative) are invariably the most easy to remember. For instance, most individuals in eastern countries can easily recall where they were or what they were doing during the 9/11 attack. Specific techniques may also facilitate memory-related processes. These include approaches based on internal (mnemonics) or external (taking notes, using alarms and the famous knot to the handkerchief) strategies.

One of the best known and oldest techniques, used to memorize individual items in sequence is the method of loci (from the Latin term “locus”, which means “place”). We proceed with the creation of a sequence of places (loci), better if well known (such as all the places I meet on the way from home to work). In the material encoding phase, the first item to remember must be associated with the first place in the list, the second item in the second place and so on. When we have to recall the material we will have to mentally retrace the sequence of places starting from the first, which constitutes the cue and which will favor the memory of the first item, and proceeding in the same way to the last place to remember the last item. In other words, this strategy takes advantage of the natural ability of our brain to create associations and to follow them.

Possible future development...

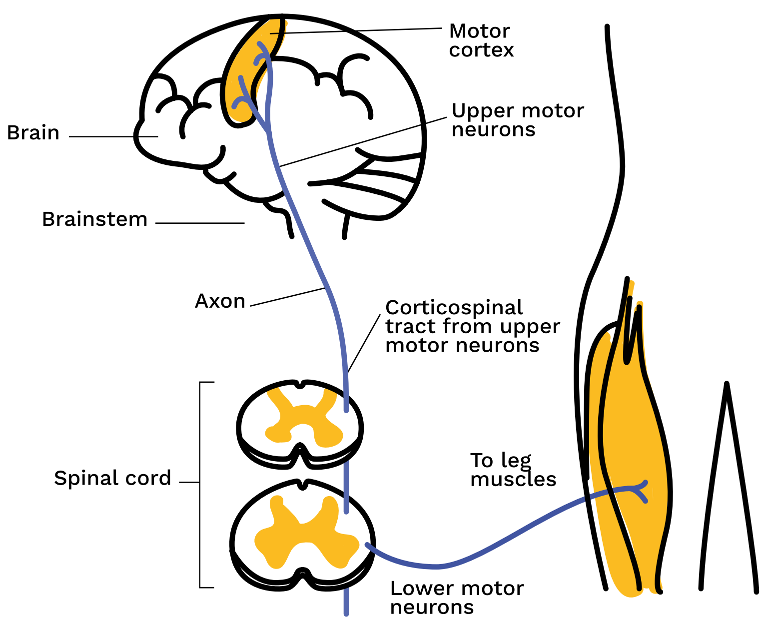
- Identification of mechanisms for the potentiation (e.g., through pharmacological or direct brain stimulation) of memory mechanisms to facilitate/accelerate learning.
- Identification of mechanisms for the de-potentiation of traumatic/negative memories in pathological conditions (e.g., post-traumatic stress disorder).
- Identification of mechanisms that may allow a more efficient (faster, more precise) recovery of previously stored information.
- Identification of strategies that may slow-down, or revert, memory alterations that accompany physiological and/or pathological aging.

How we remember and how we learn: What is in the future?

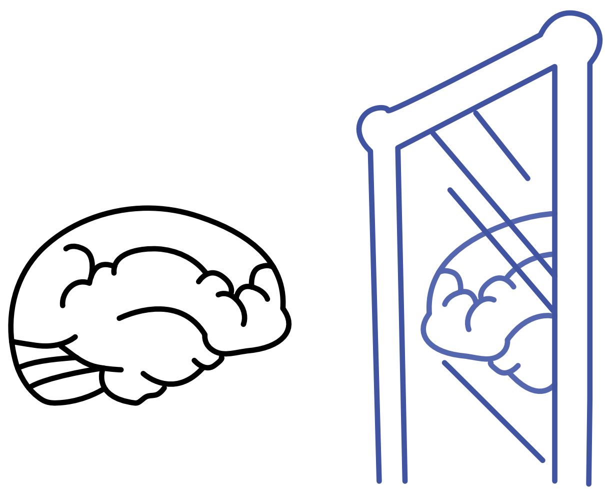
Memory and learning skills are becoming increasingly important in our modern society, which imposes high levels of productivity and efficiency.
For this reason, human beings have tried to develop strategies for improving their memory and learning skills in both physiological and pathological conditions. These attempts led to the definition of 'mnemonic techniques' allowing to optimize the organization and storing of new memories.
Some of these approaches took advantage of cognitive and psychological observations, such as those involving a reinforcement of memories associated with visual images or with a strong emotional content. Other approaches dealt instead with individual preferences and inclinations, by trying to identify the best learning strategies as a function of specific psychological traits that may render, for instance, more prone to learn through images or videos, rather than by reading a series of notions. In the neuroscience era, researchers are now trying to merge behavioral, psychological and brain-related knowledge in order to define novel approaches for the potentiation of memory encoding and storage, but also for a more efficient recovery of previously stored information.
The study of pathological conditions associated with memory impairment (e.g., Alzheimer's disease) led to the identification of drugs that may have a beneficial effect not only on patients but also in healthy individuals. Indeed, these drugs are already becoming of common use in healthy individuals who have to deal with highly competitive and demanding environments (e.g., university students). Novel techniques allowing for a direct stimulation of specific brain areas have been also suggested as a potential approach to strengthening memories, especially during the learning phase.
On a different perspective, we should note that an excessively strong memory could be as negative for our life as a 'bad memory'. A memory that stores any single piece of information may easily generate profound confusion (e.g., between recent and past experiences), as shown by the famous case described in the book 'The mind of a mnemonist', by Alexander Luria. Even in individuals with a 'normal memory', however, some disturbing or traumatic events may remain stuck in mind, despite a desire to forget them.
This happens for example in patients with the so-called 'post-traumatic stress disorder' (PTSD). Thus, researchers are not just looking for a way to potentiate memories, but also for methods that may allow their de-potentiation or complete removal. We already know that some drugs, such as those used during surgical procedures, may block the storing of new information in memory for a certain period of time. However, removing memories that are already stored in our brain certainly seems more problematic. As our knowledge about the brain rapidly grows, we can imagine a not-too-distant future in which we could be able to determine which memories should be potentiated and which should be, instead, removed.

Actions and motor control

Our hands are a key element in the interaction between our brain and the world around us: they allow us to actively explore the world through one of our most developed senses, touch, but they also allow us to modify the environment itself, by grasping, moving, beating, etc.
All this is possible thanks to a unique control mechanism that produces a broad range of distinct movements, more fine or gross, simple or complex, based on activation of few muscles or requiring coordination of many muscles in the two hands, limbs or in other parts of our body. Indeed, evolution and the increasing complexity of our behavioral repertoire have led to the development of a wide, deeply specialized machinery devoted to perform motor acts, but also to recognize those performed by others.



The term ‘motor control’ indicates the collection of brain and cognitive processes by which humans and animals activate and coordinate the muscles and limbs involved in the performance of a motor skill. Some regions in the frontal lobe of the brain – defined as primary motor and premotor areas – are directly involved in the production of movements and have connections, mediated by the spinal cord, with peripheral muscles. Other brain areas, mainly belonging to the parietal lobe, are ascribed to the sensory-based guidance of movements: they process and integrate sensory information regarding the position of the limbs and the position, shape and size of the objects actions are aimed at.



Some parts of the frontal and parietal cortex appear to contain a family of exceptional neurons that are activated both when we perform an action (e.g., we grasp an apple) and when we see someone else performing the same act (e.g., he/she grasps an apple). These ‘mirror neurons’ are thought to allow us to readily extract information about the goals and intentions of other individuals, as well as to predict their subsequent behavior, by referring to ‘internal’ models of action.

Years of research on this 'mirror neuron system' have led many scientists to believe that this particular mechanism may be fundamental for action understanding, adaptive behaviors, social interactions, learning by imitation, empathy and theory of mind (ability to understand the intention of others).

Khan Academy
Motor neurons
Muscular-skeletal system physiology
NCLEX-RN

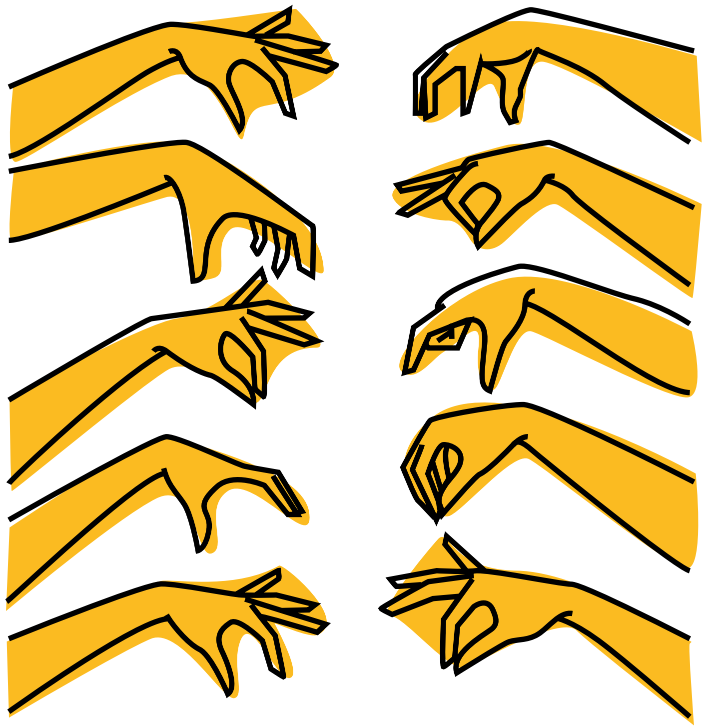
Precise motor control is essential for our ability to interact with the external world. It requires a cooperative interaction between the central nervous system and the musculoskeletal system.

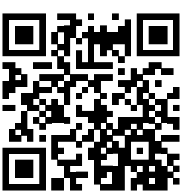
Over the years, the code with which individual motor acts are represented in the regions forming the 'motor control' network has been profoundly investigated. The old view according to which the brain controls individual limb and trunk segments has been challenged by alternative accounts: better, resource-sparing motor commands may rely on the control of groups of muscles or joints which act as functional units (synergies), or on the direct coding of complex gestures with evolutionary meaning (grasping, self-feeding) entirely 'stored' in the primary motor areas of the brain.

Motor Reflex
Fixed neuromuscular pathway that leads to automatic motor responses. A reflex occur on a much faster time scale than what is possible for reactions that depend on perceptual processing.

Motor Synergy
Multi-element system that organizes sharing of a task among a set of elemental motor variables. Synergies are guided in a bottom-up manner by sensory information. They are learned, rather than being hardwired like reflexes.

Motor Programs
Pre-structured motor activation patterns that are generated and executed by the brain. They represent a top-down approach to motor coordination.
Once the program has been executed, it cannot be altered online by intervening sensory information.





Greg Gage
How to control someone else's arm with your brain

Perception is extremely important in motor control because it carries the relevant information about the relationship between the body and the environment, which is used in organizing and executing actions and movements. For instance, our brain needs to know whether a mug of coffee is on our desk within or out our reach, or whether it has a handle or not (and if it has one, on which side it is), in order to plan the most efficient and accurate movement to reach the cup and drink a sip from it. Other factors, like how much coffee is in the mug and what material the mug is made from, may also influence the brains calculations... and sometimes, may even trick it.

This is what happens, for instance when we try to lift something that is apparently very heavy (e.g., a ball that seems made of iron) but actually is not (e.g., because the ball is actually made of plastic). In that case our action will be inappropriate to the specific object we are interacting with potential unexpected results. Thus, our senses (most often, our sight), but also our believes (e.g., if we believe or not a box to be full of books) may have significant effects on the motor plan generated by our brain.

The importance of the link between perception and motor planning becomes evident in the case of patients affected by a clinical condition called 'apraxia'. Individuals with this disorder (often caused by a damage of the posterior parietal cortex) display relevant difficulty with the motor planning required to perform tasks or movements when asked, resulting in their inability to execute or carry out learned purposeful movements. These patients may be, for instance, unable to correctly use a toothbrush to brush their teeth, because they are not able to identify the concept (idea) or purpose behind the objects (this particular form of apraxia is also called 'ideational apraxia').

Motor skill
Learned ability to achieve a predetermined movement outcome with maximum certainty.

Motor learning
Relatively change in the ability to perform a motor skill as a result of practice/experience.

The merging of observations in healthy individuals and in patients with data from animal models in an ever-deepening theoretical framework will allow to achieve a better understanding of how we interact with the external world and to develop applications in rehabilitative and clinical settings.

Possible future development...

- Creation of artificial body components able to efficiently communicate with the brain and the nervous system for individuals who lose a limb.
- Creation of artificial body components that may complement or extend existing ones (e.g., additional fingers or arms may allow to manipulate objects that are otherwise too large or heavy).

Action and motor control: What is in the future?

In medicine, a prosthesis is an artificial device intended to restore the normal functions of a missing body part. Prosthetic limbs, including wooden legs or hands, were already used more than 2000 years ago, in Egypt, Greece and in the Roman Empire. These devices remained pretty basic until recently, but we are now beginning to develop highly complex prostheses that faithfully emulate the aspect and functionality of a real limb. This thanks to the development of new technologies and materials, and to our parallel increased knowledge of how our nervous system interacts and controls the different parts of our body. By connecting these devices directly to the nervous system, individuals become able (throughout a specific training) to control the artificial prosthesis almost as if it were their original one. However, this kind of 'invasive' linkage may not be well tolerated by the body of the receiver. For this reason, although so far with a much lower degree of success, researchers are also trying to create non-invasive approaches, which are mostly based on electroencephalography or electromyography and read motor commands directly from the brain or from peripheral nerves. Promising preliminary results indicate that, in a near future, individuals who have lost a limb will likely be able to replace it with a highly realistic new one, and they will be also able to choose among different options based on invasive or non-invasive control technologies.

In addition, mechanical prostheses have stimulated the interest of scientists also for their potential advantages over our 'standard' limbs made of flesh and bones. The strength and resistance of mechanical components are certainly higher than the one offered by our own body parts. For this reason, researchers are exploring the possibility to create artificial body components that may complement or extend existing ones. Such additional fingers or arms may allow manipulating objects that are otherwise too large or heavy for a normal human being. On the same line, researchers are also developing and testing wearable mobile machines (called 'powered exoskeletons') that allow for limb movement with increased strength and endurance. Indeed, we are moving fast toward an increasing integration between humans and machines that will allow not only to restore motor functions that are lost due to trauma, disease, or congenital conditions but also to obtain new sets of movements and motor capabilities that reach far beyond common human limits.

Language and com-munication

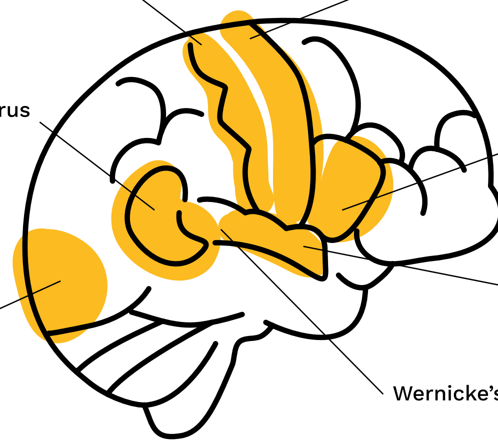
In 1861, a neurologist named Pierre-Paul Broca was able to dissect a dead patient's brain after he had been placed under the care of Bicetre hospital in Paris more than thirty years prior to his death. The man was hospitalized due to an almost complete loss of speech. Broca had known him for a few months before he died, and had been able to assess his inability to speak, together with paralysis and other neurological symptoms. The brain of the patient, who had been named "Tan" after the only syllable he could utter, revealed a large lesion in the lower and most posterior part of the frontal lobe. Almost two centuries later, we call a deficit in language production 'Broca's aphasia' and the brain region responsible for it 'Broca's area'. Lesion studies opened the way to functional neuroscience as we know it today, with the modern, added value of being able to look at healthy as well as sick brains, so to characterize their function.

Aphasia
Inability to comprehend and formulate language.

Motor Aphasia (Broca's Aphasia)
Loss of the ability to produce language.
Comprehension generally remains intact.

Sensory Aphasia (Wernicke's Aphasia)
Loss of the ability to understand written and spoken language. Patients usually demonstrate fluent speech.

Susan Wortmann-Jutt
Aphasia: the disorder that makes us lose words



The study of language as a function rooted in the brain is called 'Neurolinguistics'.

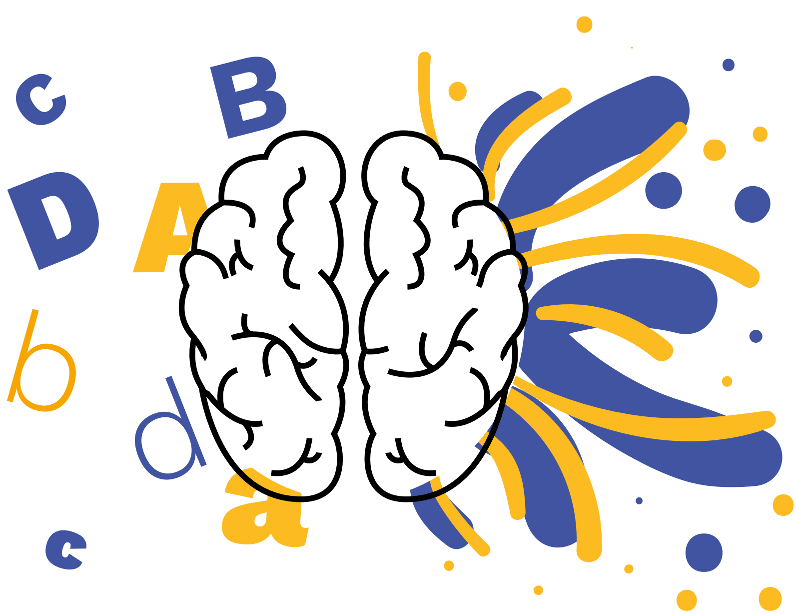
Broca's area has been repeatedly highlighted in functional neuroimaging investigations based on tasks requiring production of speech and language in healthy volunteers, and was shown to be able to process even non strictly linguistic stimuli, like musical tones. Lesions in different, smaller perimeters of Broca's area lead to different problems with speech production, such as difficulties in building sentences, as well as articulation disruption, the use of correct morphology (for example, choosing the -ed suffix versus irregular forms in English past tenses), and even the attribution of meanings.

In several decades of neuroscience investigation, the language-related system in the brain has been found to extend well-beyond Broca's area, and to cover almost the whole left hemisphere: there are locations specific to perception of frequencies typical to one's own mother tongue in the superior temporal lobe, and regions linked to the representation of meanings and word categories in the parietal and temporal lobes. These regions are responsible for deficits specular to Broca's aphasia, and respond to the comprehensive definition of "Wernicke's area" and "Geshwind's territory", after their first observers.

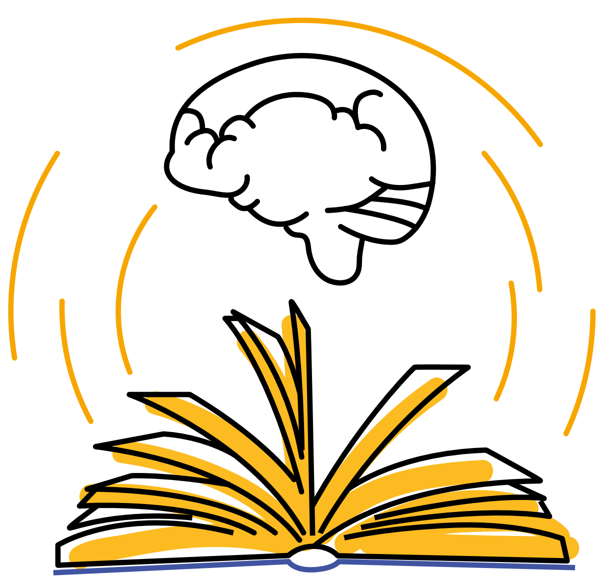
Mia Nacamulli
The benefits of
a bilingual brain

Moving up along the chain of complexity characterizing linguistic processes, we have come to possess the instruments to investigate semantics, the study of meaning, in its relationship with the senses, its link with memory, and its organization in domains.

It is well-known that language related abilities tend to differ between males and females: while men often excel in visuo-spatial and motor tasks, women perform better on verbal memory tasks, verbal fluency tasks and in speed of articulation. Moreover, language and reading disorders are reported to occur approximately twice as often in young males than in females, and brain damages in the left hemisphere (e.g., stroke) have been reported to cause verbal impairment less frequently in females than in males. What is the reason of such differences? Neuroscience investigation have shown that a substantial reason could lie in how females and males use their brain. In fact, females seem to use both brain hemispheres for language functions, while males predominantly use their left hemisphere. This would explain not only why females are superior to males in language-related tasks, but also why they seem to be less often affected by pathological conditions involving language functions.



In our increasingly global society, bilingualism (the ability to speak two languages) is becoming more and more common. When we start to learn a new language at adult age, our brain initially processes the new sounds/words simply as acoustic variations, and tends to mainly rely on the right hemisphere. However, once we become fluent bilinguals, our brain shifts from relying on the right hemisphere to the left hemisphere, as lexical tones become linguistically meaningful. In fact, learning a new language leads to a functional and structural reorganization of the brain, so that the brain of bilinguals tend to display relative differences compared to the brain of monolinguals, both at rest or during execution of verbal tasks. Several lines of evidence have suggested that bilinguals may present significant advantages over monolinguals in so-called 'executive functions', including working memory, attentional control, and inhibitory control. Learning a new language at adult age may also contribute to counteract (or slow-down) the effects of age-related cognitive decline.



However, it is also known learning two languages is easier and faster during childhood, when brain plasticity is at its maximum.

As a matter of fact, language is one of the most powerful tools our brain is endowed with. In fact, we can use it to transfer information from one individual to another, and such transfer is so efficient that we can make another person feeling as if had experienced what we experienced or felt. In fact, several neuroimaging studies revealed that when a person speaks to another, the brain of the listener tends to become 'synchronized' to the brain of the speaker. Thus, if we describe a dog to another person, some brain regions involved in the processing of its various features (was it large or small, brown or black, etc.) lights up in our brain but also in the brain of the person who is listening to us. The listener (or reader) can reproduce in his/her brain an experience without having to actually experience it first-hand. Curiously, this process also occurs when we use a metaphor: expressions such as "wet behind the ears" or "hairy situation" leads to the activation of the brain regions that are involved in touch and feeling textures, while expressions such as "he kicked the bucket" determine an activation of the motor cortex. In fact, metaphors seems to be directly connected to our immediate bodily experience, and this may explain why they are so commonly used to efficiently express abstract ideas or concepts.

Many aspects of the language faculty have been traced back to their roots in the brain, and as many still need characterization. For sure, the value of language as a product of history, and social interaction as well as biology and evolution posits exciting questions for neuroscience to explore.

Possible future development...

- Use of neuroimaging-based information to identify the optimal strategies to facilitate learning and retention of new languages.
- Identification of potential methods based on direct or pharmacological stimulation of specific brain areas to accelerate the learning of new languages and/or increase linguistic skills.
- Identification of new rehabilitative/ therapeutic strategies in aphasic patients.

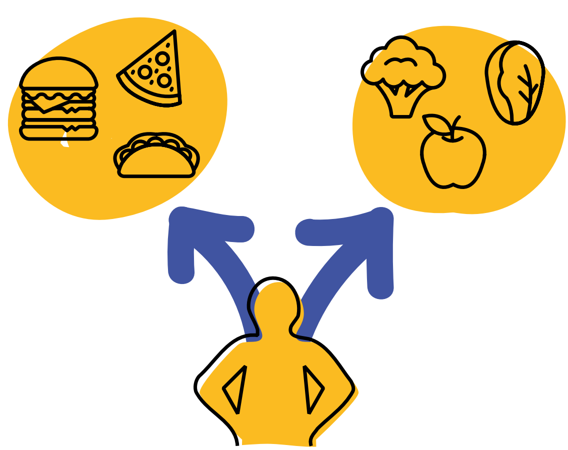
Language and communication: What is in the future?

Language has a fundamental social value as it represents an essential tool for communication and exchange of information. In our modern, globalized society, knowledge of multiple languages, or at least of 'economically powerful' languages, certainly offers an important advantage for individuals and industries. Cognitive and neuroimaging studies of language learning have already unveiled several important aspects regarding the functional and anatomical adaptations that occur in the brain during this process, as well as how this may change as a function of age, sex, or previously known languages. These lines of investigation, in parallel with others related to more general mechanisms of learning and memory, led to the identification or improvement of learning strategies that could be adopted during development or adulthood to accelerate the acquisition of a new language. Some apps and commercial software are already taking advantage of these basic principles, for example through the 'gamification' of the learning process and the addition of a reward system. This aims at exploiting the natural need of our brain for a sense of fulfillment and satisfaction.

It is expected that an increased knowledge of the brain functioning principles, together with technological and scientific advancements, will lead to a further improvement of these strategies. For instance, virtual reality systems in combination with artificial intelligence programs could be used in the future to simulate interactive environments in which a user could test his/her novel language skills. In a near future, approaches based on pharmacological substances or on direct brain stimulation of particular cortical areas could provide additional important aid for language learning or retention after a period of training. All the theoretical and technological advances will not only benefit the general population but will also provide a fundamental contribution to the identification of new rehabilitative/therapeutic strategies in aphasic patients, that is, in patients with alterations of language-related functions following brain damage. On a different perspective, language is so important for humans that it is natural for us to think machines should understand our questions and be able to promptly answer using our own words and concepts. Indeed, the last decade saw a rapid growth in the use of language-based applications for interactions with computers and machines. However, researchers are also exploring the possibility of direct brain-to-brain or brain-to-machine (or machine-to-brain) communication approaches. We should really wonder whether in just 100 or 200 hundred years from now language will still be as much important for us as it is today.

Decision making and other executive functions

We make thousands of decisions per day. From what to eat for breakfast, or which wine to buy for a dinner, to more complex ones. Imagine that you are willing to invest money in your new business or going to marry the right person. According to one recent study, more than 200 of our daily decisions are food-choice related only, and many of them occur without awareness.



Researchers from Cornell's Food and Brand Lab at Cornell University have shown that people make over 200 decisions about food every day. Most of these decisions are made unconsciously.

Executive functions
Set of brain functional processes related with managing oneself and one's resources in order to achieve a goal.

Khan Academy
Decision making processing the environment

How does the brain perform these decisions? And how does it manage itself in the achievement of a certain goal? There are special cognitive skills that are "in charge" of it, known as "executive functions". Along with the decision-making, executive functions help the brain to control and operate many different things: to maintain and re-direct attention, hold and manipulate several pieces of information at once, set and focus on a certain goal, make plans, solve the problems, and many others.

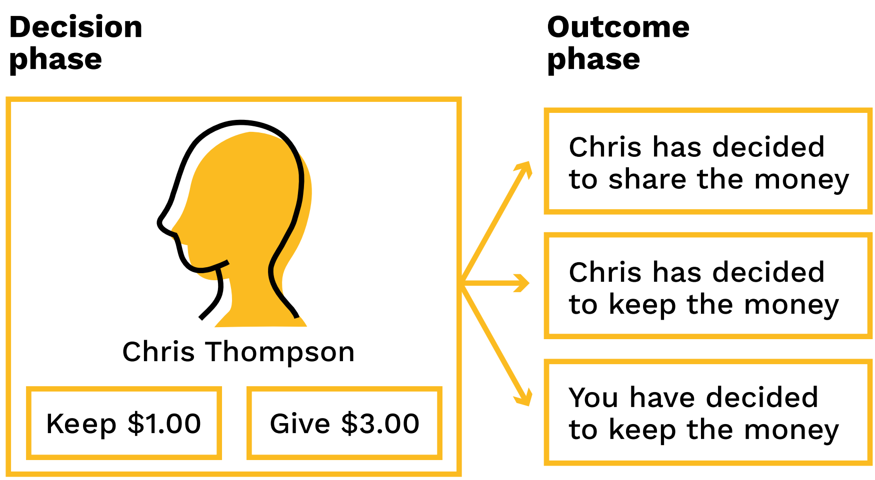
Decision-making belongs to complex cognitive processes, named "executive functions", which form the management system of the brain. Other cognitive processes include impulse control, emotional control, working memory, cognitive flexibility, reasoning, planning, and problem solving.

Are we in control of our decisions? Trying to answer this question, we face the "problem of free will". 'Free will' is a philosophical term. It can be specified by three conditions: the ability to do otherwise, the control over one's choices, and the responsiveness to reasons. In other words, free will is the limitless capacity of making decisions. We simply assume that one has it. The opposite belief could have led to dramatic changes in our society. Imagine, for example, that people would not be held as morally responsible for their own actions: it would be pointless to punish someone for a crime he has committed.

Michael Gazzaniga
Brains are automatic,
but people are free

Free will can be defined as the ability to choose a certain action or option among several alternatives, and it implies that one can be the author of his/her own actions.

Where does our ability to make decisions come from? Much of what is known about the neural mechanisms behind decision-making and other executive functions has been based on the evidence from psychiatric populations and patients with brain lesions. Nowadays, however, advanced non-invasive brain imaging methodologies in combination with state-of-the-art stimulation techniques make it possible to study brain mechanisms involved into decision-making on healthy populations as well. For instance, a number of experiments explored neural mechanisms of decision-making behavior by using functional magnetic resonance imaging (fMRI) and showed which brain areas are active during role-games that imply complex decisions. Recently, it was shown that it is also possible to modulate certain decision-making processes, such as gambling, by applying stimulation over specific areas of the brain.

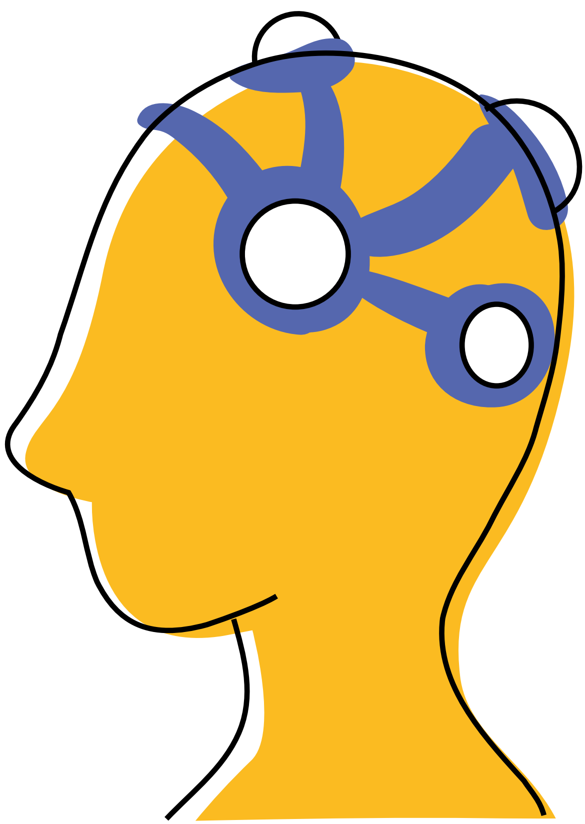


Example of a typical experimental paradigm aimed at evaluating the neural bases of decision-making

A relatively new discipline, neuroeconomics, brings together neuroscience and economics to deepen our understanding of how we make decisions in complex social environments. As an example, Trust Game is a popular paradigm of neuroeconomics for studying social decision-making and interactions between economic agents: a trustor and a trading partner. The trustor receives a certain sum of money from an experimenter and can share part of this sum with the trading partner, who receives that amount of money multiplied by some factor. Then, in turn, the trading partner may pay back all, a part, or none of his/her gain to the trustor.

A famous study explored the role of prior moral beliefs in economic decision-making. Participants played a version of Trust Game inside an MRI scanner. They had to make risky decisions about whether to trust fictional trading partners after learning certain moral information about them ('good', 'bad', or 'neutral'). The results revealed that prior moral beliefs about the partners influence the behavioral choices of trustors.
That is, the participants choose to cooperate more with the 'good' partner. Furthermore, the analysis of the brain images show that prior moral beliefs modulate an activation in the brain areas associated with reward and learning (in particular, the caudate nucleus).

Converging evidence from lesion and brain neuroimaging studies implicate specific anatomical areas in the frontal lobe, including the anterior cingulate cortex, orbitofrontal cortex and ventromedial prefrontal cortex, that play a key role in decision-making processes. The identification of the brain areas that 'guide' our behavior may have relevant implications for the future development of tools able to either predict or influence the decision of single individuals. In fact, as discussed in the next chapters, several tools for targeted brain stimulation are already available and have been successfully applied in the research laboratory to explore the role of each brain region in the decision-making process.



Non-invasive neuro-stimulation technologies are the newest trend not only in the brain- therapy but also in cognitive enhancement of a healthy brain.

Transcranial direct current stimulation (tDCS) is the most widely accessible type of brain stimulation device for cognitive enhancement on the market due to its simplicity of usage and relatively low price. It is non-invasive and involves sending a weak electrical current between electrodes to facilitate or inhibit neuronal activity of the brain. Up to date, several studies on healthy population have reported promising modulation effects of tDCS on cognitive abilities, including working memory, attention and decision-making.

$99-399

Price range for modern popular “home-used” tDCS devices in 2018 (*ApeX, TheBrainDriver, The Brain Stimulator, Foc.us, Omni Stimulator*)

Possible future development…

- Development of novel, reliable tools to identify conditions that may compromise decision making functions, and thus reduce or cancel the responsibility of an individual for his/her own actions.
- Definition of novel tools that may predict and anticipate possible choices of an individual to assist him/her in different conditions (e.g., while driving a car).
- Identification of approaches based on cognitive strategies or direct brain stimulation that may facilitate and optimize decision making processes to maximize a desired gain.

Decision making and other executive functions: What is in the future?

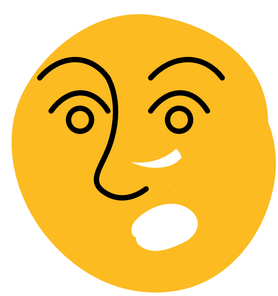
Decision-making is the cognitive process involving the selection of a specific course of action among several alternatives, based on values, preferences, and beliefs of the decision-maker. In this light, the concept of decision-making is strongly interrelated to the one of 'free-will'. While the debate regarding the actual existence of free-will in humans remains substantially unsolved, findings obtained by psychological and neuroscientific research have identified many of the 'hidden' mechanisms used by our brain to take decisions in different contexts and circumstances. It has been demonstrated, for instance, that functional or structural alterations of particular brain areas (e.g. due to a tumor), may alter the decision processes and determine behavioral 'abnormalities'. Researchers are currently trying to complete the map of brain principles underlying decision-making processes, and in the near future, we could be able to accurately identify and classify all or most conditions that affect this particular function. For instance, we could become able to determine whether particular lesions or functional alterations could significantly compromise the decision-making process, thus leading to antisocial or aggressive behavior. This means, in practice, that we could become able to determine whether an individual who committed a crime was fully conscious of the possible consequences of his/her actions, and thus responsible for them, or not. The same type of knowledge could be potentially used also to predict whether an individual will have a higher or lower probability to commit acts with negative consequences for individuals or societies. However, such an option inevitably poses many important legal and ethical questions, especially since a prediction accuracy even close to 100% seems highly unlikely to be achieved. In fact, we now know that decision-making processes may change substantially depending on many individuals or environmental factors, such as emotional states and mood, recent experiences, and others. This may certainly render a prediction highly difficult or unreliable. On the other hand, a deep knowledge of the factors that may affect the decision-making process could be exploited to guide and optimize decision-making in order to maximize the desired gain. In a near future, specific sensors or devices could evaluate our state or the current circumstances in order to alert us whether our decision-making skills could be temporarily altered, thus suggesting us whether or not we are in the right conditions to make a particular choice.

The emotional and social brain

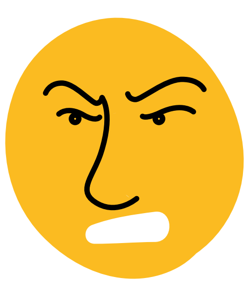
Emotion comes from the Latin verb 'emovere', which translates as 'to move'. Already the etymology of the word reminds us that emotions are our moving forces, giving color to our life and experiences. Thus, understanding the biological basis of emotions has always drawn attention of the scientific community. In particular, much effort has been devoted to find a common and universal classification of basic emotions, thought to be constant across cultures and primates. In this regard, one of the most recognized and appreciated classification comprehends six basic emotions: happiness, surprise, fear, anger, disgust and sadness.

Surprise

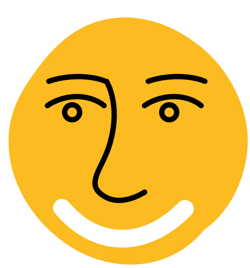
Disgust



Fear



Anger



Happiness

Sadness

Khan Academy
Three components of emotion and universal emotions

It is commonly assumed that humans can display six basic emotions: happiness, surprise, fear, anger, disgust and sadness.

Based on our experience, we should be able to easily recollect at least one episode in our life where we experienced each one of them. This is considered easy because emotional experience permeates every aspect of mental life. Indeed, emotions have profound influences on our thoughts, affecting our decisions and actions but also memories and perceptions. Through this tight interplay between other cognitive functions, emotions show their fundamental role in our survival and why we need them. Think about walking back home through a
dark and isolated alley: you will start sweating, your heart rate will increase, you will breathe faster and your pupils will enlarge and at the same time, your amygdala, a small structure in the brain similar to an almond, will increase its activity.

This precise emotion-based pattern of involuntary autonomic engagement of the whole body and specific brain responses is so important because it will automatically also form a strong new memory: we will remember how we felt and our brain next time will say: “Do not do the same”, helping us in stay safe. We can then easily imagine how and why this universal pattern evolved, facilitating our ancestors in dealing with recurrent risks.

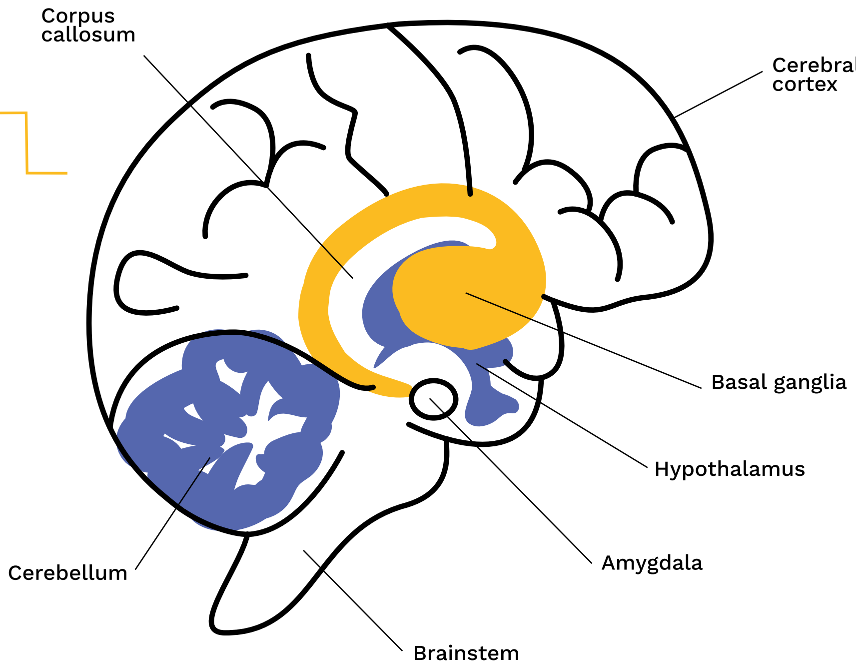
Theory of mind
Ability to attribute mental states to oneself.
It is crucial for everyday social interactions.

Emotion
Relatively short-lived feelings that come from a well-defined cause.

Mood
Positive or negative feelings that are relatively long-lasting and have no clear starting point.

Emotions have a tight-link to social phenomena, as they are fundamental for our interactions with other individuals. This is why we can recognize and display a wide range of emotions, like affection, admiration, pride, remorse and nostalgia. Specific parts of our brain seem to be specifically devoted to allow us understanding the emotions of others (as well as their intentions and beliefs), a process commonly indicated as 'theory of mind'. Thus, emotions do not represent only a confined, subjective feeling, but also constitute a mean of communication with other individuals, a way to create or reinforce social bonds (or to break them).

Jaak Panksepp
TED talk:
“The science
of emotions”



To better understand the functioning and the underlying neural underpinnings of emotional processes, a valuable opportunity comes from the study of pathological conditions. An example is the behavioral variant of ‘Frontotemporal Dementia’, a neurodegenerative disease that causes different social cognition disorders and particularly loss of empathy and emotion recognition deficits. Another example comes from the ‘alexithymia’, a condition that has as salient feature the difficulty in identifying and describing feelings, with a significant deficit in verbally labelling and recognizing emotional expressions. Investigations of these conditions based on neuroimaging techniques may allow to reveal the most basic functional brain processes involved in the different aspects of emotional processing.

Possible future development...

- Identification of new tools based on direct brain stimulation that may allow to efficiently modulate negative emotions in pathological conditions.
- Creation of tools that may allow to predict the emotional response of different individuals to a specific condition/stimulus in order to predict and accommodate behavior.
- Identification and exploitation of the emotional mechanisms that facilitate the retention of memories with a strong emotional component.

The emotional and social brain: What is in the future?

Mood and emotions affect our behavior and our social interactions. Indeed, emotional states often directly interact with psychological traits in determining responses to specific stimuli or more general behavior. Being able to 'read' the emotional state of individuals could contribute to predicting his/her behavior, and may allow for instance to accommodate it without a need for overt requests or commands. Researchers are already able to 'read' emotional tones in experimental settings by evaluating brain activity (e.g., with EEG or fMRI) and/or other peripheral signals, such as skin conductance, heart rate, respiratory rate, muscular activity, and others. However, in real-life conditions, the accuracy of these emotion-reading tools drops considerably, due to the inevitable presence of multiple sources of noise (e.g., movement, electrical signals). Thanks to the development of more efficient sensors and analysis tools, in a near future, emotion-reading technologies could be successfully used to facilitate human-machine interactions, thus allowing machines to understand or predict our desires and preferences. On a different perspective, emotions also have an important role in learning and memory formation as it is well known that experiences associated with a strong emotional content tend to leave a more profound trace in our brain and are thus more easily remembered. This mechanism could be exploited to develop more effective learning strategies. Acquiring a better knowledge of the specific physiological mechanisms that link emotions and memory will also allow developing novel approaches aimed at treating conditions such as Post-Traumatic Stress Disorder (PTSD), in which negative, traumatic memories can determine debilitative stress, and even lead to flashbacks, nightmares, and severe anxiety. However, emotions have an important role in several other psychiatric conditions, such as Major Depression, in which the emotional tone tends to excessively deviate toward a negative (or positive) mood. The study of the physiological brain mechanisms involved in emotional regulation will allow developing novel strategies based on pharmacological substances or on direct brain stimulation of specific brain areas that will allow to efficiently modulate negative emotions in these pathological conditions.

GLOSSARY

NEURAL BASES OF HUMAN COGNITIVE PROCESSES AND BEHAVIOR 2

Anterograde Amnesia
Loss of the ability to create new memories.

Aphasia
Inability to comprehend and formulate language.

Declarative memory
Form of memory that involves conscious recollection of previously acquired knowledge. It is also called explicit memory.

Default Mode Network or DMN
Set of interacting brain areas that show a high level of activity during wakeful rest.

Emotion
Relatively short-lived feelings that come from a well-defined cause.

Endogenous orienting attention
Intentional allocation of attentional resources to a predetermined location or space.

Executive functions
Set of brain functional processes related with managing oneself and one's resources in order to achieve a goal.

Exogenous orienting attention
Automatic shift of attention caused by an external stimulus.

Long-term Memory
Form of memory in which informative knowledge is held indefinitely. Explicit and implicit forms of memory are types of long-term memory.

Mood
Positive or negative feelings that are relatively long-lasting and have no clear starting point.

Motor Aphasia (Broca's Aphasia)
Loss of the ability to produce language. Comprehension generally remains intact.

Motor learning
Relatively change in the ability to perform a motor skill as a result of practice/experience.

Motor Programs
Pre-structured motor activation patterns that are generated and executed by the brain. They represent a top-down approach to motor coordination. Once the program has been executed, it cannot be altered online by intervening sensory information.

Motor Reflex
Fixed neuromuscular pathway that leads to automatic motor responses. A reflex occur on a much faster time scale than what is possible for reactions that depend on perceptual processing.

Motor skill
Learned ability to achieve a predetermined movement outcome with maximum certainty.

GLOSSARY

NEURAL BASES OF HUMAN COGNITIVE PROCESSES AND BEHAVIOR 2

Motor Synergy
Multi-element system that organizes sharing of a task among a set of elemental motor variables. Synergies are guided in a bottom-up manner by sensory information. They are learned, rather than being hardwired like reflexes.

Perception
This term refers to how sensations are interpreted to make sense of the world around us.

Procedural memory
Memory of how to do certain things. It is also called implicit memory.

Resting State Paradigm
This is an approach of functional brain imaging that is used to evaluate regional interactions that occur when a subject is not performing an explicit task.

Retrograde Amnesia
Loss of memory-access to events that occurred in the past.

Sensation
This term refers to how we are informed about the environment through touch, taste, sight, sound, and smell.

Sensory Aphasia (Wernicke's Aphasia)
Loss of the ability to understand written and spoken language. Patients usually demonstrate fluent speech.

Short-term (Working) Memory
Cognitive system with a limited storage capacity that is responsible for temporarily holding information available for processing. It is important for the guidance of decision-making.

Task-Based Paradigm
This is an investigation approach in which specific brain functions are probed using pre-defined tasks involving the passive or active processing of stimuli.

Task Positive Network or TPN
Set of interacting brain areas that show high levels of activation during attention-demanding tasks in functional imaging studies. These regions are 'anti-correlated' with DMN.

Theory of mind
Ability to attribute mental states to oneself. It is crucial for everyday social interactions.

The visible spectrum
The portion of the electromagnetic spectrum that is visible to the human eye. A typical human eye responds to wavelengths in the vicinity of 430–770 THz.

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03

Focus on: Health

Mind your mind: the neuroscience of contentment

Positive psychology has been defined as "*the scientific study of positive human functioning and flourishing on multiple levels that include the biological, personal, relational, institutional, cultural, and global dimensions of life*". This particular field of investigation is aimed at understanding how individual happiness may be fostered, in particular through voluntary changes in attitude and behavior. Indeed, our brain can adapt to new situations and contexts by reorganizing itself through changes in connections among neuronal populations. This ability, that we referred to as 'neural plasticity', is thought to be the most fundamental mechanism through which we can re-shape our attitude, beliefs, and behaviors even during adulthood. The brain changes can occur at multiple levels, ranging from single neuron's synaptic activity to large-scale cortical networks' organization.

Potentially, as described before, every experience in our life (e.g., external/environmental stimuli, physiological processes such as development and sleep, social interactions, traumatic injuries) may alter the way in which our brain works, and determine relative changes at the behavioral level. This means that while pre-determined or accidental events contribute to 'shape' our brain and behavior, we can also actively behave in order to modulate brain plasticity and enhance well-being.

The psychology and neuroscience of happiness

Behavior
Range of actions made by individuals, organisms, systems or artificial entities in response to stimuli or inputs coming from themselves or their environment.

Quality of Life
The individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals (definition of the World Health Organization).

Health
A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity (definition of the World Health Organization).

Carol Dweck
The power of
believing that
you can improve

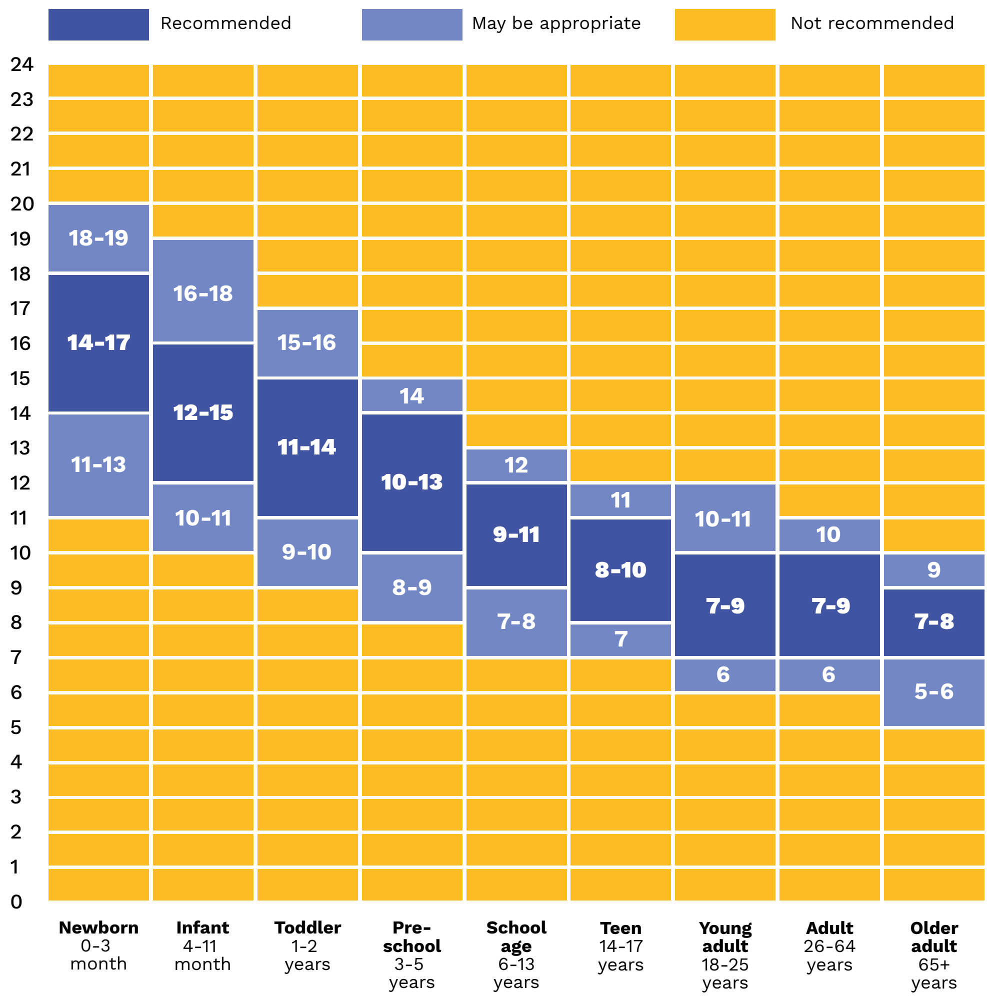
«Probably the biggest insight is that happiness is not just a place, but also a process. Happiness is an ongoing process of fresh challenges, and it takes the right attitudes and activities to continue to be happy»

Ed Diener, Professor of Psychology

Starting from many aspects of our every-day routines, we can make a difference for a happy life: for example, sleeping the right amount of hours every night helps us to better regulate our emotions and to restore our cognitive abilities, while clean-eating and regular physical activity balance energy expenditure, hormones release and mood.

In our modern society, sleep is often perceived as a waste of our time. Indeed, we sleep for about one-third of our lives. However, decades of research made clear that getting the right amount of sleep each night is indispensable in order to maintain an efficient brain functioning during wakefulness and also shown that sleep has many beneficial effects for our body and mind. In fact, sleep restriction or deprivation is associated with irritability, cognitive impairment, confusion, headache, memory lapses and impaired moral judgment. Reiterated sleep loss may even lead to altered functioning of the immune system, increased risk of diabetes and increased risk of heart diseases. Sleep seems to be necessary for the human organism to physically restore itself, healing itself and removing waste which builds up during periods of activity. Recent evidence even linked sleep to the removal of factors associated with the development of Alzheimer's disease. Moreover, a large amount of neuroscientific research demonstrated that sleep both allow the consolidation of new memories and prepare the brain for the acquisition of new information by removing redundant or unnecessary connections among neurons.

SLEEP DURATION RECOMMENDATIONS



Sleep need varies as a function of age and may also differ among individuals. In general, sleep is considered to be adequate when there is no daytime sleepiness or dysfunction.

Yuval Nir
How neuroscience redefines the borders between sleep and wakefulness

Both our body and our mind greatly benefit from the period of unconsciousness, immobility and environmental disconnection provided by sleep. However, during wakefulness, meditation practices and relaxation techniques may also produce positive effects on our physical and mental health. Meditation is commonly defined as a practice where an individual change the focus of his/her mind to achieve a mentally clear and emotionally calm state.

Mindfulness meditation
This approach involves paying attention to the present moment. It is intended to develop skills of paying attention to ourselves and the world.

Transcendental meditation
This approach is based on the silent repetition of a mantra. It is aimed at detaching oneself from anxiety, thus promoting harmony and self-realization.

Meditation practices (e.g., mindfulness, loving-kindness, the focus of attention, transcendental meditation) have been found to improve the subjective quality of life reducing stress and anxiety, and enhancing self-awareness, self-esteem, and social relationships. Neuroimaging investigations further revealed that these effects are mediated by specific changes in the functional and structural organization of our brains.

Psychological and Neuroscientific research suggests that meditation practices may have small to medium effects on empathy, compassion, and prosocial behaviors.

Sara Lazar
TED talk:
“How meditation can reshape our brains”

«Compassion is one of the few things we can practice that will bring immediate and long-term happiness to our lives»

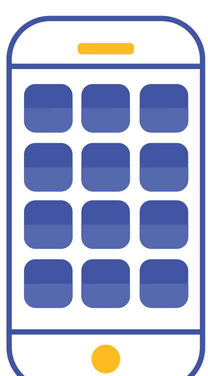
Dalai Lama

Matthieu Ricard
The habits
of happiness

Neurotransmitter
An endogenous chemical which enables signal transmission from one neuron to another neuron (i.e., across a synapse).

Ultimately, increases in self-esteem, empathy, and devotion to prosocial behaviors trigger a virtuous circle in our brain: positive social interactions, in fact, induce the release of molecules (neurotransmitters) that act as natural antidepressants and that provide a sense of reward. Thus, the more we strengthen the bonds we have with other people, and the more we behave in an emotional-aware manner, the more our brains get rewarded.

In the last few years, neuroscience research opened new opportunities and revealed novel approaches for improving our well-being through a self-guided functional and structural reshaping of our brain. A clear example of this process is provided by the rapid diffusion of computer and phone-based applications and tools aimed at analyzing levels of stress, sleep patterns, food intake or physical activity, in order to help individuals in actively changing their lifestyle.



Apps for meditation

These apps usually help the user to schedule his/her meditation sessions (often offering different options related to time-of-day and location) and provide tips and suggestions to reduce levels of stress and anxiety.
Examples: HEADSPACE, The Mindfulness App, Calm, MINDBODY, Buddhify, Smiling Mind (also for children), Sattva, Stop, Breathe & Think.

Apps for clean-eating

These apps typically offer recipes, meal plans, cooking tips and shopping lists to help the user at changing or maintaining healthy dietary habits.
Examples: Clean-Eating Plan and Recipes, Food Tripping, Fooducate.

Apps for fitness

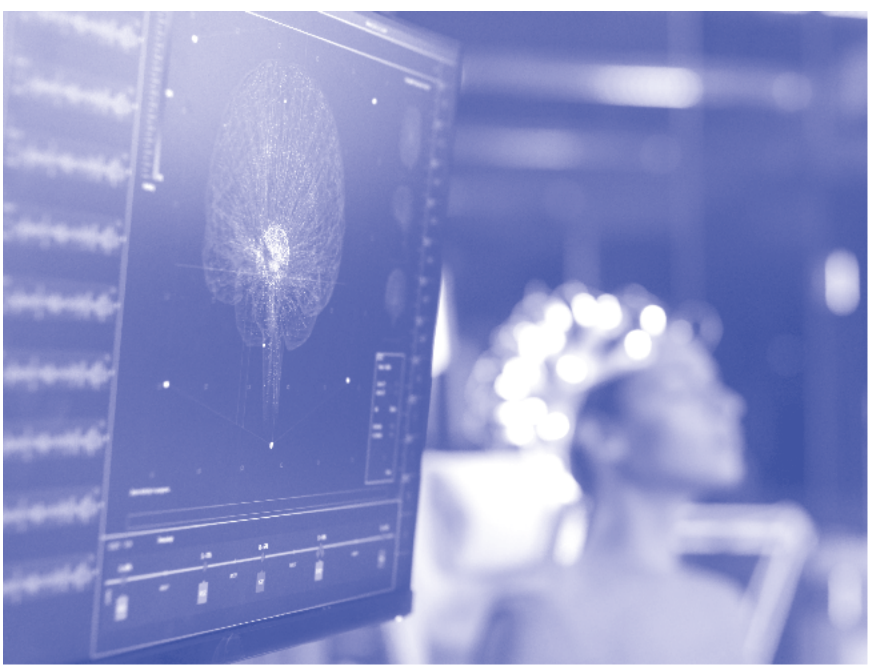
Most of these apps are tracking tools, that allow to log workouts, count calories, and collect stats about runs, walks, and bike rides to evaluate overtime improvement. Some fitness apps may also be 'coaching apps' that put the user in touch with a personal trainer or nutritionist.
Examples: FIT radio, Endomondo, Strava, Jefit Workout, Lose it!

Apps for evaluating and improving sleep quality

The majority of these apps track and analyze the sleep pattern of the user (using the accelerometer and/or the microphone included in modern smartphones). They may be also used to adjust the alarm timing, so to be awakened from relatively light sleep, allowing the user to feel more vigilant upon awakening. Some apps allow to obtain information about the potential occurrence of snoring or sleep apnoeas, and may thus help the user at identifying condition that requires clinical evaluation.
Examples: Sleep Cycle, Sleep Time, Pillow, Digipill, Pzizz.

Neuro-science and bionics

Thoughts, dreams, and intentions are all jealously concealed inside in our mind, or at least this is what we believe. What would happen if a machine could decode our brain activity, thus allowing an external observer to understand what we perceive or think? This apparently futuristic scenario may actually be not too far from happening. Indeed, scientists are delving deeper and closer in the tangle of neurons of our brain, starting to clearly reconstruct particular mental contents from a specific brain activity fingerprint.



‘Brain reading’ is possible because each experience is associated with a unique pattern of brain activity that can serve as a ‘brain fingerprint’ of the experience itself.

Functional magnetic resonance imaging (fMRI) has been proved to represent an optimal instrument to ‘read-out’ perceptions, thoughts and even dreams directly from the brain; already in 2005, it was first shown how the analysis of the fMRI signals can inform about what volunteers were perceiving through vision while data were collected. Even more, the same type of brain data has been also shown to predict a particular decision a subject is going to take, or a specific memory he is trying to retrieve. A recent study demonstrated that particular computer algorithms might allow achieving a rough reconstruction of what an individual is recalling using “visual imagery” during wakefulness, but also what he is dreaming during the first phases of sleep. In fact, neuroscience studies demonstrated that different contents of consciousness are associated to distinct patterns of brain activity, that is, a specific distribution of activity across distinct brain areas involved in the processing of particular experiential aspects (e.g., shape, color, consistency, name, usability, etc.).

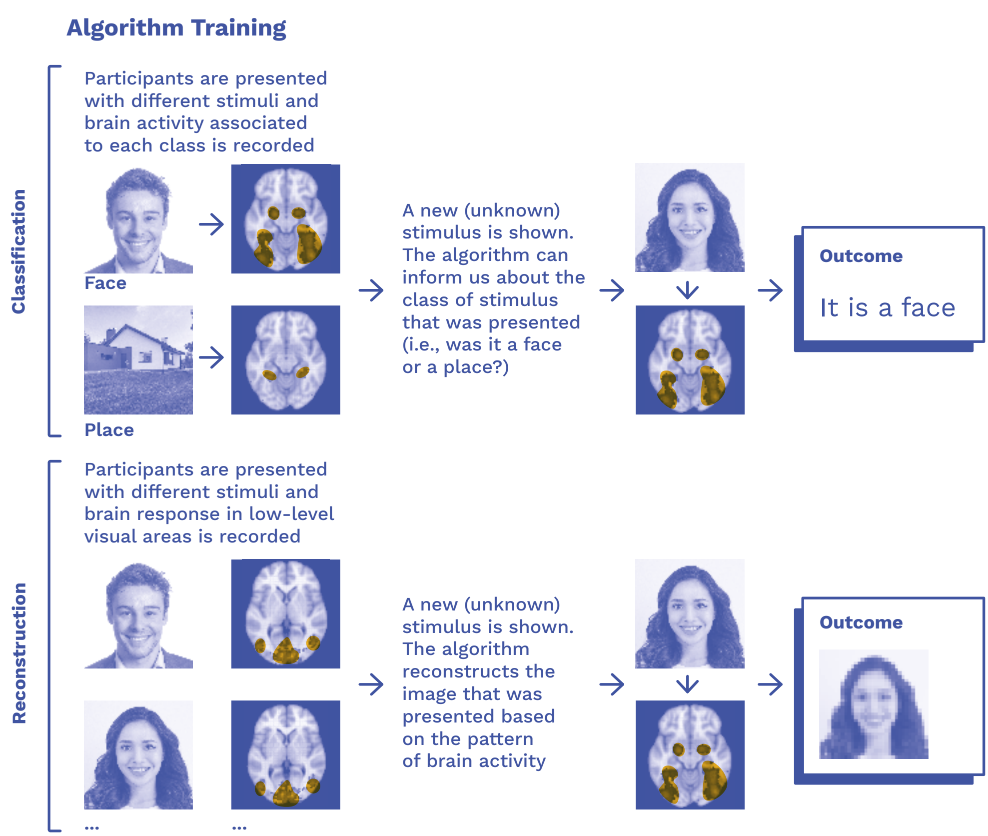
John-Dylan Haynes
TED talk:
“Mind reading with brain scanners”

Most 'brain reading' approaches require two steps. In the first step, different stimuli are presented to a participant (or he is asked to imagine the stimuli), and the specific pattern of activity associated with each stimulus is identified. Then, a computer algorithm is 'trained' at associating each pattern of activity to the specific stimulus, and may thus become able to recognize when a stimulus is perceived just by receiving information about what is happening in the brain at a specific time. The more information is provided to the computer algorithm, the greater will be its accuracy of classification. In principle, this approach is not different from the one that is commonly used for computer applications based on voice and command recognition (as in the cases of Siri or Google Assistant): all these algorithms need to be trained in order to do their job in the right way, that is, to associate each command to the right output.

The accuracy of brain-reading techniques is increasing steadily as the quality of the data and the complexity of the decoding algorithms improve.

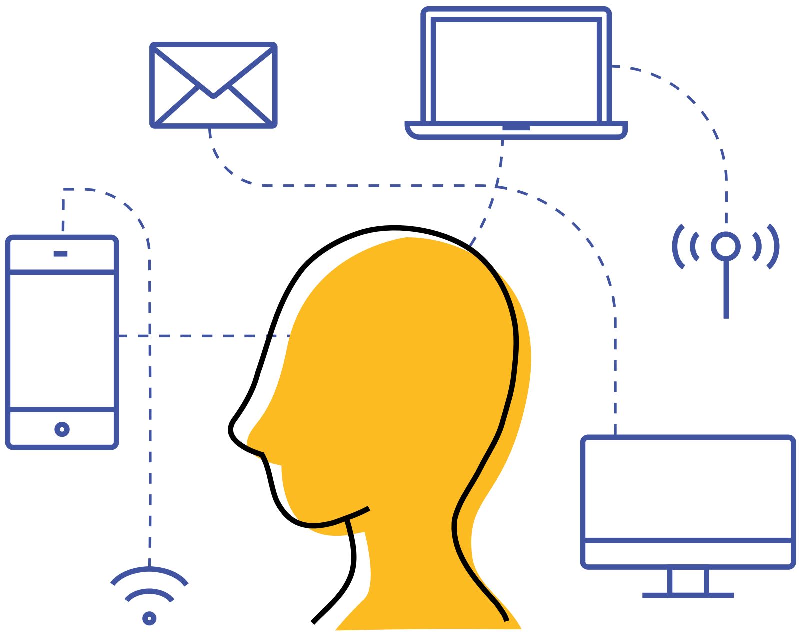
So-called 'brain reading' approaches may be used to achieve different types of results. In simple 'classification', the pattern of brain activity is used to determine the particular type or class from which the stimulus was drawn (e.g., to recognize whether the participant saw a shoe or a bottle). In 'reconstruction' approaches, the aim of 'brain reading' is to reconstruct a picture of the image (or sound, etc.) that was

presented. Thus, 'reconstruction approaches' basically try to reverse the flow of information, in an attempt to artificially re-create perceptual experiences whose brain activity patterns have been previously characterized. In these cases, a 'translation algorithm' represents the essential core of the decoding process.
The algorithm is fed with a great number of recordings (examples) and automatically learns how to extract salient examples and to efficiently differentiate between them.
The accuracy of such 'reconstructions' is still relatively low, but already sufficient to give to an external observer a general



Images of the brains created with neurosynth.org idea of what an individual perceives or imagines. While fMRI-based approaches require the use of large machines and of long periods of immobility, other electrophysiological signals, such as intra-cortical or scalp electroencephalographic (EEG) activity, can provide valuable information about the subject's inner world almost in real time. Indeed, most EEG devices are low-weight, wearable systems that could be used to record rapid changes in brain activity in a wide range of different conditions and even during active movement. While the use of such tools outside the highly controlled setting of the neuroscience laboratory occurs at the expenses of precision and accuracy (mainly because recorded signals are more variable and noisy), it also offers the possibility to create 'brain reading' systems with potential usability in 'real life', naturalistic conditions.

Each 'brain reading' algorithm only learns to read brain activity of a specific user or set of users. The development of a 'universal thought reading machine' is highly unlikely in the near future.



Brain reading techniques may allow identifying the thoughts of an individual or to predict his/her intentions. In this light, brain reading has been proposed as a form of lie detection approach, raising significant ethical concerns related to mental privacy, data security, and quality control. On a different perspective, devices for brain reading may also allow a user to directly and seamlessly interact with other devices (e.g., computers or prostheses) to control them or change their behavior without the need for overt actions or vocal commands. This type of application is commonly termed 'Brain-computer interface' (BCI).

Brain reading
Use of non-invasive measurements of an individual's brain activity to decode a person's conscious experience.

Brain–computer interface
This is a system allowing direct communication between the human brain and an external device.

Christopher deCharms
TED talk:
"A look inside the brain in real time"

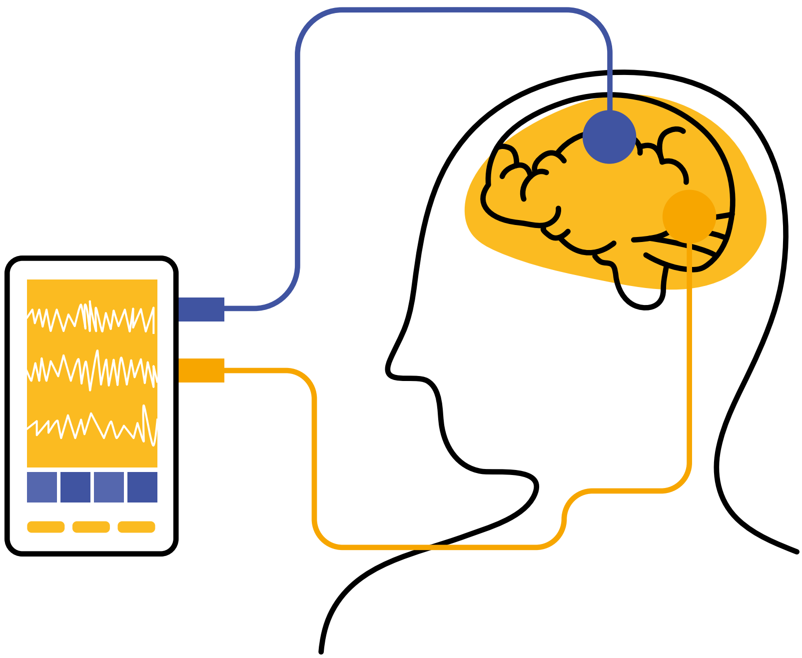
The main potential application of BCI concerns the restoration of damaged hearing, sight, and movement.
The power behind this approach is intrinsically clear: BCI provides a new and direct communication channel between the brain and other devices that bypass potentially lesioned or missing structures. Thus, for instance, a BCI device may be used by an amputee, or by a patient suffering from neuromuscular impairments, to control an artificial arm or hand. As another example, forms of invasive-BCI have been used to treat non-congenital (acquired) blindness. In this case, cameras mounted on glasses are used to send signals to an implant located in the visual cortex that allows generating coherent flashes of light (phosphenes). Thanks to the remarkable plasticity of the human brain, after an adequate period of training/learning, signals from implanted prostheses can be handled by the brain almost like a natural sensor or effector channels. Such approaches could be used not only by patients but also by healthy individuals. For instance, sensory substitution devices based on direct brain implants could be used to perceive stimuli that are not normally processed by the human brain (e.g., thermal stimuli), while artificial body components, such as additional arms or fingers, could be used to manipulate objects that are otherwise too large or heavy for a normal human being.

Invasive BCI
Invasive BCIs are implanted directly into the brain (grey matter) during neurosurgery. These devices produce a high-quality signal but are prone to scar-tissue build-up, causing the signal to become weaker.

Non-Invasive BCI
Most of these devices are based on scalp EEG systems, which are easy to wear and do not require surgery. This approach offers a lower accuracy compared to invasive-BCI.

While the first and most important application of BCI is related to the clinical field, other commercially relevant applications have been proposed in recent years. For instance, several video games based on the interpretation of signals obtained from low-cost portable EEG devices have been released in the last ten years. In addition, in the interdisciplinary field of neuroscience and marketing, the possibility to read thoughts and intentions in order to predict the reaction of individuals to a new product or advertisement is attracting a growing interest. At the same time, scientists are continuing to use ‘brain reading’ techniques and BCIs to learn more about the brain itself, and to crack the complex code it uses for storing and organizing information.

Thanks to neuroscientific discoveries and technological advances of the last decade it is now becoming possible to use our brains to take control of inanimate objects, like computer cursors, drones or robotic arms. Even commercial companies have started to adopt brain-computer interfaces for their applications. The commercial products are usually based on one or few EEG electrodes placed on the forehead or in other scalp locations. The type of information that can be extracted from these simple systems is fairly crude: it is possible to distinguish whether an individual is more relaxed/calm or alert/excited, and it is possible to voluntarily manipulate the brain state in order to achieve a specific outcome out of few (usually two) possible options (e.g., to move a ball forward and back). While the currently available commercial BCIs are rather simple and allow only a very limited set of applications, they offer a first interesting example of novel possibilities that may open in the next years thanks to scientific and technological improvements.



For instance, Emotiv offers several devices for EEG recording including up to 14 electrodes and software for brain-computer interaction, including an app that allows taking control of a small drone through the modulation of brain activity. Similarly, Neurosky offers a simple EEG headset and several games in which specific goals can be achieved by voluntarily varying the type of brain activity through changes in the relative levels of relaxation or focused attention. Other devices with similar characteristics may be used to monitor brain activity during sleep and may even recognize the specific phase of sleep to help the user entering in a state –called lucid dreaming- in which dreams can be voluntarily manipulated.

paradromics.com

Paradromics video
Paradromics is building the next-generation of brain-machine interfaces

Paradromics

Paradromics is developing high-volume bidirectional data streaming capabilities between brains and computers. These interface technologies will initially be used to help physically disabled patients reconnect with the outside world, with infinite possibilities beyond: an entire ecosystem of digital devices and online services would be available to compensate for a patient's loss of biological connectivity. A blind person could see through the aid of a digital camera. A paralyzed person could order groceries, receive them at the door, and then invite a friend for dinner, all without moving a muscle.
At present the company is working on Argo, a prototype of massively–parallel neural recordings system, featuring at present 65,536 channels.

Paradromics

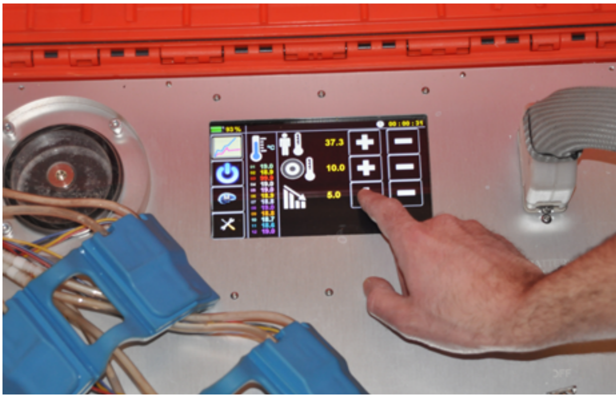
Total Funding $9 Mln

Last Round $7.14 Mln
March 2018
Seed VC

neuronguard.com

Neuron Guard

Neuron Guard has developed a targeted temperature management system composed by a therapeutic collar powered by a smart control unit (the size of a small briefcase). The collar transforms the neck into a natural heat exchanger exploiting several physiological and anatomical characteristics of the human body. It is quicker to act on brain tissue but can also function as total body temperature adjusting device if required.
A disposable protective shield makes cleaning the collar after each use simple while featuring an optimal safety profile both in term of pathogens and allergens.
The control unit collects all the data of the treatment.
The mission is to improve the safety of patients on the roadside, at home or in the workplace, and to reduce the costs of chronic care. In fact, Neuron Guard aims to be the only device that can be used in every circumstance, inside and outside the hospital, and allow the user to fully manage the temperature of the patient warming and cooling as necessary. The vision is to have a Neuron Guard kit in every public place just like the Automatic External Defibrillator (AED) to empower bystanders to immediately react in case of emergency. Under this perspective the device will become the AED for the brain: a connected-intelligent platform that takes care of the patient, connects the scene with the Emergency Response System transmitting vital data to improve the readiness and effectiveness of professional intervention.



Total Funding $1.4 Mln

Last Round €656 k by private investors 2015

mindmaze.com

MindMotion Go

Mindmaze

MindMaze builds intuitive human machine interfaces through its neuro-inspired computing platform; its innovations are at the intersection of neuroscience, mixed reality and artificial intelligence.
MindMotion systems provide a portfolio of motivating gamified activities built on evidence-based neurorehabilitation principles, designed to enhance a patient's recovery potential.
Mindmotion Pro focuses on increasing early upper limb rehab dose and intensity; Mindmotion Go aims to motivate patients in their daily rehab.

mindmaze

Total Funding $218 Mln

Last Round $100 Mln
Undisclosed
April 2018
Strategic
Investors

dreem.com

Journey
A night with the Dreem headband

Dreem
The Science of Better Sleep

Dreem

Dreem is a neurotechnology company that uses neuroscience fundamentals to enhance human potential by researching, monitoring, and understanding the brain.
With its first product, Dreem, they are introducing the first active wearable device that monitors brain activity (EEG), and stimulates the brain with sound to increase the quality of deep sleep. Five precise EEG sensors discreetly monitor the brain waves, while others track movement, heart rate, and respiration. All working together to deliver a comprehensive understanding of the sleep.
The Dreem headband works in tandem with an equally intuitive application. Simple yet insightful, it allows everybody to customize every aspect of the Dreem headband: features to activate, volume, wake-up time, alarm sounds, and more. It also helps to fully understand each one sleep and adjust the lifestyle to improve it even further.
Dreem was founded in 2014 and is based in Paris and San Francisco.

DREEM

Total Funding $57.5 Mln

Last Round $35 Mln June 2018 Series B

INTERVIEW

Carlo Miniussi
Director of Center for Mind/ Brain Sciences – CIMeC, University of Trento, Rovereto TN Italy

What tools can neuroscientists use to stimulate and probe the human brain?

In recent years, there has been an exponential rise in the number of studies that employ transcranical brain stimulation as a means of gaining, non-invasively, understanding of the neural substrates that underlie normal and pathological behaviour. Transcranical brain stimulation includes several methods that can be divided into two main categories: transcranial magnetic stimulation (TMS) and transcranial electrical stimulation (TES). TMS is primarily a method of neurostimulation that includes the induction of depolarization of neuronal membranes and the initiation of action potentials in the area stimulated by electromagnetic induction. This effect is produced using bulky and expensive machinery. TES is essentially a method of neuromodulation that uses a smaller and less expensive device. Very low-intensity electrical stimulation induces a state change in the membrane potential, thereby altering the ionic fluxes. This alteration can result in hyperpolarization or depolarization of the neurons.

INTERVIEW

What type of information can we derive from the use of these tools?

A major breakthrough in understanding where and when a given functions occur in the brain, as well as the mechanisms that underlie motor, perceptual and cognitive functions, was provided by the introduction of these methods. Many studies have shown that TMS and tES interact with brain activity and related sensory, motor and higher order cognitive abilities, offering us the opportunity to test and change their functioning. The relevance of transcranical brain stimulation as a tool in neuroscience stems mainly from its ability to transiently affect the function of the targeted cortical area, thereby testing directly the functionality of the stimulated area via a causal approach.

Is it possible to induce structural and functional modifications in the human brain using tools for brain stimulation?

All of these methods involve changes in the electrical activity of neurons, which in turn modifies the neurons' synaptic efficiency.
The fact that both TMS and tES are able to modulate synaptic efficiency means that they are able to modulate also brain plasticity and, in turn, affect behaviour opening up new horizons in the treatment of brain circuit and plasticity

disorders. When transcranical brain stimulation is used to enhance cognition in normal individuals, results are confined only to small temporary improvements obtained in the laboratory, improvements that are essential to establish the role of a brain area in a given experimental task, but that certainly do not improve functionality in healthy individuals. In this regard one study has suggested that using tDCS to "enhance" certain functions may impair temporary others. In a normal context a zero-sum model can be proposed claiming that every gain in cognitive functioning is necessarily accompanied by a loss in some other domain.
Totally different is the approach in pathological conditions.

What are the possible implications of these approaches for pathological conditions? Is it possible to use brain stimulation to enhance or accelerate recovery after brain damage?

The possibility of non-invasively interacting with the functioning of the brain and its plasticity mechanisms opens new and exciting scenarios in the neurorehabilitation field. The key element was given by studies that have shown that the repetitive (days) use of TMS and tES interacts with cortical activity more effectively than single applications. These mechanisms are generally expressed as a form of functional plasticity, which holds great potential for improving deficits of the central nervous system. Therefore, new applications began evaluating the potential benefits of these methods as an adjuvant tool in the treatment of psychiatric and neurological disorders.

It should be also considered that the possibility of altering brain functions with TMS or TES, while simultaneously assessing those functions with neuroimaging, is essential to understand whether and how TMS or TES affects sensory-motor, cognitive, and affective functions. This is important because these plastic changes in the targeted area may also induce complex widespread alteration in the global functional connectivity and net-work efficiency. Therefore, recording brain activity with fMRI or EEG during plasticity-inducing TMS/TES protocols allow to evaluate how TMS or TES effects act at network level. This is important because using these tools, we can establish, in vivo, the neurophysiological consequences of a given therapeutic manipulation.

GLOSSARY

FOCUS ON: HEALTH

3

Behavior
Range of actions made by individuals, organisms, systems or artificial entities in response to stimuli or inputs coming from themselves or their environment.

Brain–computer interface
This is a system allowing direct communication between the human brain and an external device.

Brain reading
Use of non-invasive measurements of an individual's brain activity to decode a person's conscious experience.

Health
A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity (definition of the World Health Organization).

Invasive BCI
Invasive BCIs are implanted directly into the brain (grey matter) during neurosurgery.
These devices produce a high-quality signal but are prone to scar-tissue build-up, causing the signal to become weaker.

Mindfulness meditation
This approach involves paying attention to the present moment.
It is intended to develop skills of paying attention to ourselves and the world.

Neurotransmitter
An endogenous chemical which enables signal transmission from one neuron to another neuron (i.e., across a synapse).

Non-Invasive BCI
Most of these devices are based on scalp EEG system, which are easy to wear and do not require surgery. This approach offers a lower accuracy compared to invasive-BCI.

GLOSSARY

FOCUS ON: HEALTH

3

Quality of Life
The individual's perception of their position in life in the context of the culture and value systems in which they live and in relation
to their goals (definition of the World Health Organization).

Transcendental meditation
This approach is based on the silent repetition of a mantra. It is aimed at detaching oneself from anxiety, thus promoting harmony and self-realization.

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04

Focus on: Arts & Creativity

Art and neuro-science: how the brain appre-ciates beauty

Human activities that may appear far from each other at a first glance, often share a hidden common root. This is certainly the case for art and neuroscience, as both ultimately aim at discovering the inner nature of our perceptual reality, chasing a creative, intimate or rather a scientific, objective approach. In the past decade, researchers and artists started working together to answer the fundamental questions shared by the two fields: Why do we perceive what we perceive? Why do we feel the way we feel when we perceive something such as a piece of art? The 'dialog' between the two disciplines is known under the name of 'Neuroaestethics'. Experimental Neuroaesthetics employs neuroscientific protocols to systematically investigate the neurological and neurophysiological responses to artworks and artistic experiences in human beings, and also tries to explain the evolutionary reasons of this link.

Empirical aesthetics
Study of aesthetic perceptions of art, music, or any object that can give rise to aesthetic judgments.

Neuroaesthetics
Study of the neural bases for the creation and contemplation of art works.

An artist can be considered, in a sense, a neuroscientist, who uses the tools of art to explore the potentials of the human brain.

The principal aim of the field of neuroaestethics is to comprehend and identify the neurobiological structures that trigger emotions when an artist is creating an artistic object and when a viewer is watching an artwork (aesthetic appreciation). Although some research focused on musical production and appreciation, and thus, on the relationship between auditory perception and emotion, the largest attention has been dedicated to the study of visual art.

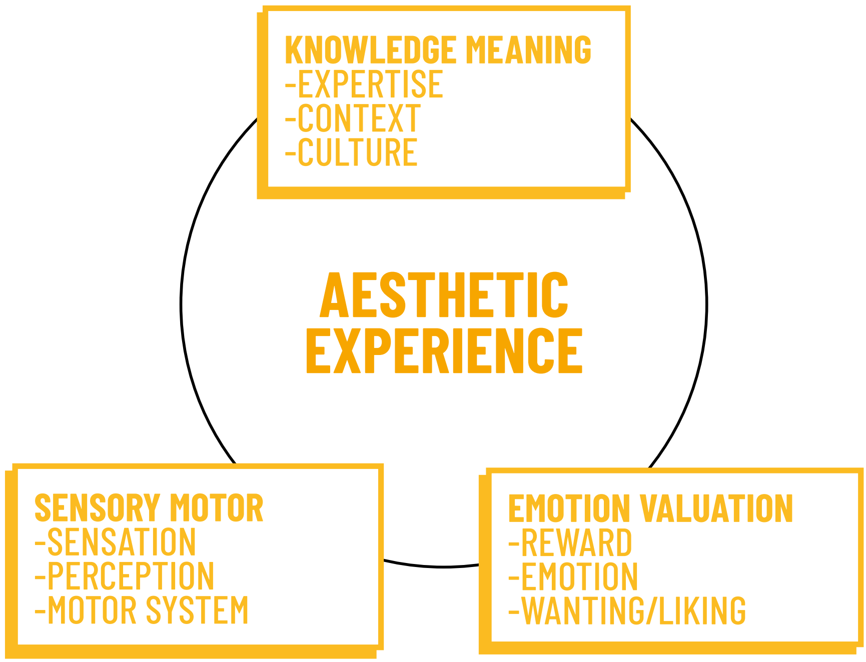
Indeed, vision is considered as the most important sensory modality for humans, and became the most studied perceptual modality in neuroaestethics, as well as in the whole field of neuroscience. Indeed, some of the most widely accepted theories on aesthetic appreciation directly rely on our current views on the organization of the visual system, which is hierarchical (meaning that visual information is transferred from regions that process simple aspects of an image, to areas that elaborate more complex and abstract aspects) and distributed (meaning that different brain areas mainly process different aspects of an image, such as shapes, color, movement, etc.).

Semir Zeki, one of the pioneers in the fields of both vision neuroscience and neuroestethics, claimed that artistic works explore the many different ways in which the same object can be represented, relying on the brain's ability to match what we see with more abstract inner representations. This capacity of abstraction could be what allow our brain to appreciate forms of artistic representation that are distant from real objects or shapes, and provides a neural basis for the primary tools of visual artists: lines, shapes and colors. Zeki's theory also extends to explain the existence of a huge number of different styles: he proposes that different styles target different cortical regions within the visual hierarchy. In sum, art may be seen as a window on the multiplicity of inner representations embodied in the human brain.

Semir Zeki
TED talk:
"The neurobiology of beauty"

However, when we appreciate a piece of art, the visual areas of our brain (or the auditory areas, in case of music) are not the only part of the brain that is involved.
Human neuroimaging studies have in fact shown that beyond visual regions – which process visual elements (e.g., luminance, color, and motion) and make sense of people, objects or landscapes -, looking at a painting also activates three other major components: part of the motor system (the so-called 'mirror system'), a network of brain areas that modulates emotion and reward, and higher-order hubs whose recruitment subserves the appreciation of compositional strategies and individual artistic styles.

→ The aesthetic experience arises from interactions between sensory-motor, emotion-valuation, and meaning-knowledge neural systems. Modified from Chatterjee & Vartanian, TICS 2014



The discovery of the so-called 'mirror system' in humans has represented a further stimulus for neuroesthetic research. The mirror system consists of a set of brain areas that are activated both when we perform an action and when we observe someone else performing the same act. This system has been suggested to mediate our understanding of the aims and intentions of other individuals.

Interestingly, researchers demonstrated that an explicit action is not always necessary to trigger an activity in the mirror system, which may also be observed when the action remains implicit as in static pictures. Based on this observation, researchers suggested that a form of "embodied action recognition" could also extend to static representations offered by paintings and sculptures.

According to the embodied cognition hypothesis, the mirror mechanism represents the key to literally 'simulate' the feelings, intentions and actions of other individuals, which resonate in our brain. Therefore, the poses, actions and scopes of bodies represented in paintings or sculptures are internally simulated by the mirror system, and thus evoke an 'emphatic' aesthetics response. The same principle has been suggested to apply to implicit actions in which an actor is not even present, such as in the cases of "the cuts" by Fontana, or in the patterns typical of Pollock's masterpieces.

The mirror neuron system may be involved in art appreciation through an embodied mechanism allowing the direct simulation of actions and emotions.

Importantly, the idea of embodied cognition has been extended beyond pictorial or sculptural forms of art, to architectural design. In fact, the use of particular materials and designs has been suggested to allow the creation of a deep relationship between the individual and the object or the environment. Potentially, the application of this idea to the working environment could help employees to feel more engaged with their surroundings.

This line of research, which extends from small home or work environments to whole cities, attracted a growing interest in the last decade due to the possible beneficial effects of specific design strategies in reducing stress levels and improving mental well-being. In fact, available evidence seems to suggest that our brain may benefit from a right

VS Ramachandran
The neurons that
shaped civilization

balance between multisensory stimulation, which increases arousal levels, and more relaxing environments (e.g., natural landscapes), which may facilitate stress recovery.

The brain areas involved in the affective responses to artworks include the same regions that mediate the judgement of objects of evolutionary importance (i.e., providing a survival advantage in a natural environment). Such regions encompass for instance the anterior insula and the orbitofrontal cortex. In fact, these brain areas are found activated, for instance, when we evaluate the desirability of a particular food, or the attractiveness of a potential mate. Such results indicate that our brain may be equipped with a general aesthetic system that determines how appealing an object is for us.

Thus, from an evolutionary perspective, our ability to appreciate artworks such as paintings and music seems to depend on brain mechanisms (i.e., specific areas and functional networks) that may have originally evolved for the appraisal of objects of biological importance (food, potential mates, etc.). In this light, the aesthetic processing may essentially correspond to the appraisal of the value of an object, that is, an evaluation of whether an object is “good” or “bad” for the observer. A similar functional brain mechanisms may thus apply to the evaluation of a wide range of objects or conditions, from food to possible mates, and from pieces of art to social interactions. In fact, ‘Pleasure’ can be regarded as the common mechanism used by our brain to ‘tell us’ that something is good for us, and that we should try to experience it again.

And finally, how does our brain recognize (and hopefully appreciate) a Kandinsky among other canvas? How does cultures and epochs influence appreciation? How do we modulate our expectation for a Van Gogh? And why do we have a greater engagement when knowing the story of an artwork? These aspects are the less understood elements of aesthetic experiences but they appear to be widely distributed through the brain and involve brain areas typically recruited for (autobiographic) memory, attention, expertise, mentalizing and many other mental functions.

Researchers suggested that discoveries within the field of neuroaesthetics could be used to greatly improve the subjective experience of pieces of art in a museum. Indeed, in exhibit design there should be a fine balance between surprising the visitor and helping the visitor make sense of the content. By understanding how visitors to the museum actually look at art, researchers hope to make the pieces in museums easier to navigate and appreciate. To this aim, researchers have started to investigate not only reactions

induced by a single piece of art, but also experiences associated to a visit in a real museum, and curators of several modern museums have started to rely more and more on neuroscientific findings for the preparation of their expositions.
This became possible thanks to novel neuroscientific tools, such as portable electroencephalographic (EEG) and eye-tracking systems, that can be wore with minimum discomfort by the visitors of the museum.

Eye tracking: An eye tracker is a device that allows to measure eye positions and eye movement. By examining parameters related to fixations, saccades, pupil dilation and blinks researchers can determine which aspects of a scene (e.g., a specific setting in which a piece of art is presented) efficiently capture the attention of the observer and which aspects produce an arousal response.

Electroencephalography: Simple EEG systems can measure electrical activity produced by the brain during observation of a particular scene. Indices obtained from EEG signals can be used to derive measures of attention, emotional valence (positive or negative) and emotional arousal.

Electrocardiograph, skin conductance, and other measures of peripheral activity: Situations associated with an emotional response modulates the activity of the so-called 'autonomous nervous system', which controls heart rate, respiratory rate, pupillary response and perspiration (sweating). Specific sensors can be used to measure these parameters and thus obtain information regarding the level of arousal and engagement of the observer.

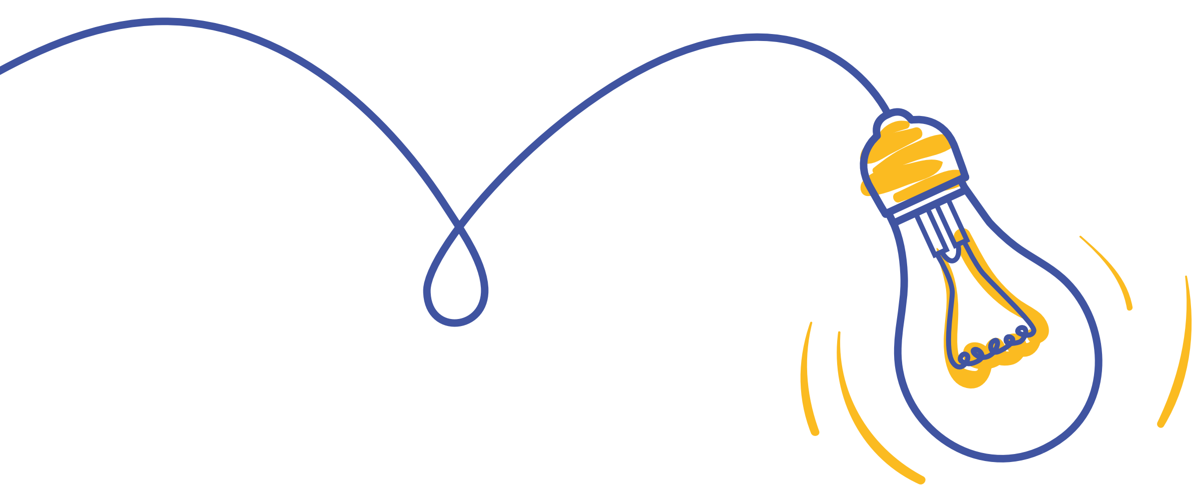
These devices may allow to determine whether the context in which the pieces of art are presented is associated to a positive brain reaction, in terms for instance of attentional focus, engagement and emotional response (but may also highlight which aspects may determine a loss of focus and attention). The combined use of multiple devices/tools and indices may allow to obtain more accurate estimations. However, it should be kept in mind that subjective experiences generated by our brains are strongly modulated by individual predisposition and previous life events. Therefore, different individuals may have distinct subjective experiences when presented with a same 'perceptual experience' (i.e., piece of art). In this light, psychometric (personality traits) and demographic (age, sex, etc.) variables should be also taken into account (they may be determined using validated questionnaires) in order to optimally tailor the museum experience for a particular type of 'target' visitor. In fact, depending on the type of individuals toward which the museum experience is oriented, different choices may lead to a better, more enjoyable subjective experience.

Although achieving a real museum experience equally enjoyable by everyone will likely remain a difficult task despite the new technologies and knowledge produced by a neuroscientific approach. We can imagine a near future in which this information is used for the creation of virtual reality visits to museums and interactive 'mixed-reality' experiences. These might accommodate in real-time the individual characteristics and preferences or, potentially, even relative variations in the psychophysical state and in specific desires of each visitor of the museum (e.g., through real-time changes affecting the environment, such as light, colors, background music, etc.).

Indeed, many modern museums are already moving in this direction, with the introduction of 'augmented-reality' systems, which allow the presentation of visual and auditory (but potentially also haptic and olfactory) stimuli that accompany and complement the 'real' experiences in the museum.
The aim of these approaches is not just to replace classical 'audio-guides', but rather to generate novel, more emotionally-rich and involving experiences for the visitors of the museum through the mixing of multiple sensory (multi-sensory) stimuli.

The neuroscience of creativity

Creativity is the process of bringing something new into being. Creativity could apply to intangible (such as an idea or a scientific theory) or a physical object (such as an invention or a piece of art). The neuroscience of creativity aims at investigating the brain functional correlates of creative behavior. Numerous studies have been performed to investigate brain activity across a myriad of creative or artistic tasks, from sketching an illustration to composing a new musical piece. These studies inevitably encountered several issues and limitations, for instance due to the fact that an 'act of creation' may be not easily attained in the experimental context of neuroimaging studies, where time and movements are often limited. Thus, additional investigations tried to compare instead individuals showing different abilities at identifying 'creative' solutions for specific problems. All these studies allowed to reveal that creativity does not depend on a single part of the brain, but rather on the integrated work of multiple brain 'networks'.



Highly creative individuals may differ from others for a high level of specialized knowledge and a strong capacity for divergent thinking. In terms of brain activity, they often display a distinctive recruitment of frontal areas, which are typically involved in fundamental high-level functions, such as decision making, impulse control, working memory, etc. Indeed, conditions associated with an abnormal function of the frontal lobe (such as depression or anxiety) are typically associated with decreased creativity. However, other investigations showed that creative thinking may ultimately involve a strong interaction between multiple areas and systems: the 'default-mode network' (related to reflection and daydreaming), the 'executive control network' (activated when a person needs to focus attention) and the 'salience network' (involved in the switching between executive and default mode networks).

Nick Skillicorn
TED talk:
"The science of improving your brain's creativity"

However, several lines of evidence from cognitive and neuroscience investigations suggest creativity may be encouraged or enhanced through optimizing the creative environment or through creativity training.

Some studies have suggested that creativity may be boosted when individuals are in the 'right' environment, and especially one with:

- Moderate levels of ambient noise; should be instead avoided loud music in headphones or environments where is common to hear other people talking on the phone.
- Moderately warm temperature; should be instead avoided environments that are too cold or too hot.
- Low level of environmental light; however, increasing the brightness may help focusing and attention, so that different types of activity may require different light conditions.
- Relative disorder; in fact, a tidy and organized environment seems to reduce potential creativity.

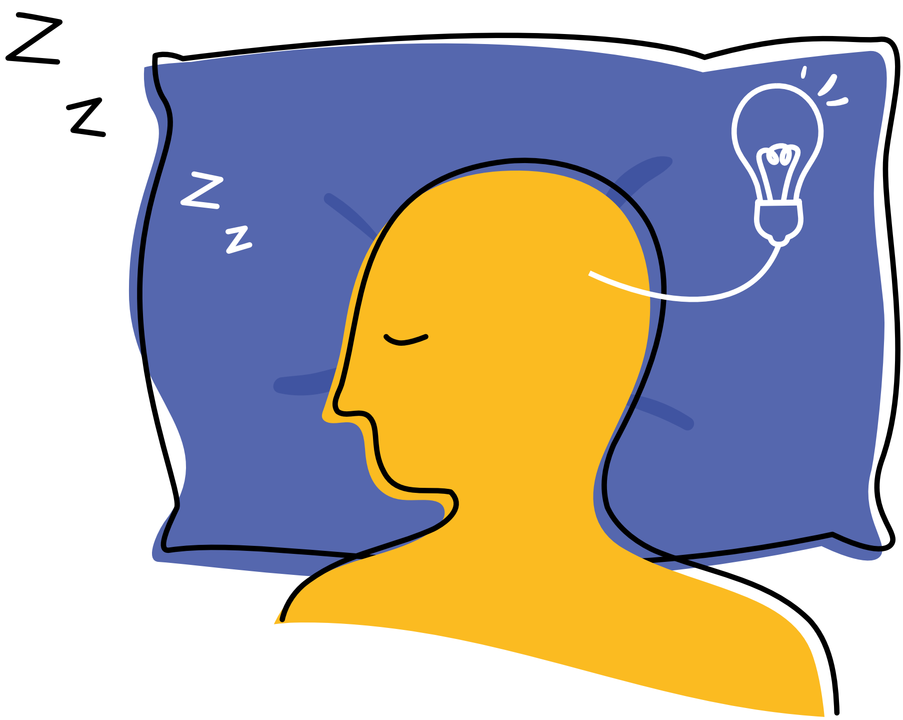
As a matter of fact, these observations simply point to an intuitive fact: creativity is impaired when we are nervous or stressed, busy or surrounded by other people's activity and noise.

On a different perspective, when it comes to teaching or learning 'creativity' things get more complicated, as scientific results are less solid and hard to be interpreted. Indeed, while some authors claimed that particular learning strategies may help to improve creativity, other research casted doubts on the validity of their claims or on their generalizability. Indeed, while creativity training may work for a specific task or context, this effect do not usually extend to other activities and situations.

The aspect on which most theories and strategies seem to agree is that creativity requires at least two (but probably more) steps: a first step based on engagement, study and reasoning, and a second step, usually referred to as 'incubation'. The key-concept of incubation is that creativity often requires our mental processes to be free of cognitive, spatial and temporal constrains. Indeed, even if we are not apparently working actively on a particular task, our brain may continue to process previously stored information, thus creating novel associations and ideas. A creative solution may thus appear at the most unexpected time, but often, exactly when we are not actively working on the specific task that we are trying to solve.

Researchers have suggested that creativity may require four fundamental steps:

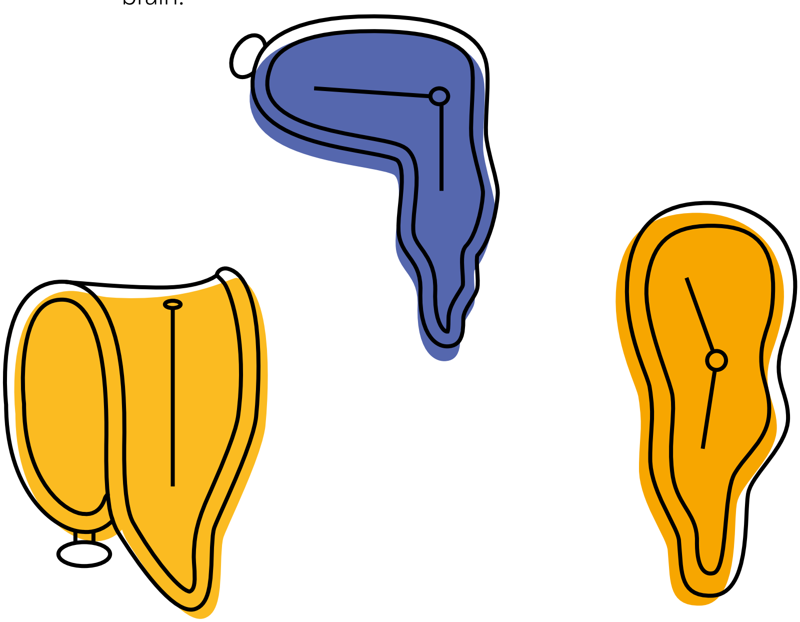
preparation (the gathering of knowledge and previous ideas), incubation, illumination (when the solution is found)... and verification!



The validity of this notion is immediately clear in a well-known example: that of sleep. Indeed, specific phases of sleep, and in particular those associated to rich and vivid dreams, have been suggested to favor the reorganization of memories and knowledge in new combinations, thus favoring creative processes. Some researchers proposed that this process could be possible thanks to a partial de-

activation of the frontal brain areas during sleep, which would lift the continuous supervision of our rational conscious part, allowing for more creative processes to emerge.
Thus, while we sleep our brain may continue to elaborate and analyze problems that our conscious minds have failed to solve. Does not surprise that many important scientific discoveries have been reported to have occurred following a night dream. For instance Dmitri Mendeleev wrote to have had a dream in which he saw a table where all elements fell into a right position relative to others. This dream led to the 'table of element' which provides a logical organization to all chemical elements. In a similar fashion August Kekulé said to have discovered that the atoms of benzene are arranged in a ring thanks to a dream in which he saw the atoms arranging themselves in the shape of a snake biting its own tail.
These are just few of many examples that show us once more time the importance of sleep for the optimal functioning of our brain.

Adam Grant
The surprising habits of original thinkers



The link between sleep, dreams and creativity was known even before the advent of neuroscientific investigations, and was even voluntarily exploited by some artists. The most famous example is certainly the one of Salvador Dalì. In fact, he did not just use dreams as a source of inspiration for his surrealist paintings, he proactively harnessed the power of sleep and dreams. His technique is known under the name "slumber with a key":

«You must seat yourself in a bony armchair, preferably of Spanish style, with your head tilted back and resting on the stretched leather back. Your two hands must hang beyond the arms of the chair, to which your own must be soldered in a supineness of complete relaxation. [...] In this posture, you must hold a heavy key which you will keep suspended, delicately pressed between the extremities of the thumb and forefinger of your left hand. Under the key you will previously have placed a plate upside down on the floor.... The moment the key drops from your fingers, you may be sure that the noise of its fall on the upside down plate will awaken you.»

Salvador Dalí, *Fifty Secrets of Magic Craftsmanship*

Using this method, the artist was able to wake-up from a state exactly in between wakefulness and sleep, where the brain may produce so called "hypnagogic images" (from Greek "leading to sleep"), often representing a mixture of recent experiences and unpredictable features created by the sleeping brain.

Experience of Artech Gallerie d’Italia

ArtTech
“Arte e innovazione si incontrano in un esperimento pionieristico presso Gallerie d’Italia”

GALLERIE D’ITALIA
PIAZZA SCALA
MILANO

Regarding Art and Neuroscience, the Intesa Sanpaolo Innovation Center and Intesa Sanpaolo Gallerie d’Italia - Piazza Scala, in collaboration with TSW (which measures personal experience quality) – carried out a pilot experiment on four artworks at Gallerie d’Italia as part of the exhibition: *L’ultimo Caravaggio. Eredi e nuovi maestri* (*The last Caravaggio. Heirs and new masters*):

The aim was to measure the emotional impact of the different artworks on a sample of 30 volunteers, ranging from employees of Intesa Sanpaolo and Intesa Sanpaolo Innovation Center, journalists and neuroscientists from the IMT school in Lucca.

→
Martyrdom of Saint Ursula
Caravaggio

→
Martyrdom of Saint Ursula
Bernardo Strozzi

→
Martyrdom of Saint Ursula
Giulio Cesare Procaccini

→
Last Supper
Giulio Cesare Procaccini

↑
SMI ETG 2W
Wearable eyetracker

↑
Emotiv Epoc +
14 channel wearable EEG

↑
Empatica E4
SCL bracelet

Thanks to TSW, which uses qualitative research protocols pertaining to human sciences as well as quantitative analysis tools, 3 devices were used, as described in the chapter:

Eye tracking: to study how volunteers looked at artworks and understand which areas interested them most;

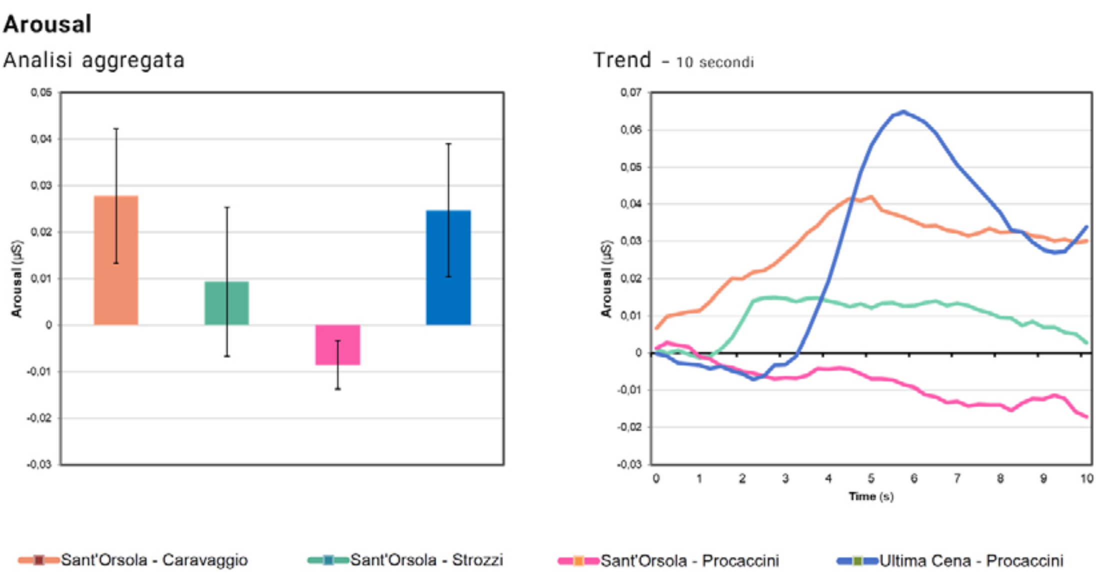
EEG 14 channel: to analyze how involved and pleased people were by the artworks;

Stress bracelet: to track the changes in skin conductance due to involuntary sweating caused by the parasympathetic system.

The procedure was as follows: After recording physiological parameters at rest (Baseline), participants were asked to look at four artworks in a certain order. To make sure each participant was exposed to the artworks in the same way and guarantee an element of surprise a screen was used and then removed when the volunteer was in front of the artwork. Participants looked at each painting for 30 seconds while seated and were then given the chance to look freely for another minute.

Executive Summary of the Pilot
After the analysis, psycho-physiological responses seem to support the evidence that:

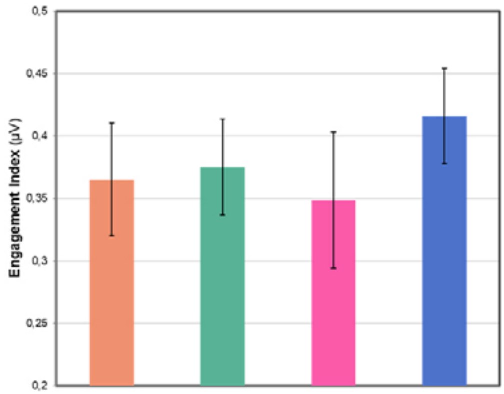
The Last Supper by Giulio Cesare Procaccini and ***Martyrdom of Saint Ursula*** by Caravaggio have the highest impact in terms of emotional intensity (i.e. **arousal - stress bracelet**).



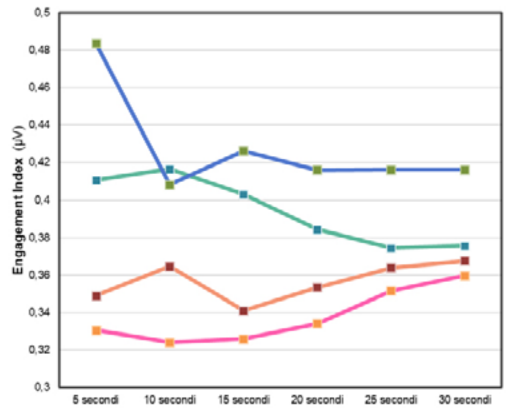
The Last Supper by Giulio Cesare Procaccini generates the highest engagement **(EEG)**.

Engagement

Analisi aggregata



Trend - 30 secondi

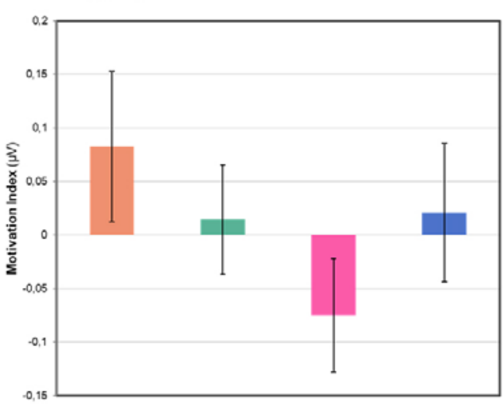


Sant'Orsola - Caravaggio   Sant'Orsola - Strozzi   Sant'Orsola - Procaccini   Ultima Cena - Procaccini

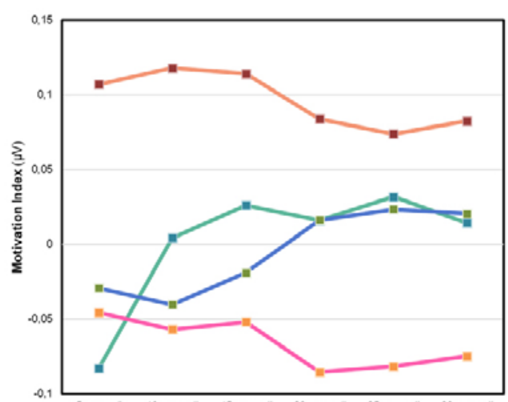
Martyrdom of Saint Ursula by **Caravaggio,** on the other hand, generated the most pleasure (EEG) and is also the artwork that creates the most impact among the three Saint Ursulas analyzed.

Motivation

Analisi aggregata



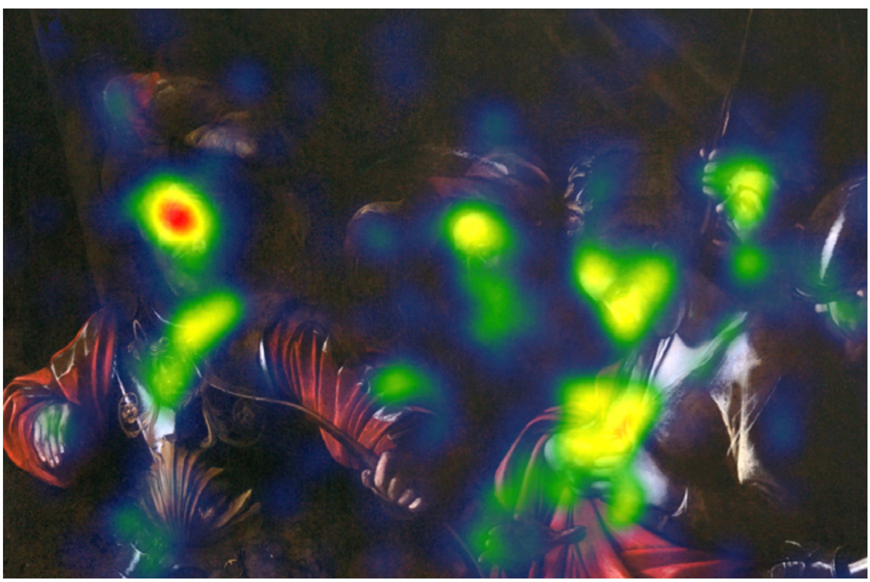
Trend - 30 secondi



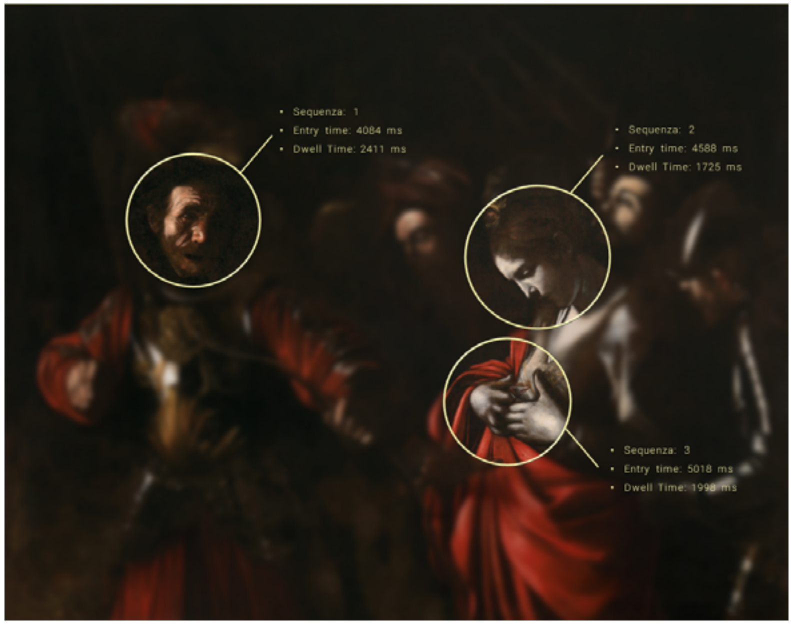
Sant'Orsola - Caravaggio   Sant'Orsola - Strozzi   Sant'Orsola - Procaccini   Ultima Cena - Procaccini

Eye tracking results– examples of results on Martyrdom of Saint Ursula by Caravaggio

Aggregate analysis of what the eye stares at – heatmap - shows us the areas of most interest, going from red to yellow to green. For instance, in the Martydom of Saint Ursula by Caravaggio during the first 30 seconds of exposal the most prominent features are the main characters' faces and the wound caused by the arrow. In particular, Attila's face and Saint Ursula's wound are very significant, while the other faces make slightly less impact.
As time passed participants' attention was also drawn to the other characters in the painting.



Furthermore, eye tracking provides indications on the AOI (Area Of Interest) thus making it possible to obtain important information regarding the order and time each person dedicates and analyze certain ocular behavior in detail.
The first thing people look at in this painting is Attila's face, followed by Saint Ursula's and lastly the wound. On average people dedicated more time analyzing Attila's face (Dwell Time 2411 ms) compared to other elements in this analysis.



When comparing **eye tracking analysis** a significantly different behavior emerges towards the three paintings of Saint Ursula.

- **Caravaggio's painting** succeeds in highlighting and maintaining a balance between three basic elements: Saint Ursula, Attila and the moment of killing. Attila has a particularly significant role.
- In **Bernardo Strozzi's work** attention focuses on Saint Ursula as a whole. Attila's role and the killing are of secondary importance.
- **The painting by Giulio Cesare Procaccini** defines a hierarchical experience which gives Saint Ursula and her face the most prominence. The second most salient element is Attila's expression. The moment of killing comes last.
- Regarding ***The Last Supper* by Giulio Cesare Procaccini**, the gaze sweeps horizontally starting from the center (interaction of Jesus). The elements to the right and left of the picture give rise to a uniformed behavior.

Conclusions

Psycho-physiological analysis proves to be fundamental in supplying clues on users' emotional experience. This analysis, carried out thanks to TSW and its methodological approach, shows it is possible to evaluate and thus create an artistic experience to bring about the desired emotional impact.

In general, it is advisable to make sure the artistic experience helps memory processes. We therefore recommend using artworks with a strong emotional impact, high engagement and motivation at the start (primacy effect) and the end (recency effect) of the viewing.

With reference to the works analyzed, the painting by Caravaggio and The Last Supper might be the founding elements of this experience. Analyzing ocular behavior could, for instance, stimulate the creation of a content (i.e. audio guide) which brings out the characteristic components of the work that are not highlighted. Moreover, it might be useful to analyze the contents of accompanying accessories (i.e. video) to understand their real role in enhancing the artistic experience.

Emotional experience of users

Processes of retention

Contents accessories

emotiv.com

Emotiv BrainViz

Emotiv + Singapore Tourism

Emotiv

Emotiv is a bioinformatics company advancing understanding of the human brain using electroencephalography (EEG). Its technology falls under the umbrella of BCIs (Brain Computer Interface) also referred to as MMI (Mind Machine Interface), DNI (Direct Neural Interface), BMI (Brain Machine Interface) and aims to track cognitive performance, monitor emotions, and control both virtual and physical objects via machine learning of trained mental commands. Emotiv's Mental Commands algorithm recognizes trained thoughts that can be assigned to control virtual and real objects just by thinking. Brain control can replace traditional input devices like keyboards, enhance interactive experiences and provide new ways for the disabled to engage with their surroundings. With Emotiv's Performance Metrics, an individual's real time cognitive and emotional state can be used to passively modulate an application. Adapt a VR experience based on a user's engagement or change the difficulty of an interactive training application based on focus levels. The EPOC+ 14 channel EEG has been independently validated against a clinical Neuro Scan EEG, providing statistically comparable EEG data in an ERP study. EMOTIV was founded in 2011 by Australian tech entrepreneurs Tan Le (CEO) and Dr. Geoff Mackellar (CTO). It now has headquarters in San Francisco, and offices in Sydney and Hanoi.

EMOTIV

Funding

Fully self funded

INTERVIEW

Zaira Cattaneo
Associate Professor in Psychobiology and Physiological Psychology, Department of Psychology, University of Milano-Bicocca, Milano, Italy

What is the impact of our experiences, and especially aesthetics experiences, on our brain and our mental status?

Reading on this topic

Chatterjee, A., & Vartanian, O. (2014). Neuroaesthetics. *Trends in Cognitive Sciences*, 18, 370–375.

Schindler, I., Hosoya, G., Menninghaus, W., Beermann, U., Wagner, V., Eid, M., & Scherer, K. R. (2017). Measuring aesthetic emotions: A review of the literature and a new assessment tool. *Plos One*, 12(6), e0178899.

Vessel, E.A., Starr, G.G., Rubin, N. (2013). *Art reaches within: aesthetic experience, the self and the default mode network*. Front. Neurosci. 7: 258.

Aesthetic experiences are emergent states, arising from interactions between sensory–motor, emotion–valuation, and meaning–knowledge neural systems. Although aesthetic experiences may be driven by different external stimuli (for instance, a sunset), a great source of aesthetic experience is art. A broad range of emotions occur in response to the perceived aesthetic appeal of artworks. Aesthetic experience affect arousal ranging from activating effects (energy and vitality) to calming (relaxation) effects. Prototypical aesthetic emotions are the feeling of beauty, of being moved, fascination, and awe; still, we may also like an artwork that we find worrying just because it moves us. Mental states like interest and insight (i.e., understanding the artist's intention) typically accompany viewing of artworks. In turn, negative emotions may contribute to aesthetic displeasure (i.e., the feeling of ugliness, boredom, and confusion). Specific questionnaires have been developed to measure different aspects implied in aesthetic experiences.

An emerging field of research within cognitive neuroscience – Neuroaesthetics - is specifically concerned with understanding the biological bases of aesthetic experiences. Research in this field suggests that aesthetic appreciation relies on the activity in a broadly distributed network of brain regions. In addition to cortical and subcortical regions related to pleasure and reward, frontal cortical areas involved in decision-making and evaluation, have been identified as key neural substrates of aesthetic appreciation. Moroever, the level of activity in sensory regions may also be an index of the extent to which we like a certain artwork. Interestingly, viewing pleasant artwork has been found to activate the default mode network (DMN) previously associated with self-referential mentation. Accordingly, recent views suggest that individuals' taste in art is linked with their sense of identity, with DMN activity possibly serving to signal "self-relevance" of a specific artwork.

Is an aesthetic experience just a neural event like any other, or are there substantive differences?

Reading on this topic
Skov M, & Nadal M. (2018). *Art is not special: an assault on the last lines of defense against the naturalization of the human mind*. Rev Neurosci. 2018 Aug 28;29(6):699-702.

This is a critical question that points to a highly debated topic in neuroaesthetics. Several recent (neuro)psychological models of art experience assume that it is possible to identify psychological and neurobiological processes and functions that are specific to art, and set the experience of art apart from non-art induced pleasant experiences (related for instance to food or drug use). However, this idea has been challenged. Indeed, it has been claimed that the belief that explaining the experience of art requires special, or especially dedicated, cognitive or neural mechanisms has no empirical basis. In turn, a common neural network is likely to represent the reward value of diverse objects, situations, or events as a single neural currency, enabling a direct assessment and comparison of the value and motivational relevance of different kinds of options (including art-derived pleasure).

How can the understanding of the neural bases of perception and aesthetics be applied to improve our social life and our well-being?

Reading on this topic
Brieber D, Nadal M, Leder H. (2015). In the white cube: museum context enhances the valuation and memory of art. *Acta Psychol*;154:36-42.

Research in neuroaesthetics has been mainly devoted to shed light on the psychological and neural mechanisms mediating aesthetic experience, this enhancing our understanding of the mind-brain complex interrelation, with no direct "application" aims (as in many other fields of basic de Tommaso M, Sardaro M, Livrea P. (2008). Aesthetic value of paintings affects pain thresholds. *Conscious Cogn.*, 17(4):1152-62.

Graham DJ, Stockinger S, Leder H. (2013). An Island of Stability: Art Images and Natural Scenes - but Not Natural Faces - Show Consistent Esthetic Response in Alzheimer's-Related Dementia. *Front Psychol*.4:107.

research in cognitive neuroscience). However, advancement of knowledge in this field certainly has a translational impact. Indeed, the aesthetic experience through art is a window into the study of emotions, and it has been shown that art-appreciation may be impacted by different neurological and psychiatric diseases, such as dementia or schizophrenia. For instance, although Alzheimer's disease causes severe impairments in cognitive functions, there is evidence that aspects of esthetic perception are somewhat spared: in these patients basic aesthetic judgment of artistic images may represent an "island of stability" and as such, aesthetic response could be a promising route to future therapies. There are also findings suggesting that the aesthetic value of paintings may affect pain thresholds, again paving the way for possible applications in clinical settings. Studies on art fruition in healthy individuals may also have a translational impact. For instance, converging findings show that encountering real art in the museum (compared to online fruition) enhances cognitive and affective processes involved in the appreciation of art and enriches information encoded in long-term memory, with important implications for educational/cultural programs.

GLOSSARY

FOCUS ON: ARTS & CREATIVITY

4

Empirical aesthetics
Study of aesthetic perceptions of art, music, or any object that can give rise to aesthetic judgments.

Neuroaesthetics
Study of the neural bases for the creation and contemplation of art works.

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Onarheim, B. and Friis-Olivarius, M., 2013. *Applying the neuroscience of creativity to creativity training*. Frontiers in human neuroscience, 7, p.656.

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https://www.youtube.com/watch?v=y44GBM99JOA
https://youtube.com/watch?v=fxbCHn6gE3U

05

Focus on: Learning & Training

Brain plasticity and cognitive efficiency

Differences in cognitive abilities among individuals are linked to behavioral performance and in turn, to the individuals' level of intelligence. In fact, intelligence is commonly defined as a general mental capability related to reasoning, problem-solving and abstract thinking, but also to emotional reasoning and creativity. In the field of psychology, intelligence is commonly measured using tests designed specifically to evaluate the set of features and resources people use to solve a wide gamut of cognitive tasks.

All tests of mental abilities are positively correlated with each other.
This implies that there is a common mental ability, usually indicated as 'general intelligence' that accounts for these associations.

The Intelligence Quotient (IQ) is one of the most common measures used to estimate general intelligence. Specifically, the IQ is a score obtained by dividing a person's 'mental age' (derived from a standardized intelligence test), by the person's chronological age (expressed in terms of years and months). The division's result is then multiplied by 100. Thus, an IQ of 100 means that the person's intelligence score is similar to the scores of other individuals of the same age. Just as a reference, the theoretical physicist Albert Einstein and the cosmologist Stephen Hawking are believed to have reached an IQ of 160 (although they probably have never undertaken an actual IQ test). The IQ is considered as a valuable index of intelligence, but many scientists criticized the idea that all different aspects of intelligence could be summarized in a single index.

Indeed, as Charles Spearman noted in 1927:
«*Every normal man, woman, and child is, then, a genius at something, as well as an idiot at something*.»

What is 'intelligence'?

Binet
Judgment, otherwise called "good sense", "practical sense", "initiative", the faculty of adapting one's self to circumstances.

Gardner
An intelligence is the ability to solve problems, or to create products, that are valued within one or more cultural settings.

Sternberg
Viewed narrowly, there seem to be almost as many definitions of intelligence as there were experts asked to define it.

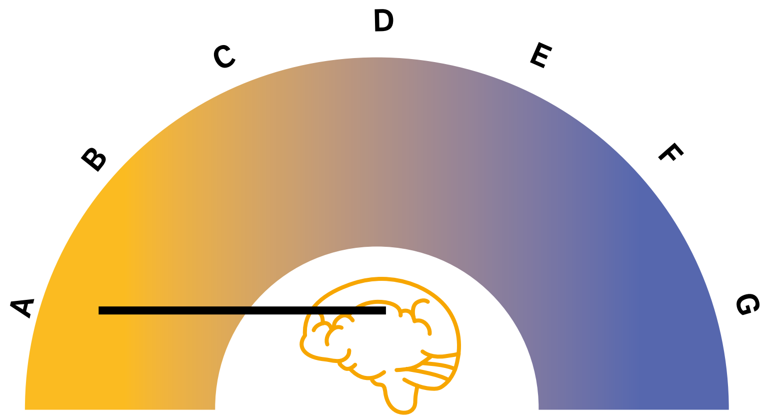
Teo Härén
TED talk:
"Let's talk about your creative IQ"

Nowadays researchers are able to investigate the neural correlates of general intelligence and its specific subtypes by means of new neuroimaging techniques. Changes in the activity or structure of a distributed brain network, including frontal and parietal areas, may predict individual differences in intelligence and reasoning. This is according to an important review study that aimed at comparing results of functional and structural neuroimaging investigations. In addition, evidence gathered by neuroimaging studies showed that the brain of skilled or more intelligent individuals might operate in a more efficient manner compared to the brains of most people of the general population.

Neural Efficiency Hypothesis
Some neuroimaging studies revealed that smarter individuals show lower (more efficient) brain activation than less bright individuals during tasks of low to moderate difficulty.

Neural plasticity
Lasting changes in our brains can occur during the lifespan. This is a specific characteristic of the brain to modify itself according to experience.

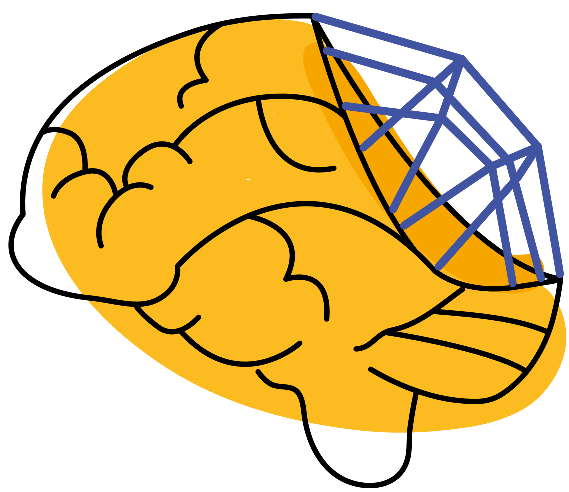
Any system can be considered 'efficient' when it can complete its duties correctly with the minimum expenditure of energy and time. An individual is said to show greater 'neural efficiency' when he/she achieves optimal performance (minimization of errors) and speed through minimization of energy waste. In an efficient brain, only the key-areas required to cope with a task are activated and communicate with each other showing minimal loss or dispersion of information, thus avoiding a redundant activation of unnecessary portions of the cerebral cortex.



Energy Efficiency

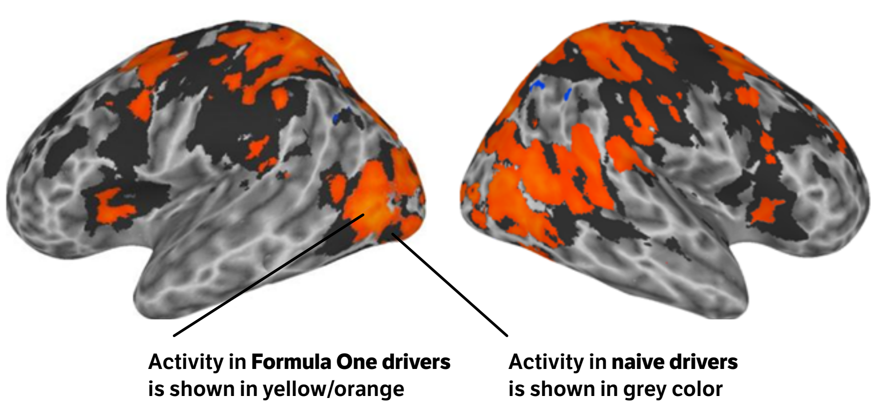
Efficiency is a feature of brain organization: different brain areas operate and communicate effectively while minimizing the waste of energy resources.

While differences in neural efficiency allow explaining at least some of the relative differences in behavioral and cognitive skills across individuals, it is currently less clear to which degree brain efficiency is an inherent, genetically determined feature or a modifiable one. Indeed, neural efficiency could be represented as an innate trait, of which only some individuals are endowed since the brain areas responsible for cognitive performance are sensitive to genetic influence. Such predisposition, potentially affecting some skills more than others, may represent the functional basis of innate talents showed by some individuals. However, it is now known that cognitive and behavioral performance, and neural efficiency, are also dependent on training, learning, and acquisition of knowledge in a specific domain. In fact, the human brain is able to learn and adapt to new challenges by reorganizing itself through changes in connections among neuronal populations. This ability is referred to as "neural plasticity", and represents the basic neural mechanism through which our brain adapts to the ever-changing environment humans constantly interact with.



Extensive practice of specific skills/activities, as for instance in athletes, not only determines an improvement in body speed and performance but may also result in permanent anatomical and functional brain modifications. Thus, for instance, the brain of a Formula One (F1) driver shows a higher degree of neural efficiency (i.e., display a lower level of activation) as compared to the brain of a common driver, during tasks that require simple visuospatial and motor skills. On the same line, a recent study showed that the Brazilian football player Neymar da Silva Santos Junior deals more efficiently with tasks requiring motor control of foot movements when compared not only with non-professional footballers but also with top-level athletes in other sports. These lines of evidence indicate that the brain rewires and refines its connections in a way that become more specific to the type of performed activity/training. Hence, the brain can develop and modify its structure and functioning through experience, and increase its operational efficiency in different tasks. Importantly, any experience –being it just mental, or purely physical- can leave an important trace in our brain, influencing the efficiency of distinct cognitive processes. For this reason, many professional athletes combine a mainly physical training with mental trainings and simulations. For instance, F1 drivers not only perform physical activities such as running, cycling or weight-lifting, but also train on special F1 racing simulators and practice with mental strategies aimed at improving concentration and stress management. Often, athletes also take advantage of mental simulations of specific actions or situations (e.g., creating a mental map of a race track), as these may contribute to strengthen specific brain circuits, thus improving efficiency and automaticity during actual trainings or competitions.

Brain activity during a visuo-spatial task



→ Neural efficiency in professional Formula One drivers (vs. naive drivers) during a simple visuo-spatial task

The Guardian
How physical exercise makes your brain work better

Wendy Suzuki
The brain-changing benefits of exercise

All forms of physical exercise not only potentiate specific skills related to strength, readiness for action and movement accuracy, but also have several beneficial effects on particular brain functions, including memory, attention, creativity, and resilience to stress and anxiety. These effects seem to be mostly mediated by changes in brain neuromodulators (i.e., chemical signals released into the brain), the release of factors that facilitate the experience-dependent strengthening of connections among neurons in the hippocampus, and the formation of new blood vessels ('angiogenesis') or even neurons ('neurogenesis').

A large body of research has demonstrated that at least 30 minutes of aerobic exercise every day may induce modulation of gene expression in the brain and beneficial forms of neural plasticity, ultimately leading to behavioral and cognitive improvements.

On a different perspective, several studies in physiological and pathological ageing demonstrated that cognitive decline is often associated with an increase in brain activity (especially within more anterior, prefrontal brain areas) during a variety of cognitive tasks. Researchers suggested that such change may reflect a reduction in brain functional efficiency (neural 'in-efficiency'), which determines an increased need for recruitment of additional brain areas, involved in attention and cognitive control, to compensate for age-related brain functional and structural dysfunctions. Since practice and learning seem to increase neural efficiency, it is natural to think that they may also contrast the effects of cognitive decline.

This idea fits well with clinical observations reporting that physical and cognitive exercises may help to prevent or counteract cognitive decline by improving brain health and functionality. Of note, while mental training is certainly important, several studies demonstrated that even a 'pure' physical exercise may improve cognitive performances, thus indicating that an efficient organism really requires a 'mens sana in corpore sano' (healthy mind in healthy body).

Training, learning and the brain

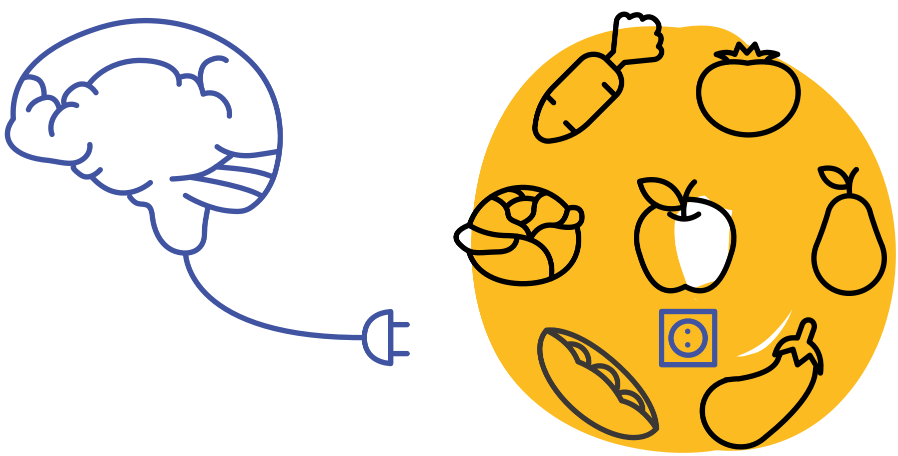
In the previous section, we discussed the beneficial effects of both mental and physical training for general brain functioning and behavior. However, in our modern society, having a trained and 'flexible' mind is often not enough, as we constantly face the necessity to learn (and maintain) novel specific notions and skills. Thus researchers from different fields have always tried to understand how our brain learns and whether learning and retention of information could be accelerated and potentiated. Is there any strategy that could allow us to learn many languages in a short time, or to retain a large amount of information presented during a course? Is there a particular training that we can use to accelerate the acquisition of specific cognitive or motor skills?

Given the relevance of these fundamental questions, it is not surprising that a large number of theories and strategies for the acceleration and improvement of training and learning have been proposed over the years. This search led to the proliferation of many mnemonic techniques (i.e., strategies to improve information retention and/or retrieval), often based on elaborative encoding of information, or on the use of visual and spatial imagery. Some of these techniques have been proved to grant a beneficial strategy for memorization of specific notions or lists of items (e.g., names). Others, however, were later found to be largely or partially inaccurate. One of the most famous examples is the idea that humans could learn during sleep (a phenomenon called sleep-learning, or hypnopaedia). Based on this theory, people were expected to learn novel notions by listening during sleep to previously recorded audio-tapes. However... this just does not work. In fact, neuroscientific investigation of the last decade demonstrated that sleep is actually fundamental for the stabilization of our memories, but only if we have acquired them during the previous waking period! Instead, during sleep, our brain tries to filter-out information coming from the environment around us, and the only effect obtained by trying to stimulate it with recorded voices is a lower sleep quality (and, potentially, a worse memory)...

John Green
Paper towns and why learning is awesome

In a similar way, some foods were believed in the past to have positive effects on memory and attention that they actually do not have. However, recent scientific studies revealed that inclusion of specific foods in a healthy diet may in fact contribute at least at maintaining (e.g., in ageing), if not at improving, an optimal memory and brain functioning. Such effects are mediated by particular substances, including for instance omega-3 fatty acids (present in fishes and walnuts), Vitamins B6, B12, K and folate (found naturally in many animal products or in vegetables), and flavonoids (found in fruits).

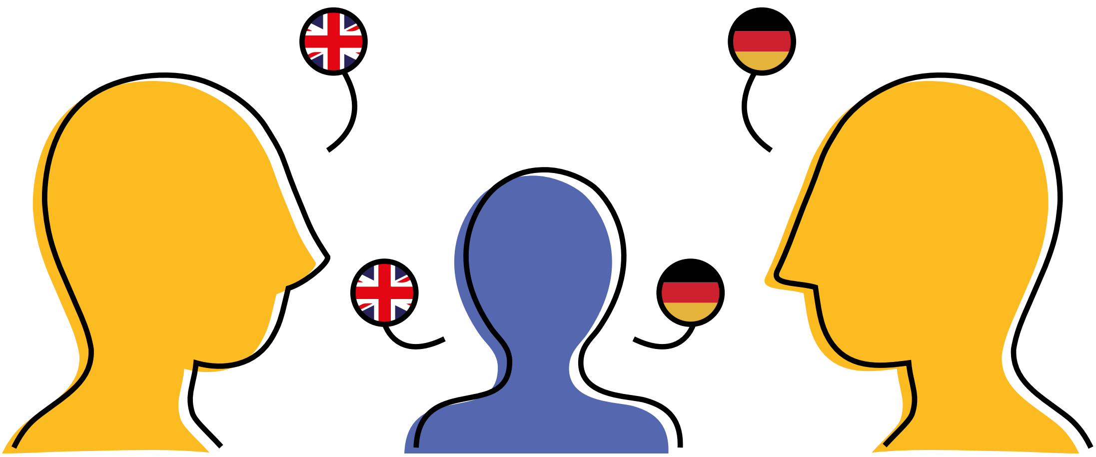
In most cases all these substances are already adequately represented in a normal diet. However, older individuals who have a poor diet and/or (potentially related) memory problems may display important memory and cognitive benefits from the inclusion of these aliments in their diet.



Many years of research have revealed that a huge number of variables may affect not only how efficiently we learn, but also what we do learn with a certain ease and what we do not. Some of these many factors include for instance age, sex, environmental conditions, previous experiences, socio-economical context, psychological traits and individual attitudes and many others. Indeed, for instance, children have a more 'plastic' brain compared to adults, and may thus more easily learn new information and skills. Also, particular skills, such as linguistic or visuo-spatial skills, may be learned more easily at different ages, as the brain undergoes maturational processes that do not involve all areas at a same time. In this respect, an optimal learning strategy should take into account the expected level of brain development in order to offer the right type of experience and information.

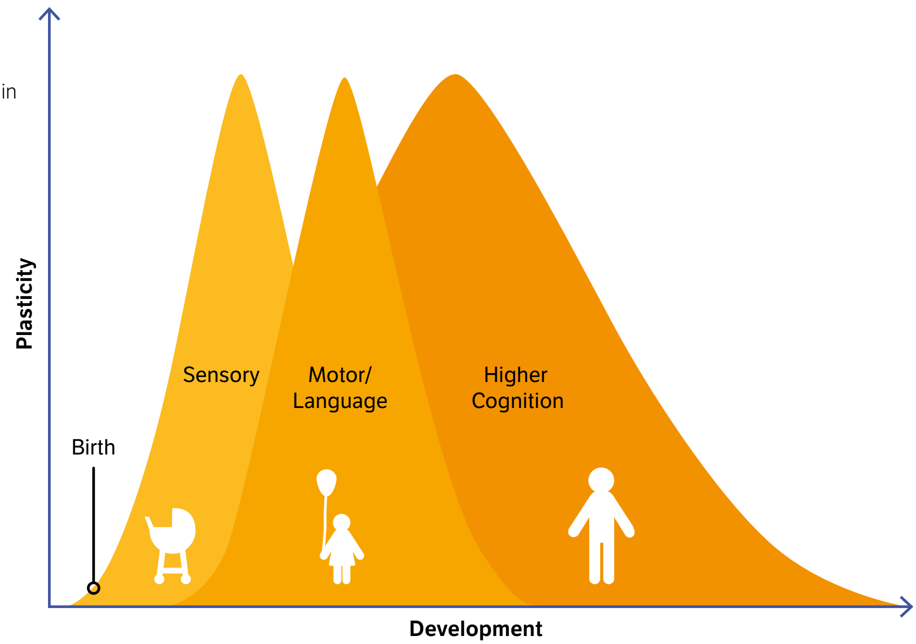
An example of this idea is represented by the acquisition of a first and second language. Several studies showed that high proficiency in a second (non-native) language is more easily attained when such a language is acquired and practiced early in life, typically before age twelve (or even earlier for some authors). In fact, when a second language is acquired early in life, its processing activates exactly the same brain regions that are involved in the processing of a first (native) language (i.e., a left lateralized network, including areas of the frontal, temporal and parietal cortices).

However, this is not the case when the second language is acquired later in life, since a partially distinct set of brain areas appears to be involved. This observation suggests that a second language may be treated differently by our brain depending on the age at which we acquired it. At the same time, it should be noted that individuals may become highly proficient in multiple languages even when these are acquired in adulthood (although the process may result slower due to the relative reduction in brain plasticity). While a possible genetic predisposition has been suggested to play an important role in such acquisition/consolidation process, it is also recognized that one of the most relevant factors in language acquisition is represented by social experience, that is, the reiterated use of a language in daily social contexts. As observed for other types of brain training, acquisition of multiple languages has been associated with a slower cognitive decline physiological ageing and with a slower progression of pathological forms of dementia, such as Alzheimer's disease. Thus, even if new technologies may now allow quasi-instantaneous translation of spoken or heard language, acquisition of multiple languages, at any ages, may still offer important beneficial effects for brain health and general cognitive functioning.



Interestingly, several studies showed that the progression of brain development could be theoretically tracked using particular tests (e.g., for linguistic skills) or neuroimaging techniques. Indeed, the development of specific skills is paralleled by brain structural and functional changes affecting different brain areas and networks, and including for instance relative variations in cortical myelination (i.e., the formation of myelin sheaths around nerves, which allow impulses to move faster) or in the refinement of subcortico-cortical connections. While neuroimaging-based approaches have been successfully used to understand how brain (and skills) development progresses, on average, during infancy and adolescence, they do not currently find a direct application for the definition of tailored learning strategies in individual children due to their limited accuracy in the evaluation of single individuals. However, one could hypothesize that, in the future, an improvement of these approaches will guide teachers and educators in defining optimal learning strategies for individual children in relation to their current level of brain and cognitive development.

→ Windows of Plasticity in Brain Development- spatial task



Autism
Developmental disorder that affects, among other things, how a person acts and interacts with others, communicates, and learns.

Dyslexia
This is a language-based learning disability characterized by trouble with reading despite normal intelligence.

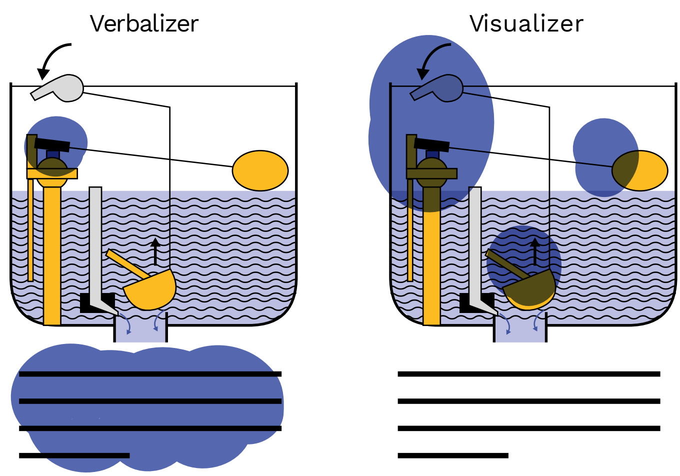
During development (but also in adulthood), particular conditions may also affect learning abilities. For instance, dyslexia, a common reading disorder may affect about 5% of people in the general population, although the percentage can rise to 20% if mild symptoms are also considered. Individuals with this condition may benefit from tailored learning strategies. For instance, it has been found that training focused on reading and spelling may provide long-lasting gains, especially when intervention is started at a young age.

There is also some evidence indicating that the use of particular, more readable text fonts (Dyslexie, OpenDyslexic, and Lexia Readable) may help individuals with dyslexia. Another disorder of development associated to learning-related issues is autism, which affects about 1% of the general population. Children with autism have problems at interacting and communicating with others, and this can directly affect their development and learning. Some studies indicate that these children may also benefit from special training approaches. For instance, discrete trial training (DTT) is a structured instructional procedure that breaks tasks down into simple subunits to shape new skills. The technique relies on the use of prompts, modeling, and positive reinforcement strategies to facilitate learning. Some preliminary studies also suggested that children with autism may learn more easily when they interact with a robot/computerized teacher rather than with a human individual. One of the most evident advantage of such artificial teachers is that they can repeat the same lessons a theoretically infinite number of times, always using exactly the same words without getting tired or upset.

While gender-related differences in learning may appear relatively small during early development, in the post-pubertal period -and in adulthood- females and males often present relevant differences in both behavioral and learning abilities. Indeed, even their brains may show small, but significant structural and functional differences. For instance, the total brain volume is larger in adult males than in females, and some brain areas, such as the amygdala (the brain emotional center) may be larger in males, while others, such as the hippocampus (involved in memory storage) are often larger in females. Moreover, men and women appear to use these brain regions in a somewhat different way when completing memory tasks. Within a particular age-range and gender, individuals may also differ in their specific attitudes. Some learning models distinguish for instance between so-called ‘verbalizers’ and ‘visualizers’. Investigations based on the eye-tracking technique showed that visualizers spend more time inspecting pictures than verbalizers, while verbalizers spend more time inspecting and reading texts. Thus, these two types of individuals seem to favor one specific way of learning over the other.

Visualizers
Individuals who learn mainly from pictures.

Verbalizers
Individuals who learn mainly from texts.



→ Eye-tracking heat-maps from a verbalizer (left) and a visualizer(right). Participants in the study were trying to understand the functioning of a particular mechanism described through text and images.

Based on current knowledge it is clear that individuals may differ in their predisposition to learn certain skills rather than others, but also in their optimal learning strategy. Moreover, their attitude and predisposition may greatly change with age or in relation to the current context and depending on the specific stimuli that they receive. Thus, no single strategy may result valid for all individuals and contexts.
This is even more evident if we think that differences in learning efficiency may also vary depending on the specific

skill or notion that the individual is trying to learn. Indeed, some people may easily and rapidly become proficient in new languages, while others may have a particular predisposition for mathematical concepts. The possible existence of separated, independent 'domains' is also supported by the common observation that newly acquired skills are often non-generalizable, that is, non-transferable to a set of tasks different from those that were practiced during training. This means that training in a particular task (e.g. visuo-spatial task) produces learning and performance changes that are typically not transferred to other cognitive domains (e.g., linguistic, motor, etc.).

Several lines of evidence indicate that training in one cognitive domain may not impact another independent domain.

Ramsey Musallam
3 rules to spark learning

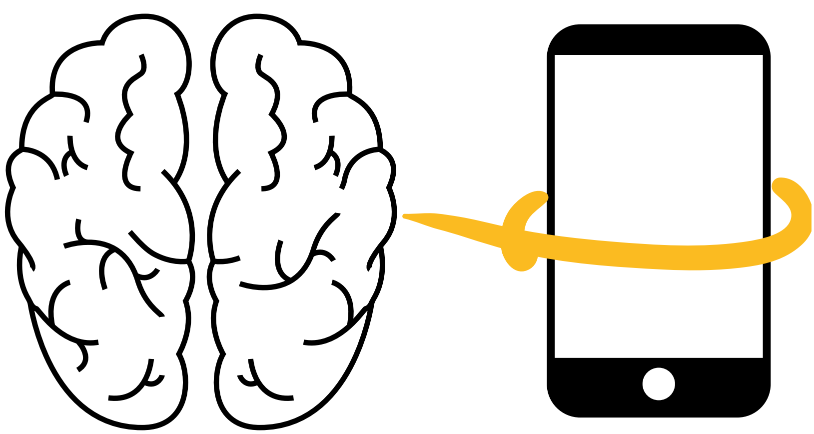
Observations described above imply that teaching and learning strategies, even adapted to specific skills that should be learned or to the environment in which they should be applied, may not benefit all 'learners' in the same way.
For this, more precisely tailored strategies should be defined by taking into account the largest possible amount of details, including for instance, age, sex and individual attitudes. While at present this may appear like an almost impossible task, in a near future, thanks to the improvement of techniques for individual profiling based on both neuroimaging and psychometric tools, it may become possible to optimize a learning strategy to each single individual and condition.

On a different perspective, psychological and neuroscientific investigation have also led to the identification of some factors that may contribute to general aspects of learning and memory retention in the great majority of individuals. First, it should be kept in mind that the human brain learns through the identification of particular 'patterns' that tend to repeat in time. Indeed, it is commonly said that "neurons that fire together, wire together" (Hebb, 1949): the repetition of particular associations strengthen the links between neurons and brain areas, thus increasing the strength of a new memory/skill.

Second, attentional and emotional engagement greatly favor the acquisition and retention of new memories. The brain tends to assign a special meaning to events that are associated with positive or negative emotions, and such events tend to leave a stronger trace compared to other 'neutral' events. Moreover, stress at the time of learning may favor attentional focus and is thought to enhance memory formation… however, high levels of stress and anxiety may instead impair memory retrieval and performance. Because of these observations, techniques allowing to improve the focus of attention and to control levels of anxiety, such as meditation techniques, have been proposed as potential aids during learning, in both childhood and adulthood. In this respect, physical activity may also play an essential role during learning, as it reduces levels of anxiety and stress on one side, and favors brain plasticity and acquisition of new memories on the other.

Finally, we should be aware that reading and imagery represent important learning strategies as they induce the activation of the same brain areas that are recruited during actual execution of specific actions or use of particular skills. On the other hand, however, they are not as efficient as direct practice, which

leads to the strongest and more reliable activation of task-related brain areas, and thus, to the most efficient and accurate learning.
Given the above premises, it does not surprise, for instance, that many schools in different countries have introduced new experimental programs including practical experiences and learning games aimed at improving emotional and attentional engagement of children, but also specific courses dedicated to meditation practices and/or physical activities, which may improve stress management and boost learning skills. While these approaches are currently limited to relatively few school environments, their application may be expected to become the new standard for children education in future years.



Of note, strategies for the improvement of focus and attention during learning-related processes will likely become more and more important in our modern, technologically advanced society. Indeed, several studies suggested that individuals rely more and more on new technological devices (e.g., smartphones, tablets, etc.) and on the huge amounts of information found on the internet, while relying substantially less on cognitive and memory brain resources.

Thus, while the internet may allow all individuals to reduce the brain effort and the time required to complete a variety of different tasks, it may also reduce our need to pay attention and remember things. This idea is well described by a recent scientific study demonstrating that, during a visit to a museum, visitors who took photos of what they saw (and thus, relied more on external sources of memory) were less likely to remember the details of the artworks, as compared to when they observed the artworks without taking photos. Moreover, the reduced ability to focus attention may render individuals more prone to rapidly switch between different tasks (multitasking), with negative consequences for cognitive performance, memory and creative processes. Neuroscientists are still actively investigating the effects of technological advances and of cognitive offloading (that is, the reliance on external devices) on brain functioning and cognitive performance. What seems already clear however, is that we will have to find a right balance between reliance on our cognitive resources and reliance on our technological devices in order to make the most of both.

Brain stimulation and cognitive potentiation

Some of the techniques used by researchers to investigate the functioning of the human brain allow to directly stimulate or inhibit particular brain regions. In research, these techniques are mainly employed to investigate the role of different brain areas in specific tasks or cognitive functions. However, the same methods could be used to induce the activation and potentiation of specific brain networks. Remember that one key principle for learning in the brain is that "neurons that fire together, wire together", so that neuronal connections are strengthened with each activation. This simple principle explains why repetition (repeated activation) is so important for learning, and also led researchers to hypothesize a possible beneficial effect of external, artificially triggered neural activations in learning.

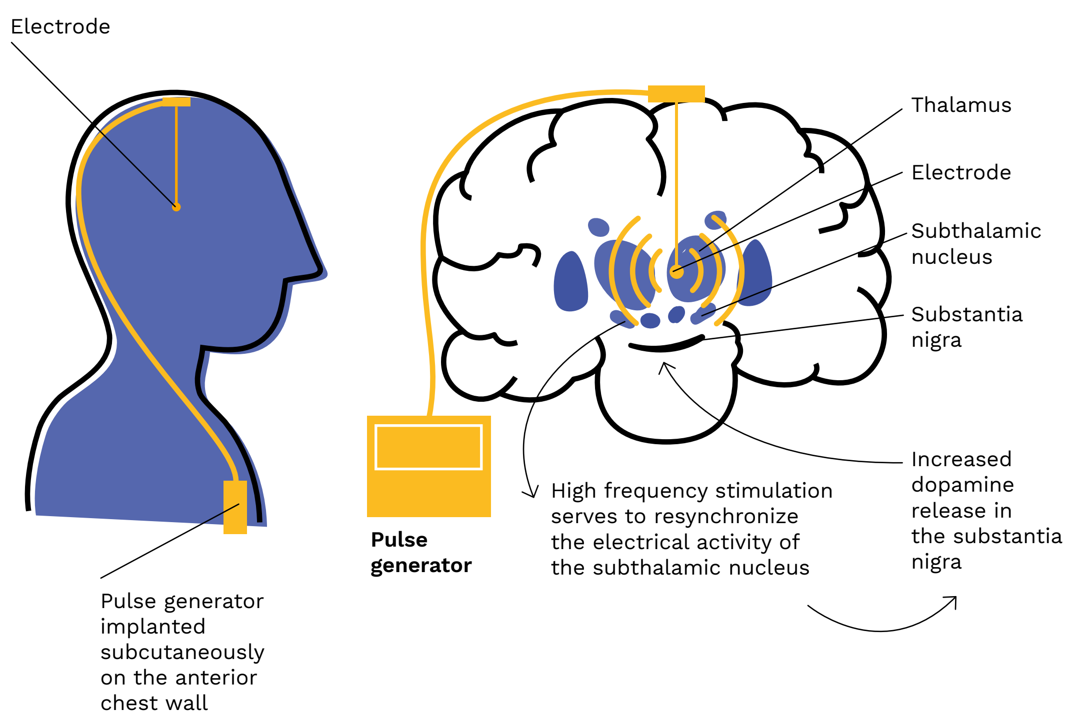
Transcranial Magnetic Stimulation
What is it and how does it work?

Transcranial Direct Current Stimulation (tDCS) uses constant, low direct current delivered via electrodes placed on the scalp to induce changes in the activity of relatively large portions of the cerebral cortex. Similarly, transcranial Magnetic Stimulation (TMS) is a technique in which a changing magnetic field is applied at scalp level to induce changes in electrical activity within a small region of the brain (electromagnetic induction). Both techniques are broadly used in basic research to 'probe' specific brain areas and investigate their function. However, they have been also suggested as potential complementary approaches for the treatment of various pathological conditions, including for instance Major Depression, Parkinson's disease and Alzheimer's disease.

Several lines of investigation are also evaluating the potential use of tDCS or TMS for cognitive enhancement and learning acceleration in healthy people. For instance, several studies suggested that a weak transcranial electrical stimulation of the motor cortex may facilitate learning of motor skills.

In these investigations, brain areas involved in the control of movement are stimulated using transcranial Direct Current Stimulation (tDCS). While later studies called into question an actual impact of tDCS on brain functioning and further research is still needed to clarify the potential utility of this technique for accelerating brain plasticity, some commercial applications have been already proposed. For instance, Halo Sport **(www.haloneuro.com/)** offers a set of headphones integrated with devices for weak direct current stimulation that should 'prime' the motor cortex before sports practice and favor subsequent learning. Indeed, an initial activation of motor areas may facilitate (prime) subsequent activations of the same areas and thus favor the formation or the strengthening of connections among neurons.

While tDCS and TMS only allow stimulating 'superficial' (i.e., cortical) brain areas, other approaches allow to directly stimulate 'deeper' brain structures. Deep Brain Stimulation (DBS) was born as a treatment for patients with dystonia (movement disorder in which a person's muscles contract uncontrollably), essential tremors, and Parkinson's disease resistant to drugs. This method involves inserting an electrode in a specific part of the brain. The electrode is then connected to a pulse generator (pacemaker) that is often placed undercut in the front and upper chest region.



Electrode
Small piece of metal or other substance that is used to take an electric current to or from a source of power or a living body.

Transcranial direct current stimulation
Approach that uses constant, low direct current delivered via electrodes placed on the scalp to induce changes in regional brain activity.

Transcranial magnetic stimulation
Technique in which a changing magnetic field is applied on the scalp to induce changes in electrical activity within a small brain cortical region.

Deep brain stimulation
Neurosurgical intervention in which implanted electrodes deliver electrical pulses to specific target areas in the brain.

The application of some electrodes to certain areas of the brain, linked to a stimulator, can help in controlling the symptoms of many neurological diseases. In recent years, this approach has been tested in many clinical conditions with relatively encouraging results. Such conditions include for instance Tourette syndrome, headache, the disorder of consciousness and vegetative state, stroke recovery, dementia, obsessive-compulsive disorder, depression, and pain. The underlying hypothesis is that DBS exerts its therapeutic effects by overriding the irregular, pathological activity of the stimulation target, replacing it with a stimulus-induced regular pattern. While the use of such approaches is currently limited to pathological conditions due to the possible occurrence of adverse effects (in particular, immune reactions against the 'extraneous bodies'), some scientists strongly believe that such devices will find application in healthy individuals, both to temporarily 'boost' specific cognitive functions and to allow for a seamless interaction between people and computers.

In conclusion, the psychological and neuroscientific research is rapidly advancing our knowledge of the mechanisms involved in learning and memory, as well as of the approaches that could allow us to exploit such mechanisms in order to make the most of our brain potentials. As seen throughout this chapter, such approaches may include: optimized and tailored training strategies, regular physical exercise, meditation techniques and optimized stress management, sleep hygiene and a well-balanced diet, work in clean but stimulating environments, but also the use of novel brain stimulation techniques. In the future we could be able to combine all these different approaches in order to accelerate and maximize learning-dependent brain plasticity.

haloneuro.com

Master Movement Faster
Olympian & Trainer
Kim Glass

Halo Neuroscience

The mission at Halo Neuroscience is to improve lives by enabling anyone to unlock their brain's full potential. Before Halo, its founding team spent more than a decade developing the world's first closed-loop neurostimulation device for epilepsy patients. After achieving unanimous FDA approval and changing the lives of thousands of patients, they founded Halo Neuroscience in 2013.
Halo Sport is a headset that stimulates the part of the brain responsible for muscle movement, with the goal to accelerate training gains.
It works by temporarily placing the brain's motor cortex (the part of your brain responsible for muscle movement) into a state of "hyperplasticity", or hyperlearning. It does this using transcranial direct current stimulation (tDCS), which applies a mild electric field to the motor cortex.
This temporarily optimizes the connection between the brain and muscles.

halo
neuroscience

Total Funding $24.6 Mln

Last Round $1 Mln
April 2018
Series B II

INTERVIEW

Prof. **Nadia Bolognini**
University of Milano Bicocca, Department of Psychology, & IRCCS Istituto Auxologico Italiano, Laboratory of Neuropsycology

What is the so-called "neural plasticity"? And how can we study it using neuroscience tools?

Neuroplasticity is a fundamental property of the brain, by which the brain reorganizes its structure or functions in order to adapt to changing conditions, such as environmental pressures, physiologic modifications (e.g. functional losses from aging or brain diseases), experiences (learning), in turn escaping the genome restrictions. The term neural plasticity is therefore used to denote changes at different levels of the central nervous system that may account for the diverse forms of short-lasting or enduring behavioral modifiability. Neuroscientists may adopt different tools to asses and measure neuroplasticity, depending upon the question being posed and the species being studied. For example, if a neuroscientist is interested in neuroplasticity associated with learning in human beings, brain imaging techniques (e.g. functional magnetic resonance, electroencephalography) can be used to track changes in cerebral activity and functional connectivity. But learning can be studied also in a laboratory animal; in this case neural plasticity could be studied by means of cellular recording or postmortem measures of neuronal morphology.

What are your main research interests and your most recent and relevant contributions to the understanding of brain plasticity in physiological and pathological conditions?

I'm a neuropsychologist, and I'm mainly interest in studying neural plasticity from a rehabilitation perspective. One of my main contribution to the field concerns the development of non-invasive tools for the rehabilitation of stroke patients

affected by cognitive, sensory or motor disorders.
For instance, I'm currently studying the therapeutic efficacy of the transcranial electric stimulation (tES). This is a very simple, painless form of brain polarization that uses prolonged low-intensity electric current applied over the scalp to modulate brain activity in a non-invasive manner. Depending on the stimulation parameters, it is possible to facilitate or to suppress brain activity with variable behavioral effects. In stroke, tES would ideally enhance standard physical or cognitive trainings utilizing mechanisms of neural plasticity to promote and shape brain changes necessary for the recovery of lost functions. Post-stroke recovery can even enhance by using specific forms of sensory stimulations. For instance, re-wiring of neural circuits can be driven also by multisensory stimulations, that is by exposing the brain to the concurrent stimulation of different senses (vision, touch, audition). I have developed a procedure for the rehabilitation of visual field loss caused by brain injuries that takes advantage of the natural and basic tendency of the human brain to integrate information from different sensory modalities; this function, called multisensory integration, seems to be spared in many brain diseases, offering a strategy for compensating sensory deficits through the recruitment of intact senses.

Can specific techniques facilitate or accelerate neural plasticity in pathological (e.g., following brain damage) or in physiological conditions?

There is now an extensive scientific literature on the available strategies that can be used to interact with neuroplasticity in healthy and pathological conditions. We should conceive the brain as a malleable object capable of activating a cascade of changes which are the consequence of each sensory input, motor act, association, reward signal, action plan, or awareness. In this view, behavior may lead to changes in brain circuitry, just as changes in brain circuitry may lead to behavioral modifications. The neuroscientific research is putting a considerable effort in the development of novel ways and tools for maximizing such brain malleability in many neurological and psychiatric diseases. Some of the available therapeutic tools are very sophisticate, such as neural implants, which are technological devices that are connected directly to the patient's brain. Other are technically more feasible, such as sensory stimulation (for example music training, tricks as the perceptual illusions), psychological interventions (mental strategies, meditation), as well as environmental improvements (external technological and institutional structures) that support cognition. Overall, current evidence is very promising, showing that we can affect neural plasticity effectively modulating the human behavior and clinical symptoms.

What are the possible implications of these approaches for pathological conditions? Is it possible to use brain stimulation to enhance learning and memory in healthy individuals?

Brain stimulation techniques, such as the above-mentioned tES, offer encouraging therapeutic options, with the hope that we will be able to improve and accelerate the recovery from cerebral injury by effectively boosting or shaping neural plasticity. Potentially, brain stimulation could be even helpful in reversing some of the devastating consequences of brain damage in the latter periods of prenatal development in human infants. Brain stimulation techniques are also likely to have uses for people without disease, as to help humans to extend their natural cognitive capabilities.

This concept is the core of the so-called 'cognitive enhancement' that is the reinforcement of cognitive abilities through improvement or augmentation of internal or external information processing systems.
A cognitively enhanced person is not necessarily somebody with particularly high ('super') cognitive capacities, rather is somebody who has benefited from an intervention that improves the performance of some cognitive system, such as memory. However, this sort of 'cosmetic neurology' raises ethical concerns, some related to the individual and others related to society.
Much remains to be learned and applied in this fascinating and medically important field of neural plasticity at the interface between basic neuroscience and clinical neurology.

GLOSSARY

FOCUS ON: LEARNING & TRAINING

5

Autism
Developmental disorder that affects, among other things, how a person acts and interacts with others, communicates, and learns.

Deep brain stimulation
Neurosurgical intervention in which implanted electrodes deliver electrical pulses to specific target areas in the brain.

Dyslexia
This is a language-based learning disability characterized by trouble with reading despite normal intelligence.

Electrode
Small piece of metal or other substance that is used to take an electric current to or from a source of power or a living body.

Neural Efficiency Hypothesis
Some neuroimaging studies revealed that smarter individuals show lower (more efficient) brain activation than less bright individuals during tasks of low to moderate difficulty.

Neural plasticity
Lasting changes in our brains can occur during the lifespan.

GLOSSARY

FOCUS ON: LEARNING & TRAINING

5

This is a specific characteristic of the brain to modify itself according to experience.

Transcranial direct current stimulation
Approach that uses constant, low direct current delivered via electrodes placed on the scalp to induce changes in regional brain activity.

Transcranial magnetic stimulation
Technique in which a changing magnetic field is applied on the scalp to induce changes in electrical activity within a small brain cortical region.

Visualizers
Individuals who learn mainly from pictures.

Verbalizers
Individuals who learn mainly from texts.

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06

Focus on: Legal & Ethics

Ethical, legal and social impact of neuro-science

Ethical issues related to neuroscience, future developments

Recent developments in neuroscience brought forth newly ethical, legal and social dilemmas over the potential impact of research findings. Among other issues, here we will focus our attention at some of the practical changes that our gradual understanding of the brain will entail for society at large.
For example, should we read the brain of a witness (so to find the guilty agent) even against their will once reached such a technology? Would it be morally acceptable to use cognitive enhancers during an entry test for a medical school? Why, or why not? Concerning more personal choices, should we seek biochemical redirections so to fit our preferences?

Brain scanning a witness in court: is it ethical?
In 2011, using fMRI, a group of neuroscientists at the University of California, Berkeley succeeded in recreating images from a movie -though very approximate in their visual definition- through an analysis of the data as measured in subjects' visual cortex activity. This breakthrough experiment paved the ground over the speculation (closer and closer to reality) that in a not too distant future we will be able to extract people's dreams and memories with the very same technique. Indeed, more recent neuroimaging studies have confirmed the practical feasibility of this idea, by showing that the general content of dreams or spontaneous thoughts could be identified based on the pattern of brain activity in specific brain areas. Interestingly, some studies even suggested that brain activity could differentiate when individuals recall in their mind scenes coming from their own memories, as compared to when they try to imagine scenes that they did not actually experience in person. While these studies should be still considered as preliminary 'proofs-of-concepts', due to their still relatively limited precision and generalizability, they also indicate that the more intimate content of our mind could become accessible to scientist in the future. Such scenario would be particularly relevant in courts, as the opportunity

to extract some definitive images of, say, a rapist (otherwise blurry because of the shock experienced by the victim of the crime) would help securing justice and could push us to think of such a tool as ethically unproblematic. Yet, this is not quite so, and some profound thought should be given to the implications of this perspective reality.

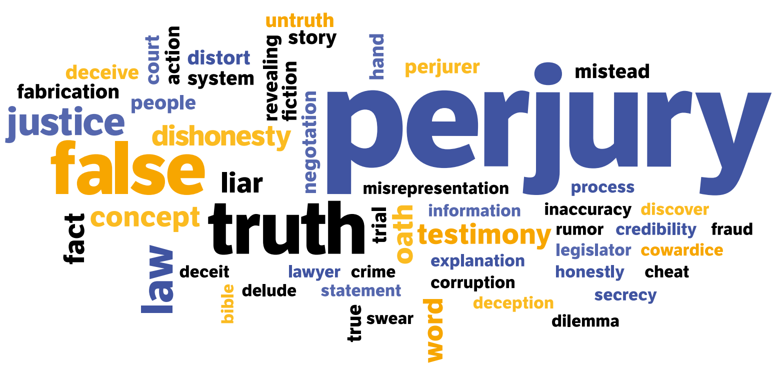
To begin with, we would have problems related to the right against self-incrimination. Differently from the current scenario in fact (where a lawyer cannot ask a suspect in court to incriminate herself unless she decides to confess), this technology could put authorities in the condition to acquire decisive information from the suspect (i.e. memories of the incriminated action) and render those sufficient proofs to condemn her. Conceptually, this might be the right way to go in terms of results of course, but it changes the burden of proof and it would limit enormously our right to say no to authority. In less positive way, we might ask ourselves what would be next? The screening of our actions during our shifts in the supermarket? It seems obvious that entrenched in this debate is the role that we want to grant to the right to privacy - and the related principle of autonomy.

The idea of privacy is often connected to that of preserving a space free from others, based on the principle of "inviolate personality" that is part of a more general right to immunity of the person that we usually grant. Notably, in a society like ours that respects the autonomy of the individual at times in an extreme way, violating the right to privacy would represent a cultural revolution.
Another, and very much related issue connected to the use of memories is the fact that they are not as fixed as one might think. In other words, we modify the composition of our memories in time. This is relevant for a number of reasons, but limiting our analysis to few here, it is worth noting that:

Nature International weekly journal of science
Lighter sentence for murderer with 'bad genes'

a) Such variable should make us question more the reliability we want to grant to this quasi achievable tool.
b) The risk for the "hacking" of our memories is very high and could be twofold: one, our memories could be stolen and two, they could be modified (before a testimony for example).
The huge impact that this way of reading our brain could have on society requires extreme attention and a balanced approach towards yet another technology that can be both useful and threatening.

Right to privacy
An element that restrains governmental and private actions that threaten the privacy of individuals.



Should we put a limit to enhance our cognition?
Do we want (or need) drugged supermen?
In recent years, the use of cognitive enhancers has had a drastic increase across the globe (from academia to workplaces through the army), with notable picks in Western countries. We can define cognitive enhancers as a group of

substances that can improve cognitive capacities through an alteration of the biochemical balance in our brains. Cognitive enhancers can increase our memory, alertness, learning, attention and executive functions such as problem-solving, planning and inhibition. The substances that are more commonly used (and considered to be more effective) are off-label drugs marketed for the treatment of various disorders -from ADHD and neurodegenerative diseases to narcolepsy- and instead taken by healthy individuals that seek an improvement in their cognitive and intellectual performances.

Cognitive enhancement in academic settings is particularly worrying as that those off-label medications can be purchased through legal, semi-legal and illegal channels does not appear to stop the increasingly relevant trend. A report published in 2015 by the Federal Substance Abuse and Mental Health Services Administration underlines how more than 135,000 college students in the US start using prescription stimulants for cognitive purposes each year. In addition, the report also shows how those off-label medications are most wanted around the key moments of the academic year. The problem is surely related to the legal dimension of the issue (there appear to be still too many jurisdictional holes in the world to appropriately tackle the black market surrounding cognitive enhancers), but the ethical one is perhaps even more pressing.

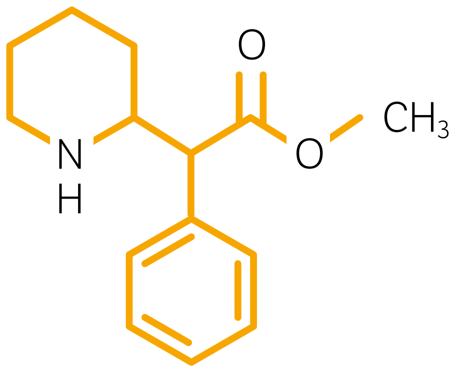
The United Nations Convention on Psychotropic Substances currently followed by many countries explicitly puts methylphenidate (one of the most common off-label drugs used as cognitive enhancer) as a Schedule II drug (a group of drugs that includes controlled substances with known medical uses). Consequently, there is an obligation by all those countries that have ratified the Convention to regulate methylphenidate in accordance with such a classification.

Hence, in some jurisdictions the legal sanctions related to the use of cognitive enhancers for study purposes can include liability and incarceration if methylphenidate is given or sold to "healthy" individuals not in need of the medical treatment. Modafinil (another one of the main medications used for enhancing purposes by healthy individuals) on the other hand, was not in existence when Convention was written, and, as a result, the legislation surrounding modafinil is very flexible and varies quite a lot from country to country. Yet, recent studies have shown how the enhancing nature of modafinil at a neurological level differs greatly from substances such as caffeine and nicotine, which represent cognitive enhancers perhaps more socially accepted but not very useful in terms of actual improvement of the performance.

Notably, some have recently argued that cognitive performance enhancement could be seen as a contribution to the wellbeing of society when applied to some specific profession (i.e. surgeons could improve their practices and outcomes thanks to enhanced attention, working memory and self-control), pushing us to question if the right to cognitively enhance oneself could soon become a duty in some professional context.

Cognitive enhancers (or 'smart drugs')
Substances that allow a person to exceed his or her standard of performance in a given context. Some of them are commonly used to reduce symptoms of pathological conditions, such as Alzheimer or Parkinson's Disease. Most cognitive enhancer stimulate specific brain systems, temporarily increasing their activity and performance.

Dara O Briain's Science Club
BBC
What are smart drugs?



Methylphenidate

Cognitive enhancers do not create new behavioral or physiological responses, but simply modify the execution of pre-existing brain 'functional programs'. Thus, these substances cannot replace the standard processes of practice and learning!

In love and war anything goes… or not?

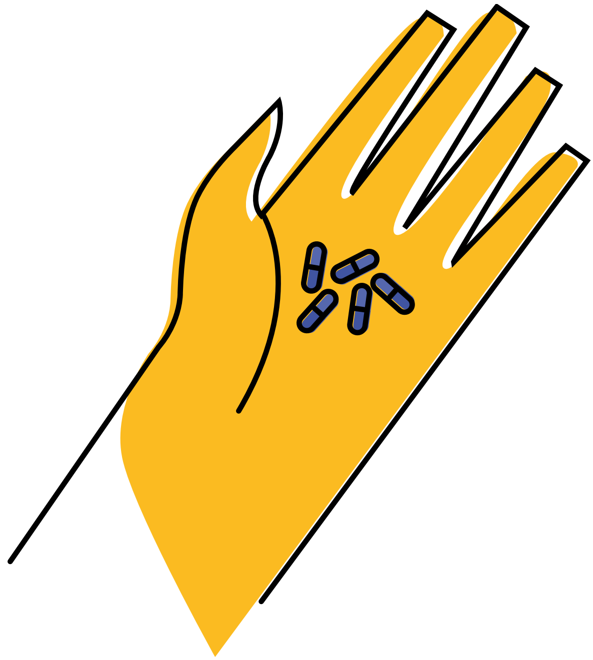
Thanks to the constant discoveries that we are making in understanding how our brain works, we are gradually realizing with more accuracy what reactions makes us addicted to videogames, cocaine or love. As strange as it might sound, these addictions do not differ that much in biochemical terms, so why not, some argue, use our knowledge to re-caliber our emotional responses in certain instances?

Surely, the case appears particularly strong in situations of broken hearts unable to cope with the sorrow associated with the departure of the loved one (due to death or a choice to end the relationship), or in instances of abusive partners that instead we are uncapable to leave (domestic violence).
In both instances we might be tempted to think that a pill

able to "help" us controlling more rationally our emotions would be good. In other words, reducing our instinctive love towards a more rational approach would be seen as positive, and possibly considered as a wise choice in a rationally driven society such as ours. Indeed, an artificial control of emotions could theoretically appear as useful in a wide range of conditions, including for instance the improvement of social interactions in work-related contexts, which may favor psychological well-being, team-work and productivity.

Again, the problem in such a scenario is represented by where we would be drawing the line. Could (or should perhaps?) we get rid of love altogether? Should we push for a conceptualization of love as a potential illness or should we refrain from categorizing this very sensitive and intimate part

Helen Fisher
The brain in love



of our lives as something to be “fixed”? In fact, the idea of standardizing our attraction towards others also in aesthetic terms may not ultimately increase much of our freedom, but rather restrict it.

Medicalization
A process that defines as medical conditions aspects of the human nature not usually classified as such.

What is clear is that, by increasing our knowledge of the brain and of the mechanisms that regulate our emotions, our mood and our empathy toward others, we could be able to modulate and regulate these aspects in the future.
And while at present such perspective appears as very remote, and there seems to be no need for a regulation in this field of research, things are likely to change dramatically in the next decades.

Understanding social and antisocial behavior: Bad or Mad?

The interest in finding the roots of criminal behavior started long time ago. It is more than a century since the famous Italian criminologist and physician Professor Cesare Lombroso (Verona, Nov. 6, 1935 – Turin, Oct. 19, 1909) stated that someone “is born criminal”. Lombroso looked at the physical defects and alterations as evidence of the inherited criminality. His chief argument stated the existence of a hereditary class of criminals, considered as “biological throwbacks” to a more primitive stage of human evolution. Lombroso contended that such criminals showed higher percentage of physical and mental anomalies, termed “stigmata”, compared to not criminals, such as various unusual skull sizes and asymmetries or exaggerated sizes of facial bones. He classified accurately different face-skull patterns related to the type of crime committed. Lombroso's theories were widely influential in Europe until the beginning of the XX Century. Indeed, accurate measurements of the shape of the skull, the musculature, the shape and flexibility of hands and fingers, heart rate and blood pressure, face expressions, temperament, natural instincts and the familiar background were part of a usual psychiatric assessment of a defendant during the XIX century (e.g., see the brigand Musolino case, 1902). However, this emphasis on hereditary causes of crime was later strongly rejected in favor of environmental factors.

Nonetheless, in the last decade, we have witnessed a growing new interest in individual factors that may indicate a predisposition to criminal behavior. Scientists have been focusing on specific genes that modulate aggressive reactions towards others, development of psychopathy, substances addiction, gambling and resistance to stressors.

Sam Harris
Science can answer moral questions

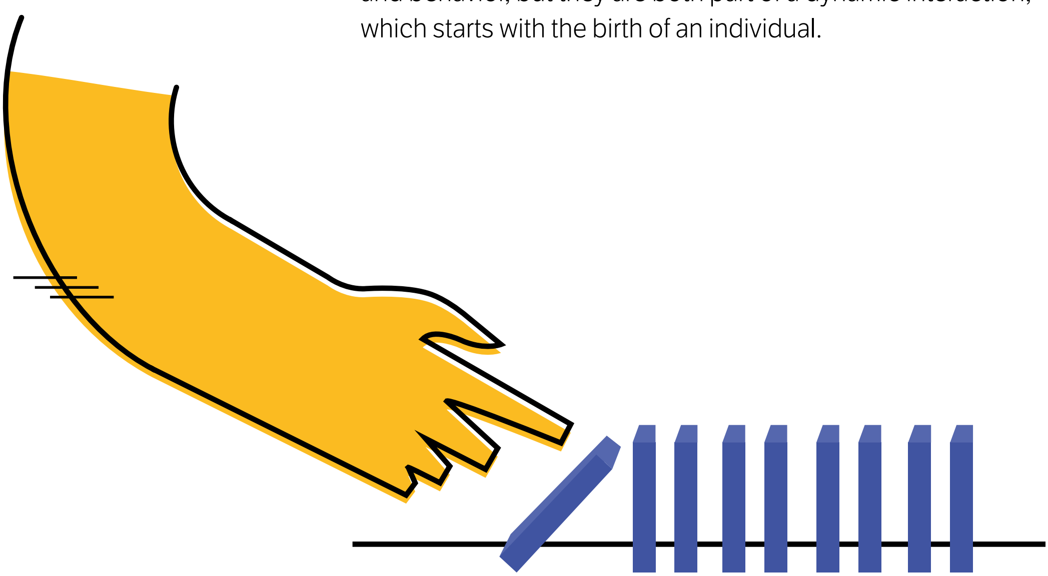
At the same time, the neuroscientific method allowed to investigate the black box of the human mind, thus revealing notable links between functional or structural brain alterations and criminal behavior. Nowadays, it is commonly assumed that some hereditary factors (genetic background), and some hereditary or acquired brain morpho-functional alterations, may actually present a relative association with antisocial or aggressive behavior, although they are never considered as sufficient to determine a criminal behavior (in clear contrast with Lombroso's idea).

Several studies showed that people who acted out recurrent aggressions, or committed heinous crimes, had peculiar genetic profiles that are known for altering the amount of certain substances released in the brain, either increasing or reducing their concentration in the brain itself. Different substances are normally involved in brain functioning and therefore in behavior; it is their unbalance that increases the risk of deviant behavior, such as extreme aggressive reactions, drug and alcohol abuse or lack of empathy in social contexts. Nevertheless, this is just one tiny piece of the puzzle that scientists are putting together in order to fully understand why some people behave against social life rules and others don't.

Another building block in the understanding of human mind comes directly from the investigation of brain structures and the multiple functional interactions among every single part of the brain. It is well known that those brain areas that develop later in humans are devoted to the most sophisticated social skills, complex reasoning and impulse control. Defects in the frontal parts of the brain, as well as in some specific more deep structures (i.e., the amygdala) may have strong effects on behavior. People carrying abnormalities like reduced brain volume in frontal brain areas or reduced functional interaction among frontal areas and other brain regions may show a range of symptoms including inability to control the impulse to act violently when triggered, or difficulties in understanding social circumstances and other people's point of view. They may also show deficits in detecting the appropriate emotion, or in evaluating when risk taking is convenient and when it is not. These antisocial personalities often have a history of drug and alcohol abuse and socially negative early home environment.

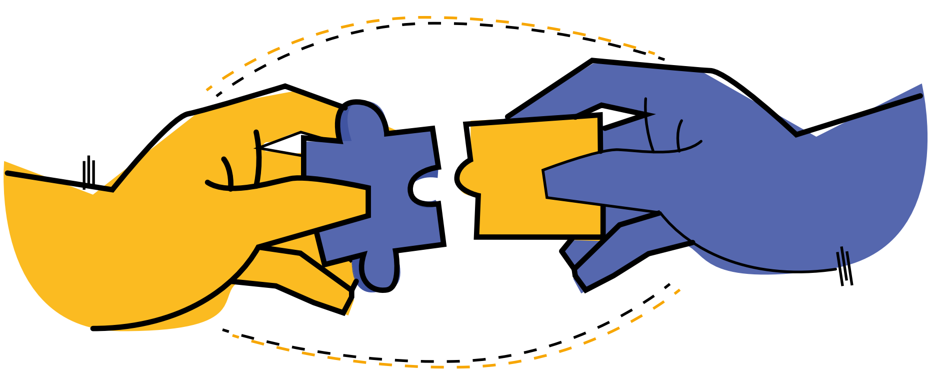
Octavio Choi
TED talk:
"Can Neuroscience help us eradicate psychopathy?"

Here is the third crucial component: the environment. Research on large populations revealed that being carrier of one or more of the "bad genes" is not enough to exhibit antisocial behaviors. There is no causal effect between genes and behavior, but they are both part of a dynamic interaction, which starts with the birth of an individual.

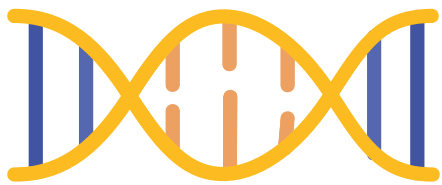


There is no causal effect between genes and behavior.

There is agreement about the fact that particular genetic variants that have been found in criminals are not that rare in the general population. Rather than antisocial genes, they constitute vulnerability factors to the environment, both positive and negative. In other words, no one is born genetically evil, though genetically more sensitive to external stimulation. The same genetic variants that increase the risk of aggressive behavior in combination with a negative, socially and emotionally deprived environment, may actually improve the sensitiveness to positive environmental inputs, which could lead to the development of so-called prosocial behavior, including cooperation, altruism and empathy.



Given the above premises, one could ask whether scientist could be able to predict the risk for antisocial conduct of an individual by knowing his genes and brain structure, as well as the type of environment in which he grew up. Let's assume that we know that somebody is a carrier of "bad genes" and that he grew up in a disadvantaged family, witnessed daily violence between parents, had an early onset of alcohol and drug abuse: can we say with certainty that he will commit a crime sooner or later?



The truth is that this kind of prediction regarding the future behavior of a single individual still remains impossible despite the availability of sophisticated, modern scientific techniques and of a broad understanding of the functional and psychological bases of human behavior. Indeed, each of the factors described in the above example can only be considered as a 'risk factor' that may relatively increase the probability, but never indicate the certainty, of future violent behavior. Thus, scientists are currently developing more precise models for assessing the risk (in terms of probability for an event to occur), rather than forecasting individual outcomes, and these novel tools are now beginning to have a role in the court.

For instance, in 2009, the Court of Appeal of Trieste took into account genetic data in defining the sentence given to a man who was convicted of stabbing another man to death in response to an insult in an earlier unprovoked attack. In fact, the assaulter was found to carry some genes (monoamine oxidase A – Low variant) that may determine a predisposition to aggressiveness and impulsivity in individuals who experienced a negative, traumatic or dysfunctional environment during youth (as was the case in this man).

Such a genetic profile has been suggested to have altered the ability of the man to control and modulate his actions. Based on this evidence the Appeals Court granted a one-year reduction of his sentence, from 9 to 8 years. This has been the first time that behavioral genetics has affected a sentence passed by a European court.

Not much later, in 2011, the Judge of the Court of Como reduced the sentence of a convicted murderer from 30 to 20 years in prison, based on the neuroimaging and genetic tests provided by the defense. In this case, a woman had murdered her sister and then burnt her body in the backyard. She was subsequently arrested while attempting to murder her mother by setting fire to her after several failed attempts to kill both her parents. Brain neuroimaging data collected in the murderer revealed clear differences with respect to the brain of healthy adult individuals, especially in those areas that control inhibition and aggressive behavior. Genetic testing also showed that the woman was carrier of the same genes mentioned above, directly linked with violent behavior. Based on this evidence and on additional psychiatric evaluation, the appellate counsel argued that the woman was mentally insane at the time of her crimes and thus modulated the sentence accordingly.

While there is still important debate regarding the use of neuroimaging and genetic information in the court, approaches based on these techniques represent an important attempt to complement common psychiatric and psychological evaluations with objective, measurable criteria. While each single measure will likely never offer, by itself, a reliable estimation of risk for antisocial behavior, there is hope that a combination of multiple indices, evaluating different factors and their interactions, will enable a significant improvement in our ability to explain antisocial acts in specific individuals. Of note, the value of these new approaches can be expected to increase in the future, thanks to technological advances, and to novel neuroscientific and genetic discoveries. In particular, researchers are investigating the potential links between a large number of genes and aggressive or impulsive behavior, as well as their potential interaction, both among each other and with environmental factors. Knowledge provided by these lines of research will significantly improve, in the future, the accuracy of risk estimation based on genetic data. In a similar fashion, neuroscientists are actively investigating the brain functional and structural bases of antisocial and aggressive behavior, both in the healthy 'normal' population and in subgroups of individuals with exacerbated forms of antisocial behavior (psychopaths). These studies are beginning to suggest that impulsivity and aggressiveness in the normal population or in psychopaths could be associated with relative alterations of a variety of brain areas, including, but not limited to, those involved in self-control and decision-making skills. Thus, for instance, teen-agers with impulsive antisocial behavior and psychopaths have been recently shown to present relative functional and structural alterations in a subcortical gray matter region named 'striatum'. This area is part of a brain network (also including part of the prefrontal cortex) involved in 'reward anticipation' and in the evaluation of the consequence of actions, and its alteration has been suggested to represent a contributing factor in antisocial behavior. A better knowledge of the relationship between (alterations in) regional brain function or structure and behavior, will potentially provide novel, more accurate, indices and measures with a higher predictive power.

INTERVIEW

Dario Nardi
Author, speaker and expert in the fields of neuroscience and personality; he currently holds a position as senior lecturer at University of California (Los Angeles)

Advances in our understanding of the brain have turned neuroscience into one of the hottest frontiers in research: what is your thinking about?

Yes, I believe the 21st century is the century of the brain, mind, and eventually, down the road, consciousness. There are lots of advances in neuroscience, some of which are practical, such as how people tend to learn best, etc. But practical applications are not as plentiful as we might like. It takes time.

Mind reading: using neuroscience as a lie detector or to analyse the emotional states. A new thread in the "privacy vs security" debate.

Sure, brain imaging can detect some emotional states, etc. But in my experience, people who are good liars fool even brain imaging. They have a very efficient way to create lies quickly while keeping their brains calm. Thusly, I would not trust brain imaging as lie detector.

In your opinion, Neuroscience frontier will change humankind ethics, becoming more brain-based and moving away from the old moral questions?

I don't think moral or ethical questions will go away. But I think the way we talk about those questions can improve. I honestly believe that in a century, most of the social science research done today (that is not neuroscience based) will be considered worthless and forgotten. If we can make psychological, sociology, communication studies, political science, etc more scientific, then the discussions will be more interesting and useful than the 19th-century ideas still used today. That is my opinion.

INTERVIEW

Nick Chater
Professor of Behavioral Science at Warwick Business School

Advances in our understanding of the brain have turned neuroscience into one of the hottest frontiers in research: what do you think about it?

There is no question that there have been some huge steps forward in our ability to study the brain. But our understanding of the calculations that the brain is carrying out remains quite limited. For example, the neural network models used in machine learning are the computational methods that most naturally fit with the structure of brain networks; but these models seem, rather frustratingly, to behave in a very different way to human brain. Specifically, they require large amounts of data from which they make very local generalisations, where is the human rating steps and make wildly creative generalisations from small amounts of data, often a single example. I think we are quite far from a convincing theory
of what the brain is really doing.

Mind reading: using neuroscience as a lie detector or to analyse emotional states. A new thread in the "privacy vs security" debate.

I suspect that the prospect of mind-reading is not really a worry. In my view, there are no beliefs and desires to be "read off" from the brain, because these are only created after we have made decisions or formulated verbal responses – all explanations of our behavior and language are post-hoc.
The relationship between brain activity and our tendencies to behave in particular ways is very indirect, I think, so it is very unlikely that we will get much beyond fairly crude abilities to guess people's beliefs attitudes, desires, and so on. Hopefully this is reassuring with respect to any concerns about privacy, at least in our lifetimes and I suspect far beyond.

INTERVIEW

In your opinion, will Neuroscience change humankind ethics, becoming more brain-based and moving away from the old moral questions?

I believe that the traditional moral questions, of how we should act, of values, rights, responsibilities and so on will be as important as ever in the future.
I suspect that the cognitive and social sciences in general will have interesting things to say about these questions. For example, if it turns out that particular moral intuitions can be seen as products of a certain type of reasoning error, which might parallel reasoning errors that we see in other aspects of thought, then we might downplay or discount those intuitions in building our moral theory. One might imagine, for instance, that people may not care 1000 times as much about 1000 deaths, as they do about a single death; and that this might cause policy to be skewed towards reducing lots of minor causes of death rather inefficiently, rather than concentrating resources on efficiently reducing major causes of death, for example through better immunisation, and so on. Neuroscience will be relevant to the extent that it helps us understand cognition and social interaction; but I suspect that it will not have much direct impact on how we understand morality.

GLOSSARY

FOCUS ON: LEGAL & ETHICS

6

Cognitive enhancers (or 'smart drugs')
Substances that allow a person to exceed his or her standard of performance in a given context. Some of them are commonly used to reduce symptoms of pathological conditions, such as Alzheimer or Parkinson's Disease. Most cognitive enhancer stimulate specific brain systems, temporarily increasing their activity and performance.

Medicalization
A process that defines as medical conditions aspects of the human nature not usually classified as such.

Right to privacy
An element that restrains governmental and private actions that threaten the privacy of individuals.

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Understanding Social and Antisocial Behavior: Bad or Mad?

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07

Focus on: Marketing

Exposing the basic decision-making processes in market-related dynamics

In our everyday life, we often have to make decisions and, in case, resolve uncertainty at various levels. This is why our nervous system has to be able to estimate, represent, and successfully cope with these situations. The act of choosing one course of goal-oriented action among several options is commonly indicated as 'decision-making' process.

From case to case, which degree of knowledge we have when making our choices may fall between deterministic, probabilistic and pure uncertainty.

Deterministic
All the possible outcomes are completely known or determined.

Probabilistic
Multiple possible outcomes have varying degrees of certainty or uncertainty of their occurrence.

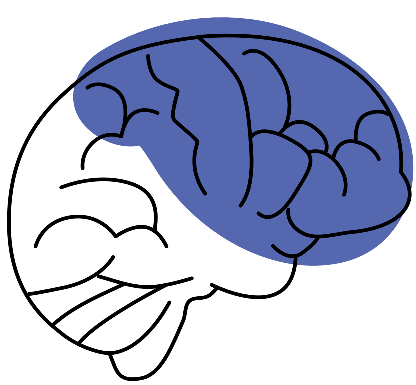
Uncertainty
Outcomes and alternatives are free from constraints.

We must somehow incorporate the risk or uncertainty into our decision-making to make a list of all possible outcomes and assign probabilities of success and failure.

The planner-doer model of Richard Thaler and Hersh Shefrin captures the modern neuroscientific view that the human brain is a collection of many conflicting selves that simultaneously exist and participate in our decision-making process.
In their framework, the authors model each human being as having two sets of preferences that are in conflict at a single point in time. Indeed, according to Thaler and Shefrin's planner-doer model, a person has two selves: a myopic doer and a farsighted planner. The doer cares only about current utility, is unconcerned with the future and her behavior tends to become short-sighted, while the planner is concerned with the maximization of lifetime utility.
In a situation in which the planner needs to maximize lifetime utility, it can either force the doer by applying willpower or by imposing rules that limit the range of doer's decisions, albeit imperfectly. The conflicting planner-doer model captures the idea that willpower can be applied at a psychic cost since it requires exerting some effort. Individual traits will determine how effectively the planner can control the doer based on the different degree of self-control.

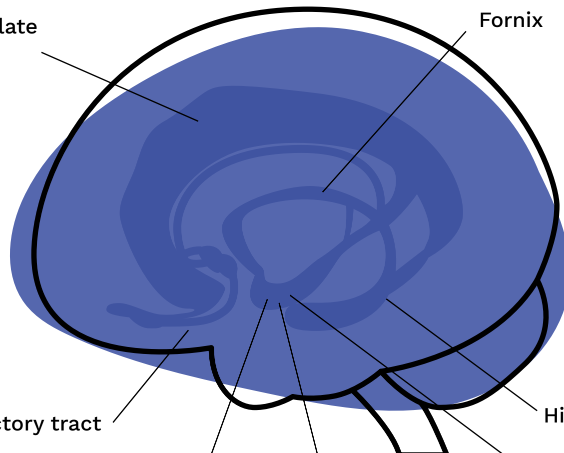
From a brain perspective, the planner's may correspond to the prefrontal cortex (where the so-called executive functions reside), while the doer may correspond to the limbic system (the emotion-regulating and reward system of our brain).

➔
The prefrontal cortex



The prefrontal cortex has been identified as the location in the brain where long-run planning takes place, while the evolutionarily older limbic system generates short-term emotions and desires. Self-control problems indeed involve the interaction of the prefrontal cortex and the limbic system.

→
The limbic system



The damage or partial loss of the prefrontal cortex might disrupt the intervention center of the farsighted-planner with a direct inability to plan for the future.

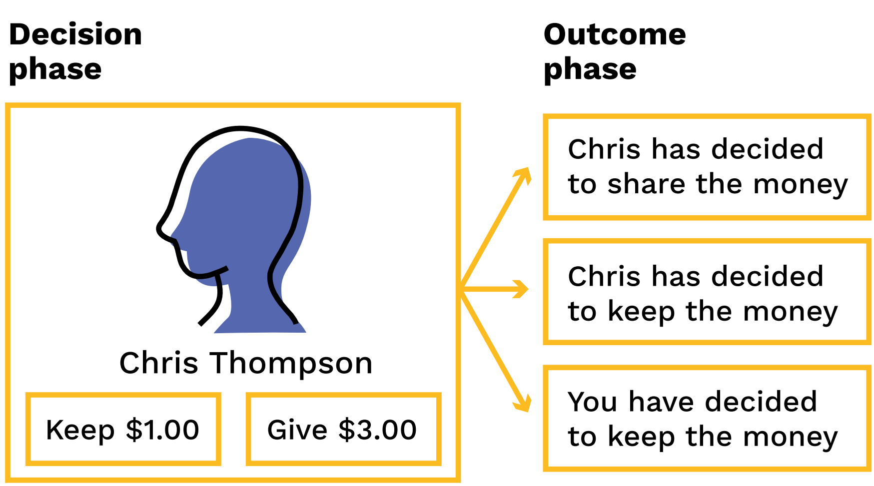
Self-control prevents people from carrying out plans or courses of actions, even if they can predict their final outcomes.

Doer and planner
Mental processes that shape our self-control through the decision-making process.

Richard Thaler
American economist and the Charles R. Walgreen Distinguished Service Professor of Behavioral Science and Economics at the University of Chicago Booth School of Business. He is a theorist in behavioral finance and collaborated with Daniel Kahneman, Amos Tversky, and others in further defining that field. In 2017, he was awarded the Nobel Memorial Prize in Economic Sciences for his contributions to behavioral economics.

Richard Thaler
Nobel Lecture:
The Sveriges
Riksbank Prize in
Economic Sciences

The planner-doer model can be compared with other dual-process theories in psychology. A dual process theory provides an account of how thought can arise as a result of an implicit and automatic unconscious process and an explicit controlled conscious process. Both automatic and controlled processes have a fundamental role in economic decision-making, though, given a person's experience and current situation, the decision process may differ.



The two decision processes, automatic and controlled, have different goals that may be more useful in particular situations. For example, a person is presented with a decision involving a selfish and a social motive. One of the two motives, either selfish or social, will be more appealing than the other based on individual preference, although the preference itself may change depending on the social context. The two-system or dual model is a common representation of human behavior in contemporary psychology and neuroscience.

> Explicit processes, attitudes, and actions may change with persuasion or education; though implicit process or attitudes usually take a long amount of time to change with the forming of new habits.

The idea of different, conflicting 'selves' in the brain has a long history in economics and was already articulated by Adam Smith (1759) in Theory of Moral Sentiments. In what Kahneman more recently calls System 1 and System 2, decisions are assumed to be governed by intuitive processes (System 1), typically characterized as being fast, automatic and effortless, as well as by deliberative processes (System 2), characterized as being slower, controlled and effortful.

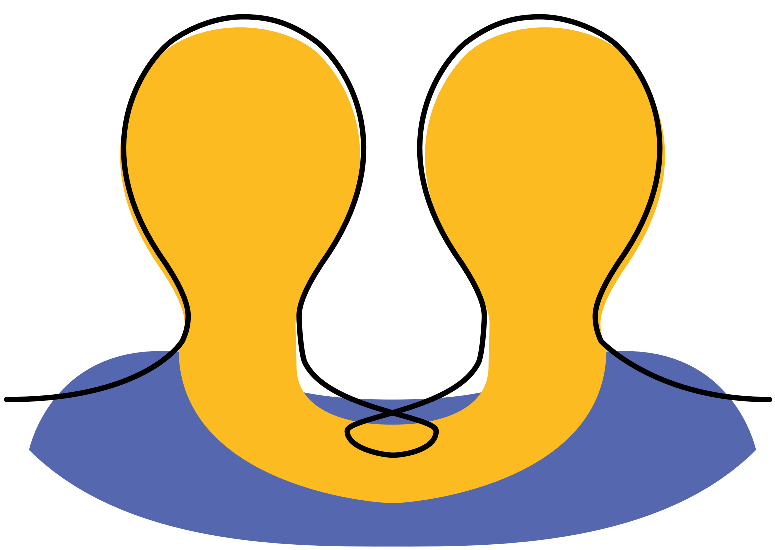
→
Two decision-making routes. System 1 is mainly driven by our emotions, is fast, instinctive, unconscious, and automatic and triggers our every-day decisions (i.e. satisfying our appetite with a delicious but unhealthy snack). System 2 is slow, conscious, reliable, and regulates complex decisions as it is based on our thinking (i.e. choosing a healthy option).

Using the dual-process theory, it is important to consider whether one choice is more automatic than the other, and in this particular case, the automaticity would depend on the individual and their experiences. A selfish person may choose the selfish motive with more automaticity than a non-selfish person, and yet a controlled process may still outweigh this based on external and social factors. A selfish person would preferably opt for the first response, or choice, as it is automatic and faces a minimum resistance. On the other hand, a decision that requires an enormous amount of energy (willpower) to move from our current status (or status quo) to different degree of uncertainty will face resistance and present itself as the least appealing.

System 1's fast thinking is often logical and useful, conversely, System 2 can be conscious and deliberate but still prone to poor (sometimes irrational) results.

Daniel Kahneman
An Israeli-American psychologist notable for his work on the psychology of judgment and decision-making, as well as behavioral economics, for which he was awarded the 2002 Nobel Memorial Prize in Economic Sciences. His empirical findings challenge the assumption of human rationality prevailing in modern economic theory. With Amos Tversky, Kahneman established the cognitive basis for common human errors that arise from heuristics and biases and developed prospect theory.

→
Dual Personality



In a landmark study, Miscel and other researchers at the Columbia University, New York, (1989) presented four-year-old children with a marshmallow and told them that if they waited fifteen minutes they would receive two instead of just the one initially offered. Some children resisted the temptation of immediate consumption while others did not. The former fared better in follow-up studies measuring their Scholastic Aptitude Test (SAT) performance, ability to cope with personal problems, a more healthy body mass indices (BMI), and others. Moffitt at the University of Chicago (2011), confirmed the same results as more impatient children tend to be less healthy, more obese, have worse financial and working situations, and tend to be less happy in their romantic relationships when they reach adulthood.
The above research suggests that knowledge of people's ability to delay gratification can be a good predictor of their future wellbeing. Delaying gratification, as done in the marshmallow test, constitutes a simple one-shot choice, which can be studied in a natural environment. Behavioral researchers have developed more sophisticated methods to allow calculation of people's discount rates.

The term discount rate describes people's ability to delay payoffs. A lower discount rate indicates a stronger ability to delay payoffs and vice versa.

This thesis has been confuted by a new study, in which Watts, Duncan, and Quan (2018) restaged the classic marshmallow test in a much larger sample group and more representatives of the general population. This study found limited support for the idea that being able to delay gratification leads to better outcomes. It suggests that the capacity to hold out for a second marshmallow is shaped in large part by a child's social and economic background. Such background plays a central role in determining kids' long-term success.

Sendhil Mullainathan, Eldar Shafir
Scarcity: Why Having Too Little Means So Much

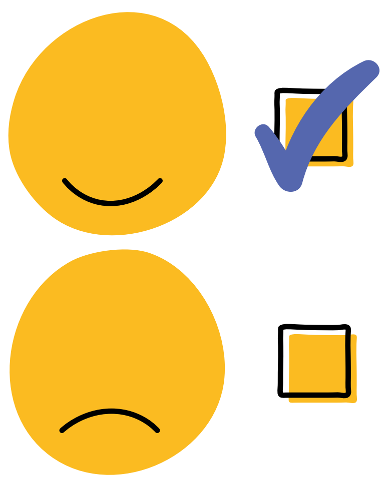
Although there is likely to be a stable preference for which motive one selected based on the individual it is important to remember that external social factors will contribute to influence the decision.

Novel psychological and neuroimaging tools are now allowing researchers to dig deeper and deeper into the bases of individual predisposition to different types of choice. However, as in the example above of the marshmallow study, we have to keep in mind that a huge number of factors may affect our ability to predict one person's behavior and future decisions. Thus, each problem has to be simplified and reduced to simple, direct questions, to which we can find an answer by trying to control for all (or most) possible confounding factors. This means that, while neuroimaging tools do not currently allow predicting a person's behavior in all possible conditions and contexts, they may allow doing it for a very specific situation. For instance, individual brain responses could tell us whether a person will take a particular decision when the mood is positive rather than negative, and they may inform us about the possible unconscious processes that guided the choice.

Target consumers when they are likely to be happy
Consumers who are in a relaxed frame of mind or a good mood are much more likely to notice an ad. Yahoo recruited 600 adults to fill in a week-long smartphone diary that tracked their moods. This revealed that when consumers are upbeat they are 24% more receptive to content in general.

Target consumers when you know they are happy
Watching happy films induce a positive attitude and a greater intention to try advertised products when compared with watching sad films. The creator of Snickers chocolate bars, for example, recently began targeting its ads by mood, believing that people who are happy, bored or stressed are more likely to snack. It identified these moods by mining information captured by Google's ad server, DoubleClick, which data analytics-based method is further explained at the end of this chapter.

Match your message to the mood
Keith Wilcox, Professor of Marketing at Columbia Business School, conducted an experiment in 2015 among 142 participants into mood congruence. The participants were either primed with a neutral clip, a documentary about Einstein, or a heart-rending scene from the 1979 movie, The Champ. The clip was followed by an ad, either a highly energetic one or a moderately energetic one. When the moods clashed participants paid less attention to the ads.



While these may appear like small, limited gains, they represent already a fundamental step toward a better understanding of the human brain and of decision-making processes.

Emotional response, brand association and loyalty

Marketing is rapidly transforming into a multidisciplinary science, which incorporates mathematics, statistics, technology, psychology, and neuroscience. New capabilities based on neuroscience and data science/ big data are leading to a new creative process, which many call Neuromarketing, the direct measurement of consumer thoughts about advertising. The application of Neuromarketing lays at the intersection of neuroscience and marketing research, identifies consumers' sensorimotor, cognitive, and affective response to marketing stimuli. In this way, we can find out how the consumers make purchase decisions by determining the unconscious thoughts, emotions, and desires and providing a better understanding in relation to the marketing products.

Brands and products have effects on consumers' emotions –emotional branding– and motivation can be measured by attention – emotional engagement– from a cognitive and emotional point of view.

Neuromarketing
The combination of consumer behavioral research with neuroscience, and includes the direct use of biometric sensors, brain imaging, and scanning, and data analytics to measure individual and group responses to specific marketing activities.

Why measuring attention, emotional engagement (arousal, motivation) and brand recall matters to marketers?

The value of measuring attention is that it increases the opportunity for brands and advertising messages to be noticed. Measuring arousal and motivation gives a read on the non-conscious effect of advertising on a consumer, while brand recall is tightly linked to consumer purchase behavior. When marketers use the optimal mix of attention, arousal, motivation and brand recall in the right sequence, they are more likely to inspire consumers to take action on the campaign's messaging.
Humans are incredibly visual as almost 50% of our brains are (directly or indirectly) involved in visual processing. When we see branding or a logo, our eyes send a signal toward a specific region of our brain called fusiform gyrus, which plays several key roles in human visual processing, including high-level recognition of words, numbers and colors.

As discussed in other parts of this book, particular stimuli with a specific social or evolutional value have a stronger effect on our brain and may more easily capture our attention.

Thus, for instance, ads that include people are much more effective than those that do not. In particular, images and videos that include babies tend to attract longer and more focused attention from potential customers. However, advertisers have demonstrated that using close-ups of adorable baby faces alone may actually limit attentional resources for the product or other relevant information in the ads. In fact, the baby's face tends to automatically capture most of our attentional resources. On the other hand, researchers discovered that when the infant is directing its gaze at the product the viewer will, in fact, focus on the advertising content more than on the baby's face.

Biometric methods, which devices have now become portable and comfortable, deliver new layers of insights beyond traditional measures.

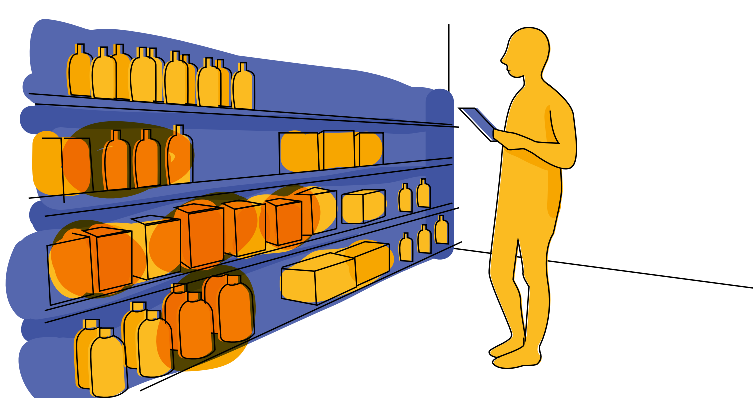
By combining different technologies and thanks to many years of technological improvements, it is now possible to reveal exactly what a person is looking at, whether he is feeling a positive or negative sentiment, the intensity of that sentiment and the emotions he is expressing at that specific point in time.

Eye tracking
Small cameras can track eye movement and measure pupil size during cognitive tasks, helping researchers understand which parts of an advertisement are most visually appealing and most engaging in test subjects.

Facial coding
Test subjects' facial expressions are analyzed to learn more about certain responses to a product or advertisement, including frustration, happiness, and more.

Galvanic skin response and electrodermal activity
Measure sweat gland excretions and often associated with measurement of heart rate, physiological arousal, and electrodermal activity that is associated with high or low levels of excitement and engagement.

All these technologies provide a real-time lens into subconscious consumer reactions that help in ensuring effective capturing-activities.
Eye tracking is often used in neuromarketing activities as it unearths an essential part of the searching process and measures what the customer is looking at and how. This gaze data reveals shopping hotspots through duration, time to first exposure and return frequency metrics.



Neuromarketing techniques are being employed extensively to redesign packaging and presentation.

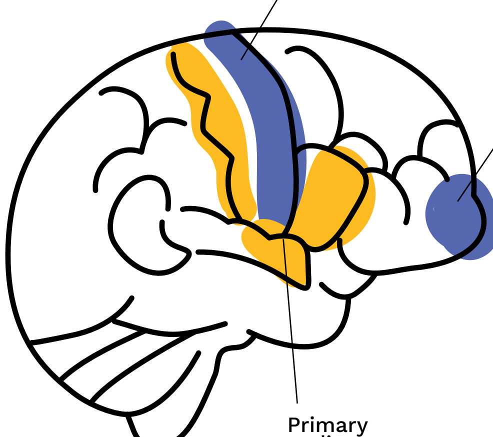
Neuromarketing has tapped into the incredible potential of functional Magnetic Resonance Imaging (fMRI) to grant us insights into human behavior and consumer habits. fMRI measures the small changes in blood flow that occur with brain activity. When a brain area is more active it consumes more oxygen and to meet this increased demand blood flow increases to the active area. fMRI can be used to produce activation maps showing which parts of the brain are involved in a particular mental process.

→ Scanner for magnetic resonance imaging

When testing a new advertisement, psychological tools and neuroimaging techniques can reveal hidden thoughts and preferences of consumers. In comparing different advertising campaigns, participants at a National Cancer Institute's telephone hotline viewed three different ads.

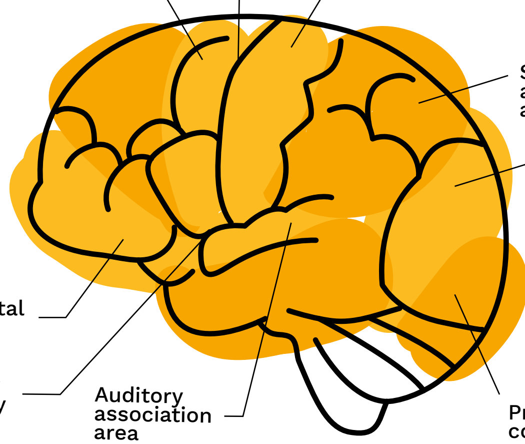
The ad campaign that elicited the highest amount of brain activity in the medial prefrontal cortex (based on fMRI investigation), led to significantly higher calls to the hotline. This novel approach of neuroimaging in marketing is a new avenue for identifying ad campaigns that will genuinely engage the public.
The involvement of neuroscience and neuroimaging into marketing research reveals that processing brands and ads is multifaceted and involves perceptual, sensorimotor, affective and decision-making processes. The part of the cerebral cortex that receives visual input from the retina is in the very back of the brain (occipital lobe), auditory information from the ears comes to the side of the brain (temporal lobe), and sensory information from the skin is sent to the top of the brain (parietal lobe).

➔
Brain regions that receive input from somatosensory, auditory, and visual receptors.



Each sensory area is divided even further into a more detailed map. Our visual field is mapped point by point onto the visual cortex. The notes of the musical scale are mapped across the

auditory cortex; the sensory pathways from the skin, which give information on pain, temperature, and touch, are mapped onto the somatosensory cortex.
The brand visual experience initially travels to the so-called early visual areas (from V1 to V4), where information like edges, outlines, and shapes in objects can be detected.



→ The visual association area and the primary visual cortex

Although subtle, brain research shows curves are typically more inviting, whereas sharp angles and edges can represent power but may also trigger aversion. While V1 elaborates lines and edges, other specific areas tend to prevalently process other aspects of the perceived image, such as colors, shapes or motion. For instance, the extrastriate area that consists of the visual area V4 is directly involved in the subjective experience of colors and in color memory.
At the Linneaus University, Sweden, a study on the color associations in marketing tested the value of context in logo design. Participants identified the color black as modern,

elegant, and luxurious, but perceptions changed based on the product type. In a new context –a tube of toothpaste– respondents associated black with dirtiness, sadness, and low quality.

Utilizing a color effectively can be a powerful marketing tool.

One of the most infamous examples is Coca Cola's ubiquitous use of the color red, but there are many more companies who have also used color to great effect. Anton de Craen, a clinical epidemiologist at the University of Amsterdam, conducted a systematic review of 12 studies and found that red painkillers were consistently more potent than blue ones. Neuromarketing experts specializing in color and advertising have divided colors into subgroups as a guide to how they may be used effectively. Cool blues, for example, are the go-to color if you wish to attract professionals. For a painkiller strength (often associated with color red) is more important than calmness (associated instead to color blue).

power sophistication mistery death	hope simplicity cleanliness godness purity	love passion romance danger energy
intelect friendliness warmth caution cowardice	peace sincerity confidence integrity tranquility	authority maturity security stability
life growth nature money freshness	innovation creativity thinking ideas	royalty luxury wisdom dignity

In a similar fashion, researchers are studying not only how individuals react to colors, but also to layouts, font size, and other aspects of each visual experience. For instance, research on website experiences showed that using certifications, testimonials and social widgets are sure to draw customers in more than those that do not.

Another interesting finding is that newer, horizontal style website layouts are less effective than traditionally vertical. When readers find something they like, they begin reading normally, forming horizontal lines. The end result is something that looks like the letter F. CNN (https://edition.cnn.com/) and NYTimes (https://www.nytimes.com/) both use the F pattern. Though when people scan in an F-shape, they miss big chunks of content based merely on how text flows in a column. The skipped phrases and words are often as important as those words that are read. But users will not realize this since by definition they do not know what they do not see. This is why reading web pages top-down engages more and makes viewers more likely to keep on scrolling.

Visual stimuli are deeply embedded in marketing activities although sensory stimuli do not always activate independent and separated areas of the brain. For example, some cortical neurons in the primary auditory area exhibit spiking responses to visual stimulation. This is because the auditory cortex is a particular example of possessing multisensory interactions.

Multisensory neurons
Highly in specialized cells of the nervous system, having the ability to be stimulated and to conduct impulses.

Researchers have identified the region that overlap the auditory and visual responsive zones as multisensory and responsive to both facial gestures and corresponding vocalizations; this is an important node in the cortical network often targeted by marketing strategies.

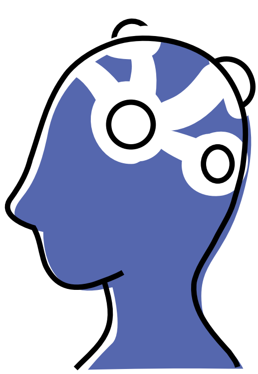
After processing the brand's experience, our brains start to elaborate and match similar patterns stored in memory (e.g. this logo also reminds me of this other thing), thus 'recovering' both abstract ideas and meanings, but also previous experiences and emotional contents that are associated in our brain to the specific experience. This is why different brand experiences, triggering different responses in our brains, are layered into an overall brand identity profile in our minds.

More than half (60%) of consumers around the world prefer to buy new products from a familiar brand than switch to a new brand, according to a 29,000 person Nielsen study published in 2013.

Schaefer and Rotte (Otto-von-Guericke University Magdeburg, Germany) have reported that sport and luxury brands like Nike and Mercedes triggered emotions and brain activity in different places than brands rated as value products (like Walmart, an American multinational retail corporation that operates a chain of hypermarkets, discount department stores, and grocery stores). Bruce et al (2014) have confirmed a brand identity profile in children whose appetite and pleasure centers lighted up in response to seeing branding from recognizable fast-food restaurants.

In the context of choice-related stress, electroencephalography (EEG) grants deeper insight into emotional and motivational processes and can be used to assess the impact of brands, concepts, and prices via the "immediate brain response".

Immediate brain response
The activity in the brain within the first half-second after the stimulus is presented.



EEG measures variations in electrical activity over the cortical brain regions. These variations are recorded at various frequencies –theta (4 to 7 Hz), alpha (8 to 12 Hz), beta (15 to 30 Hz), and gamma (> 32 Hz)– that have been related to different physiological phenomena. It offers a high temporal resolution (on a millisecond time scale) and is effective in investigating ongoing consumer responses, for instance, to different parts or scenes of TV ads.
EEG is used to validate the four metrics - desire, engagement, workload, and distraction – to deliver the most important insights with regard to emotional experience in the customer-decisional process.

Desire
The extent to which the product stimulates action or purchase intentions as a result of positive or negative emotions.

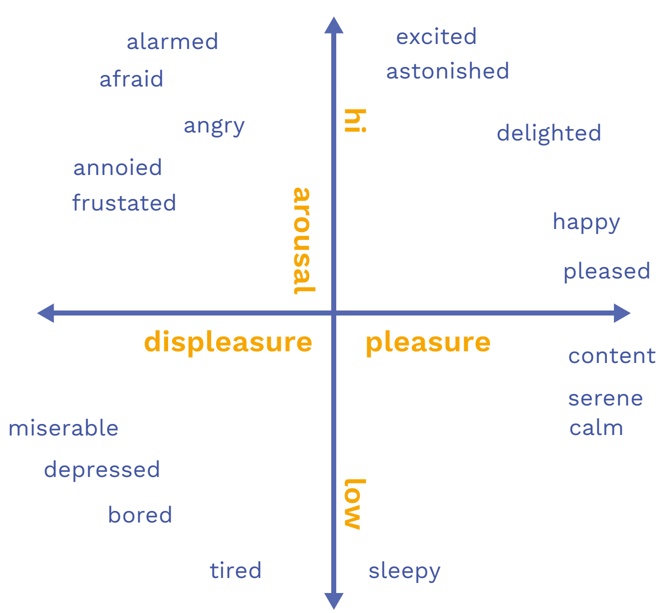
Engagement
The extent to which the products activate attention and are experienced as personally relevant.
Workload: a measure of the ease of the shopping experience. Difficulties in processing will lead to more choice-related stress.

Distraction
The degree to which the consumer experiences the product as unexpected and illogical.

EEG may be used as an indicator of advertising effectiveness and therefore for its ability to favorably affect consumer preferences and purchase behavior.

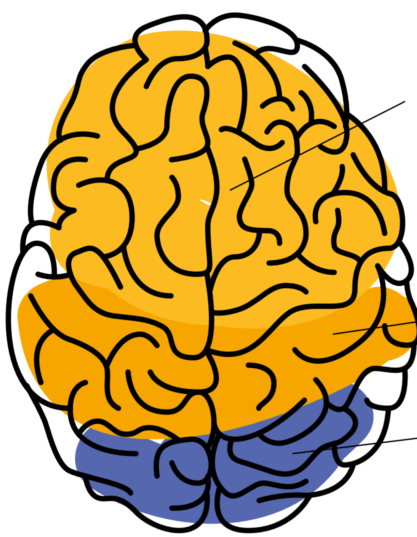
Valence and arousal are quite different in definition as valence is positive or negative affectivity, whereas arousal measures how calming or exciting the information is. Some studies have shown that our brain processes each factor independently.

→
Arousal – valence model.



The processing of unpleasant stimuli –low valence- activate specific regions with stronger activations in response to more arousing stimuli. On the contrary, activations in regions discussed to be sensitive to reward were found in response to pleasant stimuli, and these activations increased with the valence of these stimuli, not with their arousal.

➔
Cerebral lobes associated with attention processes, pleasant and unpleasant commercials.



For instance, in a series of EEG studies on advertising, researchers have found occipital alpha activity was related to attention processes, such as visual gating during the viewing of TV commercials, while right frontal alpha activity for more pleasant and liked commercials and greater left frontal activity for unpleasant ones. Further, EEG can be used to investigate brain locations of visual memory encoding in relation to dynamic visual stimuli. The left frontal activation reflected by reduced alpha activity is a reliable predictor of which ad scenes is better encoded in long-term memory and is subsequently recognized more easily through image recognition.

It is interesting how despite different levels of valence our brain encodes arousing events that are even better recalled than non-arousing events. Thus, emotional arousal works as a sort of blinder to other neutral stimuli as nicely presented in the "weapon-focus" effect.

Weapon-focus effect
A witness to a crime diverting his or her attention to the weapon the perpetrator is holding, thus leaving less attention for other details in the scene and leading to memory impairments later for those other details.

Utilizing the weapon-focus effect in marketing will change the type of information that is encoded; it can influence the memory consolidation even if stimuli themselves have not a high valence. This explains the reason why we remember more words when we watch emotional videos. Though, as presented earlier in this chapter, the baby face alone in a marketing ad may actually constrain consumers' attention for the product by inducing high arousal and being associated with the weapon-focus effect.

The take-home message in exploiting arousal and valence in marketing is to understand the target audience, taking great care of preferably not-using the high-arousal and low-valence combination. It is indeed preferable creating the marketing communication strategy using the upper right side of the arousal-valence model with the optimal association of positive valence and high arousal.

At the end of the processing system, after our brains complete their initial memory association steps, we enrich our understanding of a brand by tagging other semantic attributes to what we are seeing. These additional associations, which include for example specific products, slogans, store locations and supplemental imagery that we are familiar with, can further contribute to emotional engagement and to the creation of a 'bond' between consumers and the product.

In particular, the emotional excitement level triggers the emotional engagement level. For instance, the more intense an experience is perceived, the greater our emotional engagement level is. A high level of emotional engagement and encoding process activation can predict (in part) the consumer choice. In this perspective, it is clearly essential to differentiate a product from other products to induce consumers' emotional engagement and eventually drive consumers' choices.

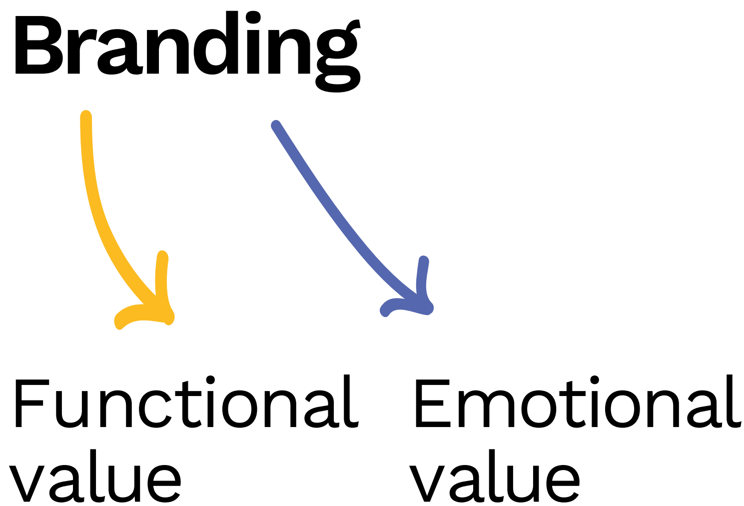
Brand association
Anything such as a symbol, activity, famous person, etc. that makes a consumer think of a particular brand or product.

Emotional branding
The strategy of linking a brand with the human emotions through marketing and positioning of the brand.

Emotional engagement
Appealing to or arousing emotion.

Brand loyalty
The tendency of some consumers to continue buying the same brand of goods rather than competing brands.

Patrick Renvoise
TED talk:
"Is there a buy button inside the brain?"



«Therefore, it is possible to argue that the emotional, social, and cultural value of brand recognition are capable to activate deep reward circuits, even to a significantly greater extent than generic images...»

Casarotto et al, 2012

Emotional branding aims to understand emotional response, customer satisfaction and loyalty to brands in the effort to implement successful marketing strategies. This marketing activity refers to the practice of building brands that appeal directly to a consumer's emotional state and needs with the ultimate goal to create a strong and lasting attachment to the brand.

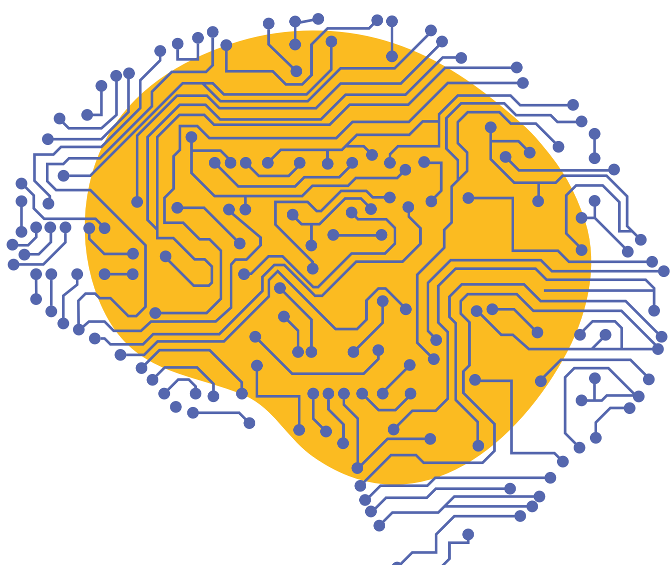
Big data and network maps to predict and understand consumer behavior

Neuroscience is extremely important in market research and in studying consumer behavior; although, there is an open question of whether that contribution may be better achieved through the use of other research technologies that create more efficient and representative measures in larger groups of subjects.

The world around us is changing dramatically and marketing leaders need to develop complete pictures of their customers so they can tailor messages and products that are relevant to them. The fundamentals of neuroscience and data science make neuromarketing an essential transformational research area.

Neuromarketing is basically a process that asks companies to consider the research, findings and scientific study before they tackle a process that might help them to influence customers' buying decisions.

It is worth noting that there is more content online today than ever before. That means that brands have to work infinitely harder to capture the attention of their target audience and, according to a research from Google, about 50% of ads do not get any recognition.



Behavioral analysis and data science are shifting toward the use of volumes of raw data that people create while they are on social media, in gaming applications, marketing or retail sites, to determine future trends and commercial activity.

The development of new hardware and software has helped to increase the acceptance and utilization of neuroscience and data analytics in marketing.

As a result of the computer revolution that started at the end of last century, we all live in a hyperconnected community where (thanks to the Internet) every person is able to communicate (with almost everyone else on the planet) and where (thanks to the reduced costs of memory) almost any digital trace of our activities and behaviors is recorded. Given the unimaginable amount of unstructured and unrelated data available today, what is needed is an efficient search method for extracting insights.

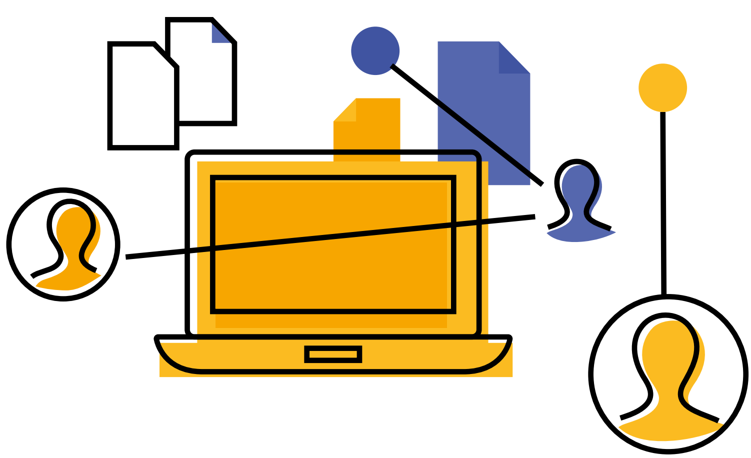
Susan Etlinger
What do we do
with all this big data?

Set of data are collected and analyzed, and then combined with neuroscience research in laying the ground to identify the basis of the human attitudes and behavior. Therefore, the challenge is not so much to get the data, but more to analyze the (right) data for knowledge discoveries to support real-time and future actions.

The analysis of raw data provides marketers powerful new ways to help customers get the most out of their lives. But couple this with neuroscience will provide extraordinary new opportunities to satisfy customers' needs, reduce the need for advertising clutter and costly 'trial and error' marketing campaigns.

Neuroscience and data analytics can provide valuable insights for marketers about customer choices and behavior.

Big data applications and neuromarketing share a need to search and extract potentially useful information for supporting consumer decision-making.



Many marketing researchers are firmly convinced that social media analytics presents a unique opportunity for businesses to treat the market as a "conversation" between businesses and customers instead of the traditional business-to-customer, one-way "marketing". The exploitation of data from social networks offers huge potential in terms of augmenting the already substantial transactional and behavioral data currently inherent in data sets, and garnering new variables and insights; ultimately leading to better predictive models.

When we use any online service, we routinely expose vast amounts of information about ourselves, including everything from our name, location, hobbies, friends and opinions to our thoughts, hopes, dreams and fears.

The number of clicks, conversions, and impressions all represent varying levels of consumer engagement with content that can be measured and forecasted over time. Mail exchanged, things bought on electronic shops, investments made on savings, likes on Facebook, retweets on Twitter create a corpus of information – big data – accessible to everyone and used by several companies for a variety of purposes.

Big data
The collection and/or systematic storage of large amounts of data for the purpose of finding hitherto unknown patterns, relationships or other informative features by computational analysis, often involving advanced machine learning algorithms.

Tricia Wang
TED talk:
"The human insights missing from big data"

The potential of *Big Data* to transform the decision-making process by marketers has been realized, and rapidly adopted within the industry, and juxtapose with neuromarketing to make or break the success of any marketing campaign. The predictive models can rely on consumers' behavioral activity; any preferences for products or behavior-driven choices are reflected in the overall market segment or population. To achieve this goal, computer science is the most important asset that marketers can advance in social behavior research through the analysis of the big data.

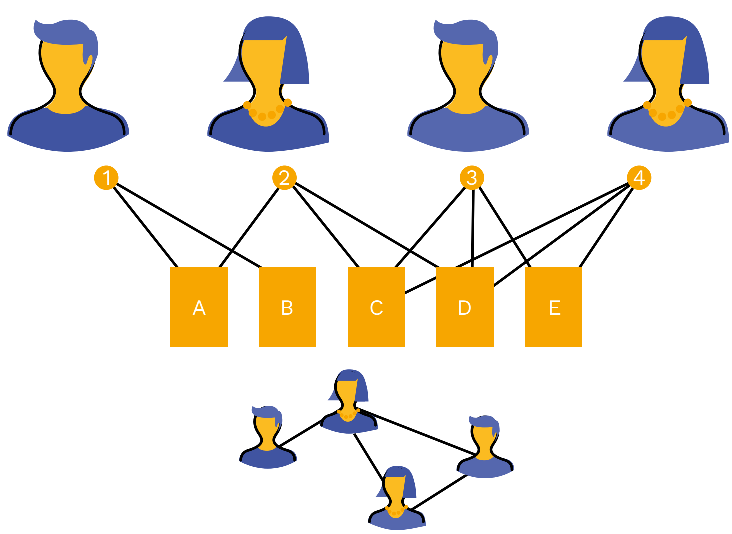
Computer science and statistical physics allow disentangling the complexity of big data.

Marketers do not necessarily answer why consumer click ads. The question that marketers' insights try to answer is the question of motivation. So although the metrics quantify human behavior, it is important to look at the story they tell over time to help answer why the numbers might look the way they do. For example, some brands are using implicit reaction time testing within their online surveys to measure not just what people say but how quickly they say it. This reveals the level of confidence that people have in their responses and provides a more detailed picture of the different motivations driving consumers who may have expressed the same view in a survey.

Complex networks
Complex networks are the paramount example of a mathematical instrument that can extract information from unstructured data (media on YouTube, news on websites, tweets on Twitter), and are composed by N nodes fixed that are connected with a probability *p*.

The pervasive presence of networks everywhere makes possible to use the topological quantities describing them as an instrument to characterize people behavior, as for example buying habits.

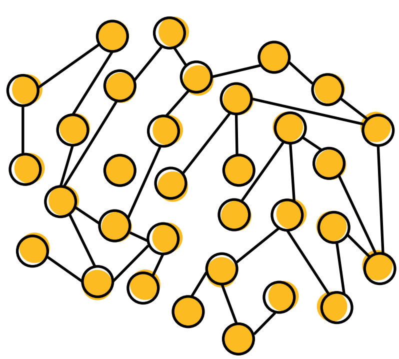
Imagine having access to the Netflix history of a series of persons (Alice, Bob, Charlie, Daisy etc.). We can visualize their activity by representing them as vertices in a graph and connecting them to the films they rented from Netflix as in the figure on the side.



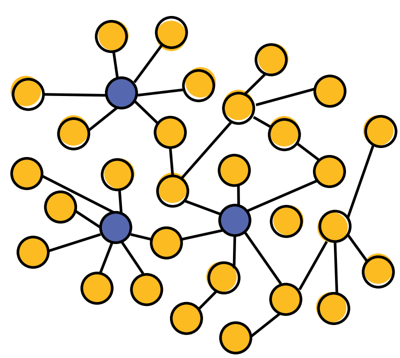
The more films a group of people rents the more similar they are. In particular in this case, we can imagine that the group of people 2-3-4 are great fans of Leonardo Di Caprio.

This information is so important for companies that Netflix decided to give a prize of 1 million of US dollars to a team of researchers that could "...substantially improve the accuracy of predictions about how much someone is going to enjoy a movie based on their movie preferences". The Prize was awarded in a ceremony in New York City on September 21st, 2009 and the papers in which the algorithm is explained have been made publicly available. Becoming ever more effective with this kind of targeting can deliver higher Return-on-Investment on marketing spend.

A scale-free network has the structure shown in the picture below.



(a) Random network



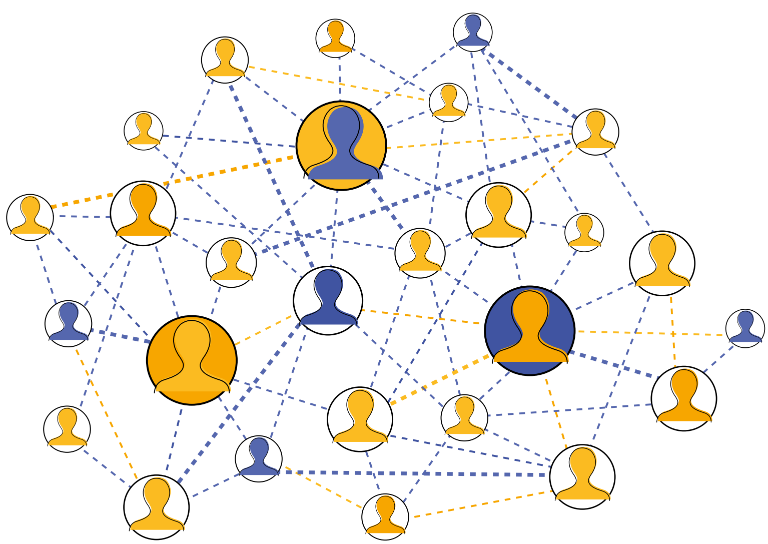
(B) Scale-free network

Imagine that this graph represents the set of connections in a group of friends. If the hubs (i.e. the two central nodes with the largest set of connections) start acting by promoting an idea or a product, they would be certainly more influential than any other person in this circle. This is the concept of "influencer" in a network.

> There are various companies that make a profit by studying the properties of influencers in a network and pushing specific advertisements through them.

One case of study is that of Traackr (www.traackr.com). This company takes the public or semi-public information that all of us leave in the digital world (our posts, our tweets, our web page our network of contacts in social networks) and rank us as more or less influencers. This set of data is then used by various companies to make profiled advertisements for their products.

«Influencer marketing is the process of identifying, researching, engaging and supporting the people who create high-impact conversations with customers about your brand, products or services.»



«Influencer marketing has the potential to target the

Traackr
Discover the Value of Influencer Marketing

market through powerful high-impact conversations between influential people and customers»

For big data to fulfill its big mission it needs to get beyond surveillance data collection methods that only report what behaviors people engaged in and begin to integrate a human component that informs marketers about the most important aspect of behavior – the why and how to influence. Attitude-behavior prediction models derived from the big-data analysis may offer fundamental information to understand the neural bases of inter-individual differences in decision-making processes. For instance, models derived from the big-data analysis could be used to derive classification models indicating how individuals with distinct psychological or cognitive characteristics perform their choices in different social contexts.

Nicholas Christakis
The hidden influence of social networks

Studies have shown that specific variables derived from the analysis of social networks such as Facebook or Twitter, including the number of friends or of direct/indirect connections with other individuals, may correlate with specific brain anatomical and functional features.
Thus, individuals within different behaviors in social networks may be examined in terms of anatomical and functional brain characteristics with neuroimaging methods to determine the neural bases of different types of attitude.
Interestingly, our brain typically undergoes several functional and structural changes each day, which may be directly related to daily changes in mood and behaviors; in a recent work, their occurrence has been revealed on the analysis of data extracted from hundreds of Twitter accounts.

The cooperation between big data and neuromarketing results in neural network analytics that are needed to process all the retrieved data and uncover hidden patterns of knowledge.

There are still some key issues in the use of "big data" approaches to neuromarketing. The high-dimensionality and huge size of data sets can lead to inferential problems of their own, and the often-uncontrolled collection of such big data sets has the potential to raise issues of public interest regarding the ethics of social research.

→
Social data research

In light of such concerns, big data provides opportunities for neuromarketing as a science of influence, in particular thanks to... «*(i) its cohort sizes; (ii) its attention to demographic and socio-economic variables; and (iii) its broad array of variables that can be aligned to neuroscience variables*.»

(Breiter et al, 2015)

Integrating the best elements of both approaches provides the greatest potential in enhancing customer understanding and improving marketing business results.

These investigations clearly indicate that the combined use of big-data analysis with neuroimaging approaches may provide a unique insight into the neural bases of human attitudes and behavior.

neuralya.com

Neuralya
Think Feel Decide

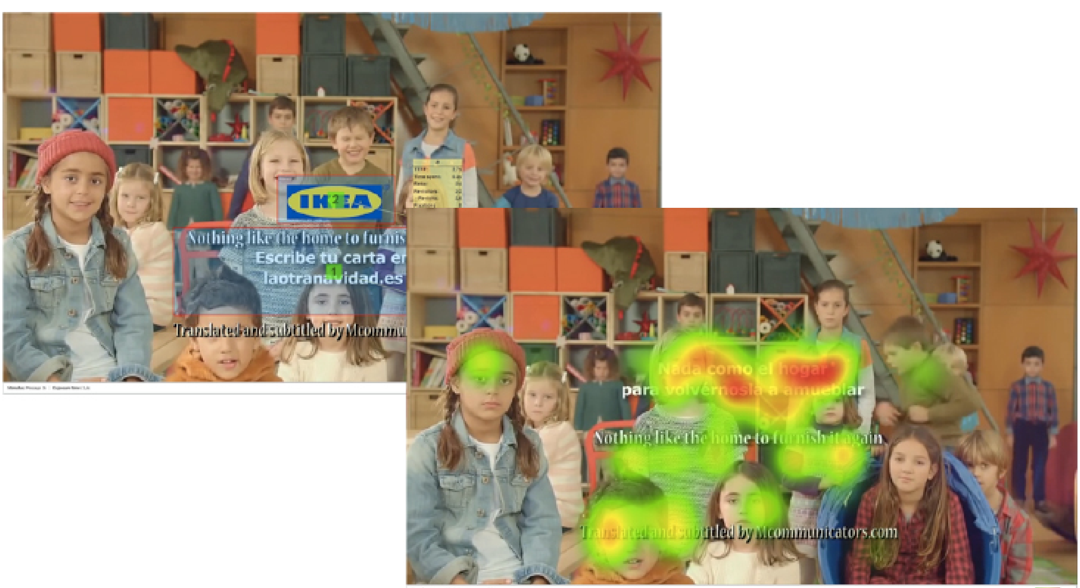
Neuralya

Neuralya is a platform which extends the set of traditional neuromarketing metrics and gives a wider understanding of what the customer is thinking and feeling. By using the newest technologies, we evaluate the customer's behavior, rational, emotional and instinctual components. By applying neuroscience and behavioral analysis principles, we use emerging technology that measures people's behaviors and reactions to products. The use data to deliver a strategy that helps you understand your brand and grow your business.

neuralya

Total Funding n.a.

Last Round n.a.



neuralsense.com

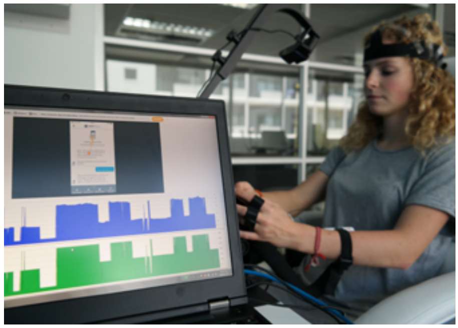
Neural Sense™
An Introduction

Neural Sense™
NeuroWine 2.0
Project

Neural Sense

Neural Sense™ empowers companies to optimise Online User Experiences; In-Store Shopping Behavior; Advertising and Marketing Communications; New Product Design and Development; Store Design and Ergonomics; Neural Sense™ is Africa's first Neuromarketing company and the leader of this field in developing markets and informal trade economies; and so much more. To achieve this, its researchers use Electroencephalography (EEG) technology to measure brain activity and Galvanic Skin Response (GSR) biometric sensors to measure changes in one's physiological state, to learn why consumers make the decisions they do. It also investigates the emotions experienced through Facial Coding and identifies the visual influencers with Mobile Eye-tracking glasses, Virtual Reality eye-tracking headsets and Remote eye-tracking technologies. The final goal is to scientifically assess emotional processes that are subconscious and implicit, thereby providing access to richer and less biased insights than traditional research techniques.

NEURAL SENSE™



Total Funding Undisclosed

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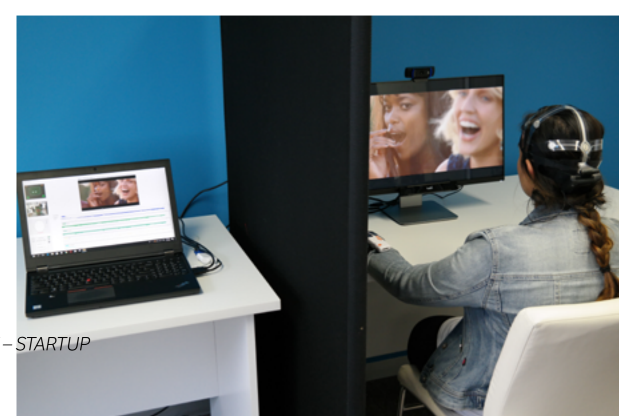
Angel



synetiq.net

Synetiq with the customers' eyes

Synetiq

Synetiq is focused on understanding audience emotions to create better video ads; it helps advertisers and their agencies create high - performing video ads with emotional insights from their target audience.
The sec-by-sec analysis of physiological data enables Synetiq to reveal even the smallest changes of the customer audience's unconscious state; they might not be aware of all their feelings but their body tells everything which Synetiq can analyse and deliver to the customer as actionable marketing insights.

SYNETIQ

Total Funding *n.a.*

Last Round *December 2017 Incubator/ Accelerator*

GLOSSARY

FOCUS ON: MARKETING

7

Big data
The collection and/or systematic storage of large amounts of data for the purpose of finding hitherto unknown patterns, relationships or other informative features by computational analysis, often involving advanced machine learning algorithms.

Brand association
Anything such as a symbol, activity, famous person, etc. that makes a consumer think of a particular brand or product.

Brand loyalty
The tendency of some consumers to continue buying the same brand of goods rather than competing brands.

Desire
The extent to which the product stimulates action or purchase intentions as a result of positive or negative emotions.

Deterministic
All the possible outcomes are completely known or determined.

Distraction
The degree to which the consumer experiences the product as unexpected and illogical.

Doer and planner
Mental processes that shape our self-control through the decision-making process.

Emotional branding
The strategy of linking a brand with the human emotions through marketing and positioning of the brand.

Emotional engagement
Appealing to or arousing emotion.

Engagement
The extent to which the products activate attention and are experienced as personally relevant. Workload: a measure of the ease of the shopping experience. Difficulties in processing will lead to more choice-related stress.

Eye tracking
Small cameras can track eye movement and measure pupil size during cognitive tasks, helping researchers understand which parts of an advertisement are most visually appealing and most engaging in test subjects.

Facial coding
Test subjects' facial expressions are analyzed to learn more about certain responses to a product or advertisement, including frustration, happiness, and more.

Galvanic skin response and electrodermal activity
Measure sweat gland excretions and often associated with measurement of heart rate, physiological arousal, and electrodermal activity

GLOSSARY

FOCUS ON: MARKETING

7

that is associated with high or low levels of excitement and engagement.

Immediate brain response
The activity in the brain within the first half-second after the stimulus is presented.

Multisensory neurons
Highly in specialized cells of the nervous system, having the ability to be stimulated and to conduct impulses.

Neuromarketing
The combination of consumer behavioral research with neuroscience, and includes the direct use of biometric sensors, brain imaging, and scanning, and data analytics to measure individual and group responses to specific marketing activities.

Probabilistic
Multiple possible outcomes have varying degrees of certainty or uncertainty of their occurrence.

Uncertainty
Outcomes and alternatives are free from constraints.

Weapon-focus effect
A witness to a crime diverting his or her attention to the weapon the perpetrator is holding, thus leaving less attention for other details in the scene and leading to memory impairments later for those other details.

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08

Focus on: Finance & Investments

Neuro-science identifies behavioral traits of traders and investors

The neural approach of financial decision-making, nowadays known as Neurofinance, has become more evident after the pioneering studies that looked beyond the mere psychological aspects influencing decision making processes and went deeper into the mind of the decision-makers. It has created more realistic models of decision-making and become able to explain a much wide range of individual economic behaviors.

Frydman (2014) defines the field of neurofinance as: *«Seeking to characterize the computations undertaken by the brain to make financial decisions, and to understand how these computations map to behavior»*.

We live in an era of technological advances that can help us visualize brain activity in professional traders and investors, herein defined as whoever is called to make a financial decision. Behavioral traits can be complemented with the neural profiling to identify and answer to any behaviors, and exploit them.

Neuroscience puts the human factor closer to finance science and the financial decision-maker changes from the rational Homo Economicus to evolve into the "irrational" Homo Sapiens.

In the presence of risky outcomes, a decision maker does not always choose the option with higher expected value investments but, instead, choose the outcome that is preferred, or preferable, to the alternatives.

Expected utility theory
The decision maker chooses between risky or uncertain prospects by comparing their expected utility values.

Bounded Rationality
Rationality is often limited by the tractability of the decision problem, the cognitive limitations of our minds, and the time available to make the decision.

As well represented by the expected utility theory, some people are risk-averse enough to prefer the safest alternative, even though with a lower expected value, while less risk adverse people would choose the riskier, higher-mean gamble.
As reported herein, expected utility theory and bounded rationality suggest that value, risk, and risk aversion influence choice behavior, though the contribution of these economic decision theories to actual choices is unknown. Neuroimaging has been essential to correlate activity in the brain areas associated with decision making (such as the ventral striatum and anterior cingulate) to value and risk.

The ventral striatum, and especially the nucleus accumbens, is active during the anticipation and receipt of monetary and social rewards; while, the anterior cingulate generally contribute to cognitive control by recruiting brain activity to avoid risk.

The third factor, risk aversion, is highly correlated with activity in the inferior frontal cortex.

→
Right Inferior Frontal Gyrus

The Anatomy and Functions of the Frontal Lobe

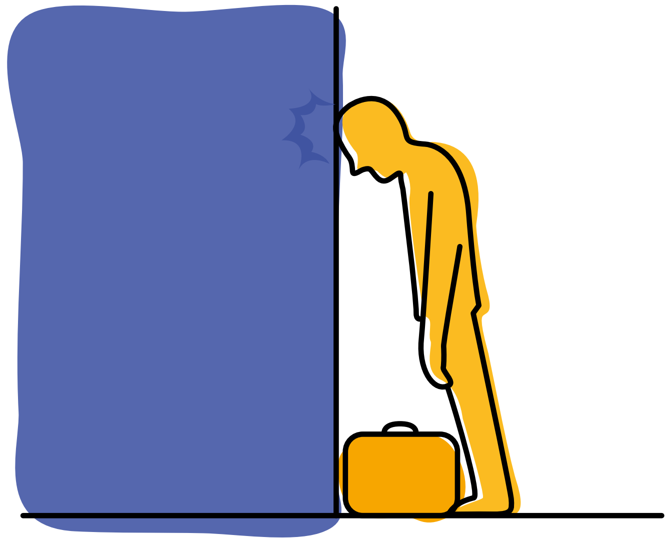
The right inferior frontal cortex has been implicated in go/no-go tasks. Higher risk aversion through rejection of risky options has been correlated with higher activity at the inferior frontal cortex; transcranial Direct Current Stimulation (tDCS) of this area has been shown to lead changes in risk attitudes, thus brain imaging is essential in identifying how decision factors are involved in behavioral choices. These results open an applicative scenario in which tDCS and cognitive strategies might help us sometime in the future to make the optimal choice in risky situations.

Furthermore, we need not forget that individuals tend to be risk averse in the domain of gains, or when things are going well, and relatively risk-seeking in a domain of losses, as when a trader is in the midst of a loss.

Prospect Theory
Individuals are more willing to take risks to avoid a loss since they dislike losses more than equivalent gains.

Thus, the individual attitude of losses/gains and mind- and time-limited rationality should be highly considered in assessing risk preference as subjects with high-risk aversion are willing, for example, with purchasing financial insurance products. The evaluation of the risky outcomes is based on the need for security (fear of losing and fear of becoming regretful) and potential (hope) as well as a given aspiration level.

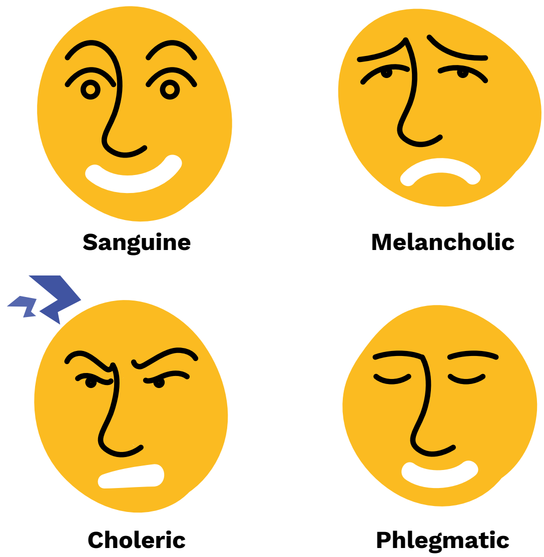
Monitoring the activity in the striatum area during valuation of monetary gambles, which is nonlinear in probabilities in the pattern predicted by prospect theory, would predict the reward encoding or valuing the process of an individual.



From the overall assessment of the current situation to the falsely-rational weighting of possible outcomes, we should consider any behavior by the probability matching, loss aversion, uncertainty effect and confirmation bias in an adaptive model. As we are in continuous search for risk aversion, switching dynamics are highly dependable on individual risk perception and risk attitudes. Any switch from a risk-seeking to a risk-averse profile can be monitored using brain imaging. Risk seeking and risk/loss aversion are highly associated with the activation of the medial and lateral prefrontal cortex, respectively. The prefrontal cortex has been implicated in planning complex cognitive behavior, personality expression, decision-making, and moderating social behavior. All aspects carried out by the executive function that relates to the abilities to differentiate among conflicting thoughts.

While the high anterior insula, an area that resides next to the inferior frontal gyrus (see above) and is believed to process convergent information, produce an emotionally relevant context for sensory experiences, which precede the switch to risk-averse choices. The activation of this area has been associated with the anticipation of physical pain and aversive visual stimuli, and overall negative aroused effect. Financial decisions at either traders or investors side are crucial life-shaping decisions and the importance of understanding their underlying neural mechanisms has recently gained much attention.

In the early 2000s, behavioral scholars and practitioners started considering whoever was called to make a financial decision and investors' personalities in behavioral studies. Pompian (2012) explicitly refers to the theory of personality temperaments, built on previous theories of the Twentieth century such as Jung's theory of psychological type, the theory of personality types developed by Myers and Briggs, or the Big-Five theory, underlining the five main personality traits that characterize people (though, it is possible to claim that four personality temperaments find their roots in the Hippocrates' traditional four temperaments and dated back more than 2,000 years ago!).



Pompian moved from the four temperaments to propose corresponding four Behavioral Investor Types (BITs). Specific cognitive biases can be associated with each BIT because a specific BIT is more prone to some biases than others. Linking cognitive biases to personalities are thus important in several respects. For example, financial advisors may improve their relationship with clients, once they understand their corresponding BIT. Investors themselves may improve their behaviors and decisions once they recognize to have a specific personality that predisposes them to peculiar biases. Nowadays, the challenge is to identify specific strategies suitable for distinct personality types.

Neuroscientific techniques able to monitor body reactions and brain responses are now helping financial researchers in collecting new measures of individuals' cognitive features and automatic behavioral mechanisms, whose role has been largely disregarded by economists since the difficulty to quantify them.

Brain imaging techniques are complementary tools that can be used to test assumptions about the investor behavior that are difficult to evaluate using field data or experimental data alone.

Shlomo Benartzi
TED talk:
"Saving for tomorrow, tomorrow"

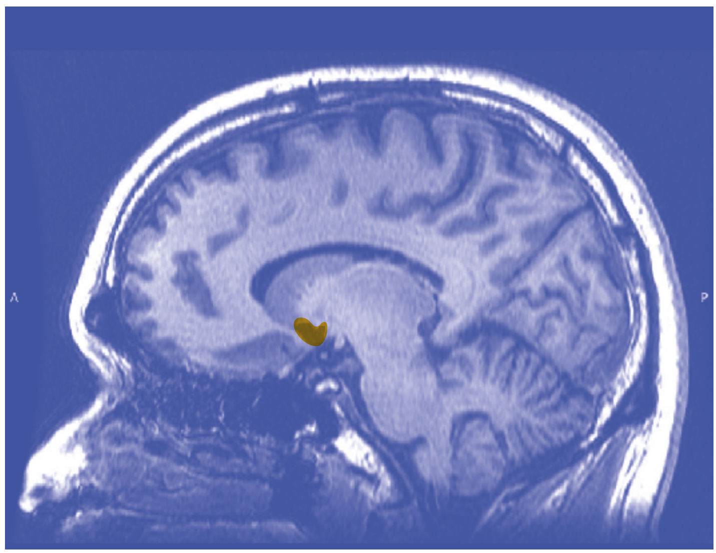
Neurofinance is finally shedding light on the neural substrates that drive agents' behavior in financial markets, in situations of intertemporal choices, risk, uncertainty, or ambiguity, investment and funding decisions, and trading in asset markets.

Several researchers in between 1990 and 2000s measured the skin conductance response and blood pressure of traders, discussing how suspense and anxiety influence portfolio choice.

The first investigation in the area of finance using advanced technology to map the brain was developed in 2002 when Gehring and Willoughby used EEG and a finance game simulation. Results showed brain activity is indeed related to results from final game outcomes.

Later on, other researchers complemented the original information describing that a wide network of neural circuits is involved in risk assessment, benefits, conflicts and the intent to make a purchase or to sell. The nucleus accumbens, the brain area subserving reward, is activated before investors make risky choices as well as risk-seeking mistakes, and the anterior insula activation precedes riskless choices as well as mistakes in assessing risk-aversion.

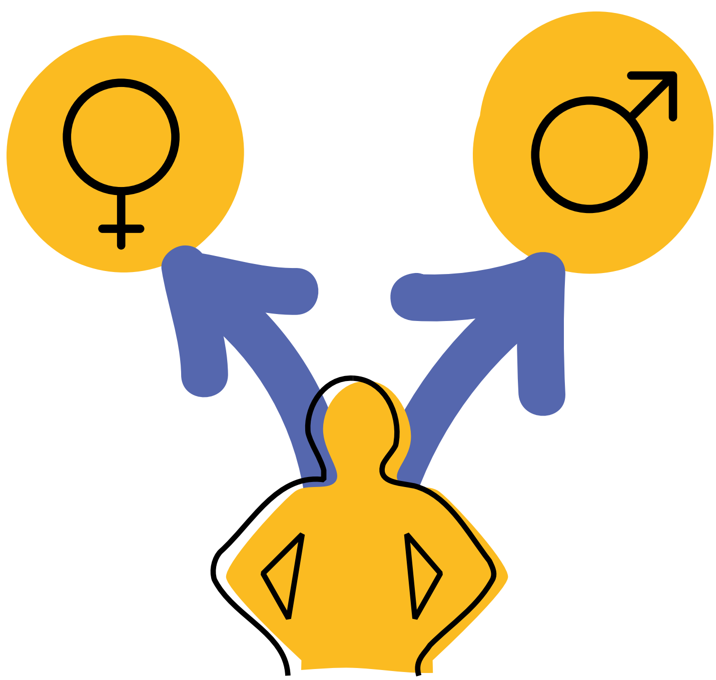
→ Nucleus Accumbens



Nucleus Accumbens is referred to as the pleasure center and plays a role in motivation and cognitive processing of aversion. It has a significant role

in the translation and inhibition of an emotional stimulus into behavior.

Recently a group of researchers provided evidence that men and women differ in their abilities and preferences, leading to different behavioral attitudes across the life cycle. In the financial area, researchers have paid much less attention to gender differences in decision-making. The research field has focused on overconfidence, excessive optimism, confirmation biases, and heuristics with men tending to exhibit greater overconfidence, trading more into mutual funds and equity portfolios. Further prior work in decision-making has found that risk-taking behavior in finance differs between men and women. Men are more tolerant to risk than women, who normally see risk as a threat, whereas men prefer to see risk as a challenge.



The literature suggests that decision-making is different across gender.

Vieito et al (2014) revealed patterns of neural activity that are consistently different for males and females. These results highlight the importance of understanding exactly how risk is interpreted by individuals and that whilst many see risk as an opportunity others see it as a threat.

Men and women use different parts of the brain to make financial investment decisions. Men trade more stocks (buy, hold and sell) while women buy more and sell less. Moreover, women prefer to hold a larger proportion of the portfolio in cash and men more stocks.

The financial decision process changes over a lifetime and older adults make more suboptimal choices, in terms of risk-seeking mistakes than younger adults when choosing between risky assets. Interestingly, younger and older adults show similar neural responses following gain and loss outcomes in both the medial prefrontal cortex and the ventral striatum, however, activation in the latter, an area associated with 'rewarding', show significant differences between young and older adults. Young adults show reduced activation of the ventral striatum for delayed rewards compared to rewards available now, whereas older adults showed equivalent activation of the ventral striatum for rewards available at short and long delays. Thus, neuroimaging studies have implicated nucleus accumbens and medial prefrontal cortex activity in the tendency of younger adults to weight immediate rewards over future rewards.

These statements indicate there is little structural change in the medial prefrontal cortex with healthy aging, but its connection with the ventral striatum degenerates with adulthood. It is important to underscore that functional relationships with prefrontal cortex seem to differ as a function of specific task-based contexts and manifest across childhood into adulthood.

This is why older adults' more optimal temporal choices result from physiological changes, experience, or both; although wisdom is not always a good thing especially considering risky assets.

The latest research in finance and cognitive sciences has highlighted the link between emotions and decision making, pointing out to the need of widening the knowledge of the influence of emotional mechanisms on financial choices.

Emotions and bias: an integral component of reasoning that can inflate bubbles.

A positive emotional state induces people to take risks and to be confident to evaluate investment options, whereas negative emotions, like anxiety, reduce the propensity to take a risk.

Emotions play an important role when people make a decision under risk.

The financial decision-making has important implications for understanding the interacting neural systems underlying the interface between emotion and cognition, but we have to emphasize the important role of emotions as an integral cog of rationality in *neuroeconomics*.

Theories of regret, developed in neuroscience and in decision-making theory, are excellent examples of realistic models that have been introduced into the study of financial behavior. The neurobiologist Antonio Damasio studied the manner in which decision-making and emotional processes interacted to generate optimal behavior. Somatic signals move up from the depths of the limbic system toward the regions of the prefrontal cortex, where the neural foundations of our thinking and decision-making abilities are situated. This area operates as the interface between the evaluation of consequences of our choices and the emotions we feel when the results of our choices are understood. More accurately, activities in the orbitofrontal cortex are differentiated depending on whether subjects feel regret or disappointment.

Paris innovation review
Understanding the financial brain: the goal of neuroeconomics

Regret
The emotion we feel when we are able to compare what we have with what we could have had.

This presumes information on the consequences of options that were not chosen is available. Disappointment is different; it is the emotion felt when we are unhappy with the results obtained without actually knowing what would have what would have happened if we had behaved otherwise. Only regret brings about significant activity in the orbitofrontal cortex. We even know the amount of neural activity linked to regret depends on the difference between obtained gains and unattained gains. In most situations information on consequences of unselected choices is unavailable. In financial markets, however, this information is known. So modeling the activities of the orbitofrontal cortex as a function of regret becomes extremely relevant. We can use our understanding of regret, as registered by our analysis of the activity in the orbitofrontal cortex, to provide modeling resources for behavioral finance.

Frydman et al. (2014) conducted a study in which participants traded stocks in an experimental market while measuring their brain activity using fMRI. They demonstrated that neural data could be helpful in testing model of investor behavior. Activity in the ventral striatum, an area known to encode information about changes in expected lifetime utility, exhibits a positive response when subjects realized capital gains.

Realization utility
The size of the gain or loss realized.

Raggetti et al (2017) have replicated some previous results combining fMRI brain scanning and a Direct Access Trading platform instead of using specific restrained laboratory setting. In addition to confirming activation of brain areas involved in decision-making and risk preferences, they found traders to heavily rely on heuristics to reduce their cognitive effort. Financial agents are emotionally-dependent, irrational and unable to estimate perfectly probabilities and economic value of any risk faced. These preliminary observations highlight how crucial may be to conduct other neuroeconomics studies to improve traditional asset pricing models and investors' behavior theories, to take into account the role of emotions and unconscious processes.

Heuristics
Cognitive shortcuts or rules of thumb that simplify decisions. They represent a process of substituting a difficult question with an easier one.

More recent work using neuroimaging during stock trading has examined the psychological underpinnings of trading biases such as the disposition effect and the repurchase effect.

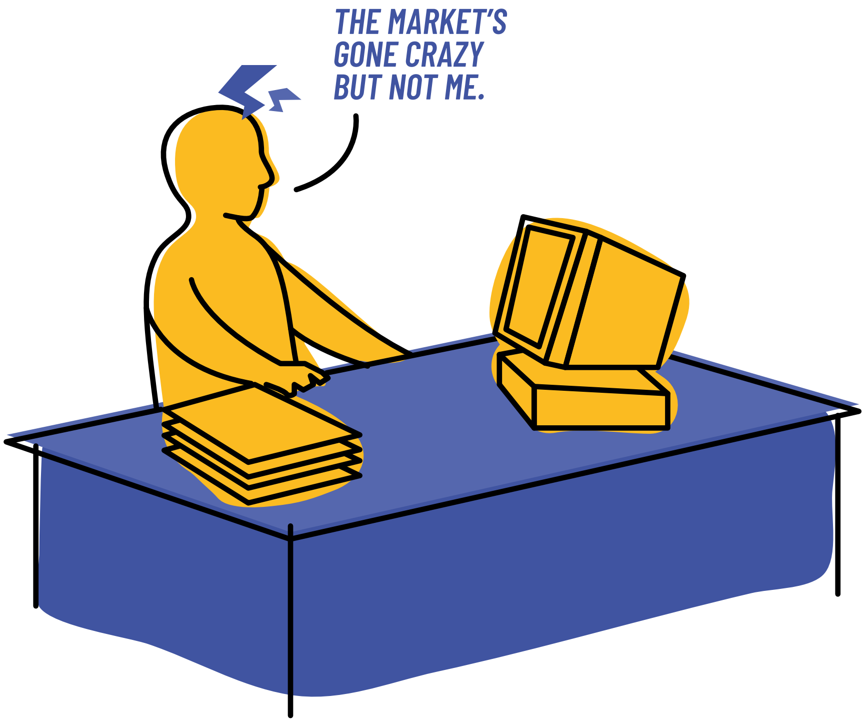
Disposition effect
Is the tendency of investors to sell shares whose price has increased, while keeping assets that have dropped in value.

Repurchase effect
People are reluctant to repurchase stocks that have increased in price after selling them.

«Technology has changed, the height of humans has changed, and fashions have changed. Yet the ability of governments and investors to delude themselves, giving rise to periodic bouts of euphoria that usually end in tears, seems to have remained a constant»

Reinhart and Rogoff (2009)

Princeton University Press
This time is different
Eight centuries
of financial folly



A growing body of research suggests investors make suboptimal financial decisions. One prominent example is the disposition effect: investors tend to sell more stocks that have gone in up value than stocks that have gone down in value, leading to lower average profits. Realization Utility (RU) can explain the disposition effect: subjects derive a positive hedonic impact from the act of selling a stock at a gain. fMRI can succeed where behavioral experiments or data from the field have failed to show consistent results. The ventral medial portion of the prefrontal cortex encodes capital gain in deciding the value of selling. This signal is stronger for subjects who realize more gains. The nucleus accumbens exhibits increased activity when subjects realize a gain, relative to holding it.

The disposition effect is evident in individual trading records from retail brokerages, professional money managers' trades, and laboratory experiments that carefully control the statistical process of price movements. While the disposition effect is now a solid empirical fact, its cause is still debated.

Theories describe neural mechanisms (only) implicitly as a fundamental ingredient of bubble episodes. Indeed, market participants become increasingly euphoric and then (some of them) realize they have been invested for too long and panic.

Ben S. Bernanke
Implications of the Financial Crisis for Economics

«[An] issue that clearly needs more attention is the formation and propagation of asset price bubbles... I suspect that progress will require careful empirical research with attention to psychological as well as economic factors..I would add that we also don't know very much about how bubbles stop either...»

Cfr. Ben Bernanke, 2010 speech

In literature, researchers have created paradigms that reliably generate bubbles and crashes. In this context, researchers were able to measure neural activity to bubbles and crashes. Robert J. Shiller in 2015 stated the news and media in 2007 and 2014 seemed to relish trumpeting new records set (in nominal terms) by the stock market. And yet, deep down people know that the market was highly priced, and is now highly priced, and they feel uncomfortable with this fact.

Theories describe neural mechanism (only) implicitly as a fundamental ingredient of bubble episodes is that market participants become increasingly euphoric and then (some of them) realize they have been invested for too long and panic. In literature, researchers have created paradigms that reliably generate bubbles and crashes. In this context, they measured neural activity using fMRI and connected neural activity to bubbles and crashes. Robert J. Shiller in 2015 stated the news and media in 2007 and 2014 seemed to relish trumpeting new records set (in nominal terms) by the stock market. And yet, deep down people know that the market was highly priced, and they feel uncomfortable with this fact. Can neuroscience identify where "deep down" is?

Researchers have connected bubble buying to activity in the Nucleus Accumbens (see above). A region of our brain involved in drug addiction and behavioral disorders (e.g compulsive gambling). This trigger the hypothesis confirmed by many that bubbles are the result of a collective behavioral pathology in which the common biological foundations rely on addiction and impulse control disorders. Despite this primordial impulse, a neural "early warning" signal can be located in the right anterior insula. Activity in this region is associated with awareness of bodily states, pain, risk, "gut feelings" and emotion, suggesting causal changes that increase insula activity could reduce bubbles.

The societal goal of neuroscience in economics and finance is to improve the theory of decision-making. If we better understand the reason why we make mistakes and sub-optimal financial choices we can develop tools to improve our decision-making. Just a handful of devices have been experimentally tested to improve the objectivity of our decision making in the financial sector (e.g. tDCS).

Paul Craven
Behavioral Finance: from biases to bubbles

Although the lack of results in this sector might seem a weakness, the strength becomes evident in identifying such behavioral and neural profiles associated with a better performance. The brain has gotten used to the processing of incomplete information ultra-fast. We cannot expect the brain, over a short period of time, to adapt to something as historically new and complex, for example is the financial market. But understanding brain mechanisms will help make these environments more comprehensible.

INTERVIEW

Enrico Maria Cervellati
Associate Professor of Corporate Finance at the Department of Management Ca' Foscari University of Venice

How can neuroscience research contribute to behavioral economics?

Neuroscience research contributed a lot to behavioral economics and will contribute even more in the future. It helped in suggesting the ways in which we can help people improve their decisions. Thanks to neuroeconomics, behavioral economists such as Richard Thaler – Nobel Prize in Economics in 2017 – or Shlomo Benartzi were able to understand why we have self-control problems and how to address them. Their work signed the shift to what has been called "behavioral economics 2.0" or "behavioral economics in action", that helped millions of people in taking, among others, better retirement decisions.

How can your research help us understand the decision processes underlying human behavior?

My research mainly deals with behavioral finance. I analyze managerial, entrepreneurial, and investment decisions. I show that not only unsophisticated investors or entrepreneurs – let's say, "normal people" – but also financial analysts or managers – i.e., "professionals" – are prone to behavioral biases, decision heuristics and framing effects. I stress the importance of recognizing the effects of these behavioral issues as well as the importance of "debiasing" techniques to reduce their negative effects on corporations, markets, and the society as a whole. Recently, I have been working on what I call "behavioral finance 3.0" or "personalized" behavioral finance, that links personality theories to the behavioral approach.

What tools do you use in your research?

I typically analyze empirical data using econometric techniques. Recently, I started using questionnaires to detect investors' financial personality. I would like to collaborate with experimental economists as well as neuroscientists to start using their tools to corroborate my research ideas. In particular, while it still may be early to talk about "personalized" medicine, I think that in finance it is easier to use the tools used in personality theories to help investors, financial consultants, but also managers and entrepreneurs in understanding their decision processes, and potentially debias their behavioral biases.

Will it be possible to predict human behavior and how we make choices?

Somehow, it is already possible, at least as behavioral biases are concerned. We are "predictably irrational" as Dan Ariely would say. I don't like the word "irrational", since most of the decision heuristics we use are somehow "ecologically rational". Nevertheless, it is important to remember that the same heuristics that work in everyday life, may lead us to error in other decision fields, such as in finance. While we somehow already can predict human behavior, I think there is still a long way to go in "debiasing", i.e., in helping people correcting or avoiding errors. We are hard-wired.

Will it help us to make better economic decision?

Many behavioral economists, such as Thaler, have shown how it is possible to improve economic decisions with the so-called "nudges". Of course, one should first define what a "better" economic decision really is, but it is quite evident that is possible to use behavioral techniques linked to choice architecture to change – if not improve – people decisions not only in the economic field, but also in other fields, such as nutrition or politics, just to name a few.

In your opinion, what are the next big questions to be answered in the field of neuroeconomics?

I am not a neuroscientist, so I hope they will forgive me, but I think that "personalized" neuroeconomics maybe a promising field. While probably most of the decision processes are common to all human beings, other may be different depending on the personality of the single person. Personality may, in other words, somehow change people response to the same stimulus, as culture somehow does. Another big question that neuroeconomics may answer is "how do we may help people changing their behavior?". We know how hard is to change our own behavior even when we want to change it (e.g., exercise more, put ourselves on a diet, etc.).

Will they have any ethical implications?

Of course, they will have many ethical implications. "Nudges", for example, are part of what has been called "Libertarian Paternalism" – an apparent oxymoron – that raised a lively debate in terms of ethics, given the importance of setting the so-called "default option", i.e., the option that you get if you don't decide. This is just an example of what happens when we devise tools to change people decisions. I think this is a very important issue, that we should always consider, either if we use neuroeconomics or behavioral economics or the traditional approach. Every time we deals with people decisions and with the possibility of distorting them – even "for good" – we have to keep in mind the ethical implications.

GLOSSARY

FOCUS ON: FINANCE & INVESTMENTS 8

Bounded Rationality
Rationality is often limited by the tractability of the decision problem, the cognitive limitations of our minds, and the time available to make the decision.

Disposition effect
Is the tendency of investors to sell shares whose price has increased, while keeping assets that have dropped in value.

Expected utility theory
The decision maker chooses between risky or uncertain prospects by comparing their expected utility values.

Heuristics
Cognitive shortcuts or rules of thumb that simplify decisions. They represent a process of substituting a difficult question with an easier one.

Prospect Theory
Individuals are more willing to take risks to avoid a loss since they dislike losses more than equivalent gains.

Repurchase effect
People are reluctant to repurchase stocks that have increased in price after selling them.

Realization utility
The size of the gain or loss realized.

Regret
The emotion we feel when we are able to compare what we have with what we could have had.

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09

Focus on: Human Resources

The benefits deriving from the application of neuroscience can be numerous in several different fields but in Human Resources (HR) is where it becomes the central core. Neuroscience has already attracted a lot of interest in, but not limited to, leadership, management, digital assessment of soft skills and hiring, and its application in optimizing HR services will definitely increase in the near future.

Enrichment of strategy and man-agement

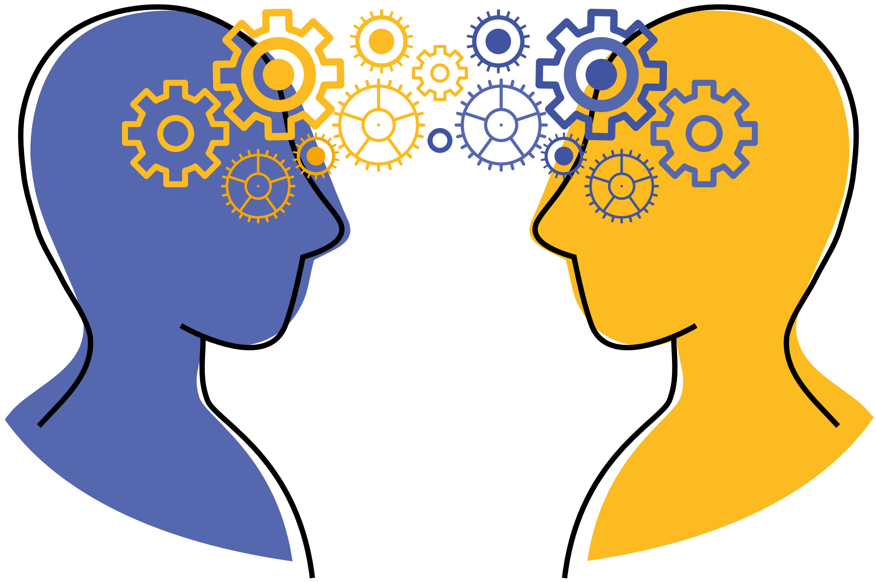
Organizational neuroscience is a subfield of neuroscience dedicated to the investigation of social-cognitive phenomena in organizations. The main objective of organizational neuroscience is to answer many important questions and provide a better understanding of the interaction between the human brain and the environment.
Through neuroscience, we have achieved a great point where we are scientifically competent in expanding leadership practices and affecting innovation and creativity, to successfully create and secure employee engagement. Managing and leadership collide with neuroscience to bring neuroscientific knowledge into the areas of organizational development, management training, organizational changes and executive and corporate management.

Organizational neuroscience
Explores the implications of brain science for workplace behavior.

Internal and external factors to the individual, as individual differences, mental processes, and environmental factors and organizational contexts, become the bases of social neuroscience, a strong complement to organizational behavior.

Social neuroscience
The science behind intergroup relations, social networks, altruistic behavior, social learning, and self-biases.

While organizational neuroscience still requires further testing and methodological research before considering any realistic implementation within an organization, this field already relies on preliminary evidence as obtained by neuroscientists in controlled experimental settings.
A rapid evolution of neuroimaging techniques, like functional magnetic resonance imaging, electroencephalography, and magnetoencephalography, will allow in the future for a more complete and accurate understanding of human behavior. These tools open a new level of analysis to organizational researchers and hold the promise of addressing new questions. Indeed, researchers are getting closer and closer to the definition of approaches that will grant us with a deeper understanding of people's behavioral intentions, beliefs, and psychological traits.



Although a high level of expertise is required to design, execute, and analyze neuroscience studies, and given the constraints of neuroimaging, organizational neuroscience could offer new tools to potentially improve assessment of top performers. Commercial EEG headsets could be used indeed to record the real-time brain activity of individual team members during team-based cooperative work, something of interest to organizations seeking to train employees to exceed goals and expectations. Innovative approaches in brain imaging may even 1. reproduce specific working scenarios to understand behavioral and neurobiological underpinnings (e.g., brokers selling in the stock market, branch manager-customer interactions, cognitive ergonomics in the working station), 2. reveal the mechanisms that determine why communications from upper management or other leaders succeed or fail in motivating subordinates or even contrast neural activity of free-riders or low-performers. Furthermore these methods will provide insights into more specific steps or information to be included in training procedures.

It is advisable to extend the concept of organizational neuroscience to include both direct measures of cognitive activity as well as indirect measures of brain activity (e.g. cardiovascular or electrodermal biomarkers). The latter set of measures acquired from the periphery of the body provides insight into cognitive functions that originate in the brain. Particular techniques employed in neuroscientific investigations could be used to obtain information related to cognitive difficulties of tasks (e.g. related to a particular work position), also referred to as organizational cognitive neuroscience. For instance, the 'eye-tracking' technique provides a very close proxy to measures of focused attention. Similarly, 'pupillometry', the measurement of pupil size and reactivity, acts as a proxy marker of cognitive load and changes in mental states, particularly changes in attention allocation. In combination, these two techniques provide real-time, sensitive indices of continuous visual and cognitive processing, which could serve a number of practical purposes like creating a taxonomy of work tasks by the tasks' levels of cognitive load.

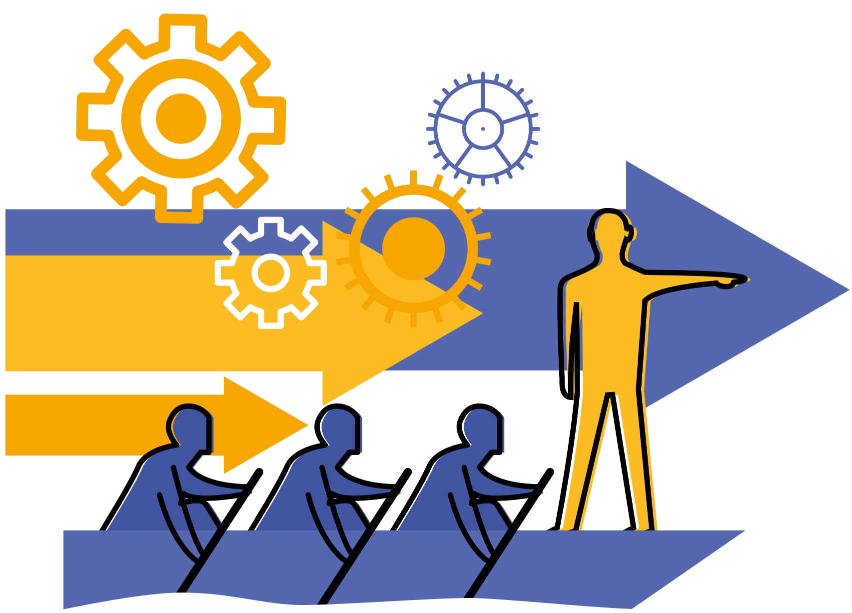
Eyetracking and pupillometry provide HR professionals with information about the cognitive difficulties of tasks within a position.

An overview of organizational neuroscience

«...We should caution that the utility of different neurological and biological measurements in organizations depends on the continued development of technology that can minimize invasiveness and maximize portability. Creating an environment where people consciously consent to passive data collection could result in an unprecedented richness of data by incorporating the brain-level of analysis and its application....»

as reported by Ward et al (2015)

As discussed in other parts of this book, neuroscience research could also offer novel tools to improve learning efficiency or the retention of novel information, thus accelerating training procedures in the context of organizations. For instance, noninvasive brain stimulation methods, in which a changing magnetic field is used to cause an electric current to flow in a small region of the brain via electromagnetic induction, have been proposed as a tool for speeding up training and development programs.



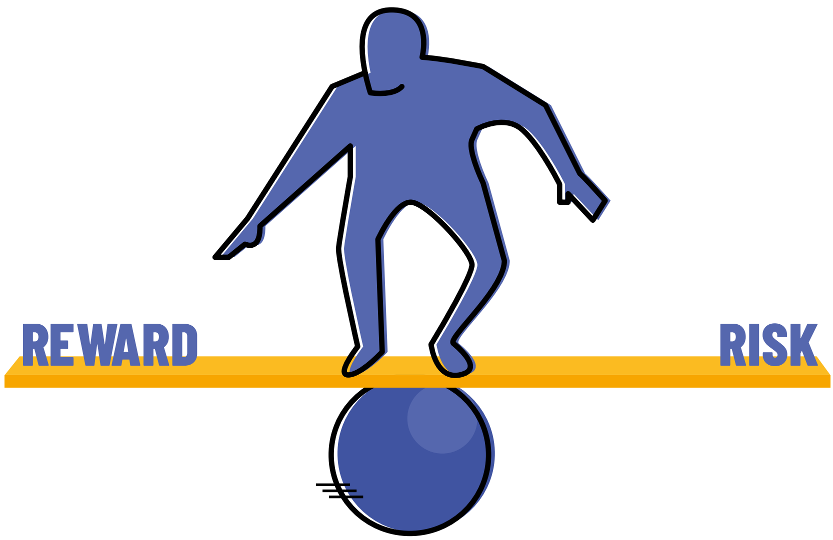
Simon Sinek
Why good leaders make you feel safe

Among other topics, research in cognitive sciences is leading us to a better understanding of how to improve leadership performance, for instance by modulating general behaviors or how the 'leader' engages with and motivates others. Neuroscience findings are helping us to connect the dots between human interaction and effective leadership practices and how we might better structure and manage organizations. It is now becoming clear that human resources professionals need to reinforce their role in management by applying neuroscience findings to optimize and facilitate the development of trust and relationship building in organizations.

As neuroscience reveals the social nature of the workplace, companies can now increase retention rates and reduce the rising costs associated with turnover.

David Rock, founder, and CEO of the NeuroLeadership Group developed the so-called 'SCARF Model', which targets the top five social rewards and threats identified so far that are deeply important to the brain:

Status,
Certainty,
Autonomy,
Relatedness,
Fairness.



David Rock
Science Behind
Leadership

This model can be used as a guide to assess existing and proposed management practices and determine whether they trigger a "primary reward" or "primary threat" response in the brain. The SCARF model can be used in coaching and by human resource professionals to manage the social needs of others at work. One of the main aims of the model is to increase reward and reduce the threat.
This lies on the assumption that when the brain perceives a threat, whether real or imagined, it blocks individuals' ability to plan and create.

Neuroleadership
A term coined by David Rock, founder, and CEO of the NeuroLeadership Group focuses on applying neuroscience to leadership development, management training, change management education and consulting, and coaching.

Digital assessment, hiring and team cooperation

Gamification is the concept, which uses game theory, mechanics, and game designs to digitally engage and motivate people. Many companies are finding that virtual games, which integrate points, badges, competition, and role-playing, can be used to effectively attract and assess candidates. Recruiting agencies have started using game-based methods in matching organizations with skilled job applicants. Users play a series of quick and engaging games that identify cognitive, social and emotional traits that are predictive of job fit and success.

The end result is a faster, less expensive hiring process that identifies top candidates among hundreds of thousands of job seekers. That means hiring decisions are supported by objective data to profile existing high-performing teams and use the results as a benchmark for new hires.

Internal Demo Day Pitch
Pymetrics

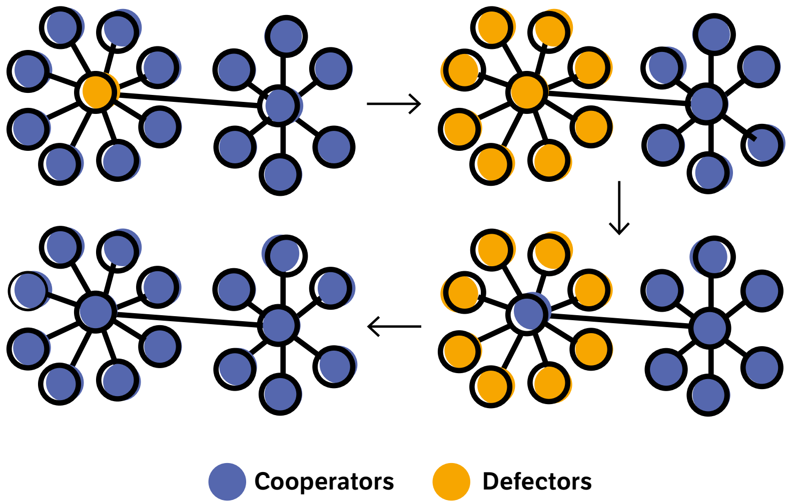
A great example in which neuroscience has a major role in profiling job applicants comes from Pymetrics. The company uses a “big data”-search platform and machine learning in recommending career paths to job seekers. The big data are results from the assessment of more than 50 cognitive and personality traits using neuroscience games.
The transition of neuroscientific methods from cognitive tasks aimed at diagnosing learning disabilities in medicine through screening resume and matching career paths has been a great achievement for corporate HR.

Once the candidate personal traits have been assessed in the recruiting process, these can be stored within the organization to map the right human ‘personality’ network based on neuroscience. Personalities, indeed, can make or break a group, and now psychologists along with human resource professionals may know why. To simplify, it all comes down to three personalities - cooperators, free riders (or defectors), and reciprocators. Cooperators are the first to step up to the plate and give to the group almost immediately. Free riders (or defectors) are at the other end of the spectrum. They chip in far less than anyone else, coasting on the contributions of others. Reciprocators take a “wait and see” approach, hanging back until it is clear that they will serve their own best interest by helping out the team. Despite this broad generalization of three interpersonal and motivational profiles, there are currently numerous examples in literature in which other tests are commonly used and will be largely implemented in the screening process in several industries.

Primavera De Filippi
TED talk:
“From Competition to Cooperation”

Competition between and among different living forms is one of the most important forces in evolution, and human beings are no exception. The more a certain resource is limited, the more competition arises between individuals. However, cooperation is the social value that shall be maximized in a context where there is a strong commitment to a cooperative organizational culture.

To better understand how cooperation both succeeds and fails, recent research in cognitive neuroscience has begun to explore novel paradigms to examine how cooperative mechanisms may be encoded in the brain. Combining functional neuroimaging techniques with simple, but realistic, tasks adapted from experimental economics allows for the discrimination and modeling of processes that are important in cooperative behavior. While culture itself can fulfill an integrative function, cooperation among various stakeholders has to be carried out with a specific purpose in mind. Humans can cooperate or compete, and various social factors influence the extent to which they are willing to sacrifice their personal gains to increase or decrease the well-being of others.
Once HR will be able to profile the cooperative and interpersonal skills of employees and define defectors, cooperators, and reciprocators, a cooperative environment will be created in which collective cooperative action will be fostered through combining and networking the right resources.



When a defector occupies a high-fitness location, the fact that he/she places other defectors in his/her neighborhood leads to his/her own demise in a cooperative environment; while the relative fitness of a single cooperator increases with his/her connectivity.

In companies (and communities) under the influence of social norms, individual contributions are easily classified as acts of cooperation (or not). In this context, successful teams are those in which the act of giving is more important than the amount given. Economic games combined with social and organizational neuroscience has confirmed team led by a cooperator has a higher probability of success if this is measured as collective cooperative actions. The opposite does not subsist, as a team with a defective behavior leads to its demise in a highly cooperative network.

Yves Morieux
As work gets more complex, 6 rules to simplify

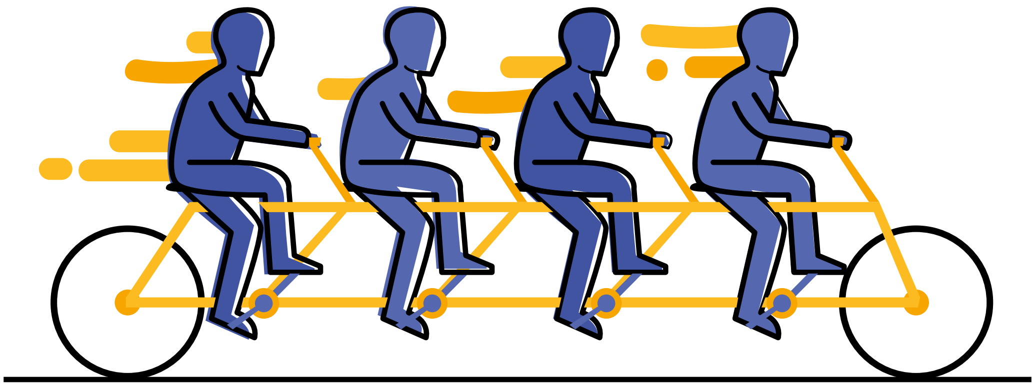
Teamwork, cooperation, and helpfulness between workers can be of substantial value to a firm, although exertion of cooperative effort is usually costly to a worker. Both empirical evidence and carefully designed experiments suggest that workers have a preference to cooperate conditionally on the cooperation of others, or in other words 'conditional cooperation'.

Conditional cooperators
Contribute to the public good only if they expect other group members to do so as well.

Strategic human resources within a company have the responsibility to integrate skills and abilities to identify either conditional or unconditional cooperative traits, which will be necessary to secure and leverage a cooperative environment. Specifically, unconditional cooperation can be captured by common preferences shared by all employees with a common gain. This is associated with consistent activation in brain areas that have been linked with a social rewarding process. Vice versa conditional cooperation is much more heterogeneous and depends on individual neural bases. It has been largely associated with brain regions activated by self-reported pleasure and satisfaction.

It is essential to understand contextual factors and individual neural bases to create and leverage a cooperative environment.

Organizational trust reflects an open cooperative atmosphere where productivity, high job satisfaction and participation in decision-making can be observed. Overall, unconditional cooperation and conditional trust develop a sustainable competitive advantage for a company; therefore, the benefits from understanding cooperation within an organization open to trust and integration are not only individual but collective as well.



Many of the processes underlying cooperation overlap with rather fundamental brain mechanisms, such as, for example, those involved in reward, punishment, and learning.

In order to maintain cooperative behavior in society, people are willing to punish deviant behavior on their own expenses and even without any personal benefits.

The prosocial behavior is a quite complex matter as two brain networks, associated with psychological components of fairness-related normative decision-making, co-exists with a more immediate emotional response to inequity aversion.

Observations from different functional studies focusing on interactive economic games on prosociality showed that a more intuitive network appears to perform a rapid evaluation of inequity, while a deliberate system integrates both equity and self-interest, to resolve the conflict by either suppressing the intuitive responses or over-riding self-interest. In a more simplistic model, cooperative behavior has often been associated with positive emotions, while on the contrary non-cooperative behavior has been linked to negative emotions. On a neural level, the temporoparietal junction, the striatum, and other reward-related brain areas are activated by cooperation, whereas non-cooperation is associated with activity in the insula, a region of the brain linked with inequity aversion.

Inequity aversion
Human resistance to inequitable outcomes, which occurs when people prefer fairness and resist inequalities.

The available evidence from neuroscience poses a challenge for views of human behavior that leverage conscious processing but ignore our non-conscious self.

Non-conscious processes
Make up the most interesting psychological aspects of our lives and define all the processes people are not consciously aware of.

Neuroscientists have made a good deal of progress toward understanding a number of non-conscious issues such as person perception, attitude formation, and so on. Therefore, as a number of researchers have asserted that non-conscious processes need to play a greater role in the organizational theory. The introduction of neuroscientific tools and knowledge in the organizational science will allow in the future to improve all aspects of social and cognitive phenomena in organizations, from leadership and management to engagement and cooperation. Softs skills build up our individual competence profile in the organization where these become our personal ID. At the corporate level, once the right individual competencies will be identified and matched with the others peers, neuroscience will be able to address the needs of tailored activities to create the right 'personality' network. Although a lot has been done the biggest challenge is to better understand how neuroscience can be implemented to shape HR services in the hiring process, digital assessment, and training activities.

Neuroscience for Management science: from brain to business, and back

Management science is a domain of multidisciplinary knowledge with the focus on the analysis of problems in business and industry, involving the building of models and applications problem solving oriented, and on decision-making process in human organizations.

Management science has deep roots in many different research fields as well management, economic, strategy, mathematics, physics, psychology, sociology, computer science and, the last joined, neuroscience.

Management science today is really pervasive and it embraces any organizational activity for which the problem can be organized and designed as a functional system so as to obtain a solution set with recognized variables. It helps managers to implement a practical strategy and to achieve goals adopting various scientific methods by improving organization ability to facilitate the decision-making process in a scenario characterized by high level of complexity.
The study of the brain is currently shedding light on the way entrepreneurs, executives, managers, employees as well as consumers make decisions.
Humankind is rich in diversity; people differ from each other greatly. Not only physical attributes such as size, weight, hair and eye color are concerned with those differences but also many psychological characteristics such as temperamental characteristics and motivational aspects. Differences are also to be found concerning the extent to which individuals are willing to be committed to the aims of the organization where they work and give their best to make it function well.

Does brain science add any insight on the comprehension of these phenomena?

Does this understand helpful in improving management science and interaction in organizations? In particular, neuroscientific investigations of the way the brain works and responds in organizational contexts are still at beginning of

its exploration. However, the first insights on important issues that regard organizational behavior have been highlighted already, such as studies on human fairness and cooperation, as well as on altruistic punishment.
Knowledge of the cognitive or emotional nature of a specific type of decision-making process can be used by managers to increase their self-awareness on what happens while engaging in decision-making processes or when deciding to delay a decision if a critical event happens and affects the ability to make a rational or a more convenient choice.

Improved awareness may be helpful in preventing and solving problems in social situations. These results could explain the motives of employees' behavior in organizations and their causes. For instance, since people have a strong desire and take pleasure in punishing cheaters or offenders, managers may capitalize on this important knowledge to create working places where conflicts are handled in a proactive way, giving time to people to discuss their issues and to solve conflicts, as well as fostering the ability of people to speak about interpersonal problems that may affect their interaction and productiveness.

Figuring out which are the desires, the goals and the intentions of the players in a working place is clearly useful for a better managing to the aim of reaching a common goal. Neuroscientific evidence can be used to define models of personality, prototypical responses to critical situations that can be helpful to predict future behavior, actions and reactions of people under stress, or in other critical situations. Collaborations with colleagues and the creation of new partnerships are of high value as they represent the source of learning of new organizational paradigms, which may be beneficial for the firm as they highlight shortcomings of the present routines.

The manager's tasks of coordinating and finding a positive interaction among all these aspects may be crucial in conferring to the firm the potentiality to reach success.
In a business company, an orchestration of the efforts as a whole is more important than the singular parts for achieving success.

Neuroscientific advances might give the entrepreneurs, executives, and managers the possibility of adopting new perspectives for interpreting human processes and for influencing behaviors. Even though we are only at the beginning of the process of uncovering how the brain functions in the organization, we believe that this knowledge will be very important in the future to better capitalize on human resources and to respond rapidly to a continuously changing environment.

Dynamic capabilities - the firm's ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments - concur in posing the basis for responding in a quick manner to changing environmental situations by means of a continuous reconfiguration of competencies that are internal or external to the firm.
Adaptation by means of the adoption of a continuous monitoring of efficacy is very important given the fast-pacing times to which technology and the environment change: dynamic capabilities have their roots in both exploratory and exploiting behaviors in the firm.

The ability of a manager to find an optimal trade-off between exploiting the resources that are currently available to the firm and exploring the environment for new opportunities and resources is essential for maintaining competitiveness. Both activities of exploiting what is currently in possession and exploring what is still unknown are costly in term of resources

and time and pose the problem of deciding what has to be preferred and chosen over the other one.
Recent researches explain the contributions of neuroscience to management skills in finding an optimal trade-off between exploiting and exploring. Exploitation activates regions associated with reward-seeking, which track and evaluate the value of current choices, while exploration relies on regions associated with attentional control, tracking the value of alternative choices.

Studies argue and suggest that a number of factors may intervene in modulating the way the manager handles this paradox and that a deeper knowledge of those factors, which can be achieved through the methods of neuroscience, can help in handling the presence of shortcomings, which then will greatly advantage the business.

So far, most models have focused on the level of the social organizational context for addressing this paradox, leaving aside the gap of the manager's mind to be fully uncovered.

Neuroscience, in fact, increases our understanding of the micro-level functioning, i.e., the manners in which the single person cognitive and the emotional processes function.

Individuals are not all the same with respect to their tendency to engage in an exploratory behavior. Some of them may be more inclined to exploration as stronger activation of the brain circuits related to attentional control allows individuals to achieve better decision-making performance as a result than others. The way the manager handles attention does affect its performances. There are two types of focus: broad and narrow. This distinction refers to the number of elements that are being attended to at a given time.

Based on neuroscientific findings, when a situation is characterized by high uncertainty there are more possibilities that broad attention and explorative strategies will lead to a better outcome, while, in other contexts, narrow attention as well as relying on well-known routines, can prove to be the successful strategy.

The perception of the utility of a given action, then, appears to be another factor that plays an important role in sustaining attention in a broad rather than in a narrow manner, thus affecting the tendency of embracing one set of actions or the other one.

The ability to balance the tendency toward exploration and the tendency toward exploitation and to keep management abilities very flexible depending on the contextual situation can be regarded as the key factor of success for the firm as it enables to take advantage of continuously changing opportunities.

Given the importance of attentional processes in decision-making it would be very important to develop and apply protocols that help the manager to control and self-modulate his attentional focus and resources according to the mode that is more helpful given under each circumstance of interest.

Also, the perception of time and the emotional state of the managers are other factors that may influence decision-making processes and that should be investigated in future research.

How far can the contributions of neuroscience to management science go?

Management science can be enriched by the comprehension of how people react to environmental situations in the business and the social life.

Until recently, it was believed that the brain would not change in adulthood and that after maturation there was place for decline only and not for modifications.

Today, neuroscientific advances demonstrated the brain to be a plastic organ that constantly adapts to environmental stimulations. Thus, providing workers with a stimulating environment that facilitates and rewards learning and the development on individual initiatives is a first step in promoting excellence.

Strengthening processes such as personal growth and development, which are intrinsically rewarding processes, should continuously foster the commitment to the aims of the firm.

Management strategies should be kept under continuous upgrading in order to offer a continuously stimulating environment to the employees and diverse possibilities to develop their different inclinations.

The idea presented in this book is that human being is the center. As described, the discipline of neuroscience can help managers, businessmen and researchers observing behaviors of people both, inside and outside of the company. This considered, it is important to remember that the managers‘ mind and its engagement in the firm cannot be modeled in an easy way. This is due to the fact that the firm is not the man; a business mind is not the single individual but rather it is created by the continuing interaction of each individual and the socio-economic system of many different relations. Thus, neuroscientific investigations, which focus on the single level, cannot completely be used to bridge the gap that exists between the individual and the organizational system in which he is at work.

The ability to quickly learn and adapt to changing environmental situations is very important in the contemporary firm scenario.

Corporate agility is essential for the firm and consists in a number of conditions such as the capacity (1) to sense and shape opportunities and threats, (2) to seize opportunities, and (3) to maintain competitiveness through enhancing, combining, protecting, and, when necessary, reconfiguring the business enterprise's intangible and tangible assets; other important topic is the ability to create and build strategic assets as well as their coordination and integration can influence competitive advantage of the firm on the markets.

The ability to adopt rapid pace changes is subordinated on the prior ability to identify subtle indexes of change in the environments, which can be used as predictors of future greater modifications. This follows on the ability to foresee specific trends and establish a competitive advantage by devising new products to outperform competitors.

Nevertheless, the fact that firms need to continuously reconfigure existing assets and routines in order to meet ongoing changes in the external environment imposes a cost on the firm's budget.

In a company orchestration of the efforts as a whole is more important than the singular parts for achieving success: elements concur in creating a competitive advantage when they are combined to each other, that is when they appear in a synergic fruitful combination rather than when they are dissociated. Thus, the ability to find a good harmonization of all these elements and of making them work in synergy is crucial for providing a competitive advantage to the firm.

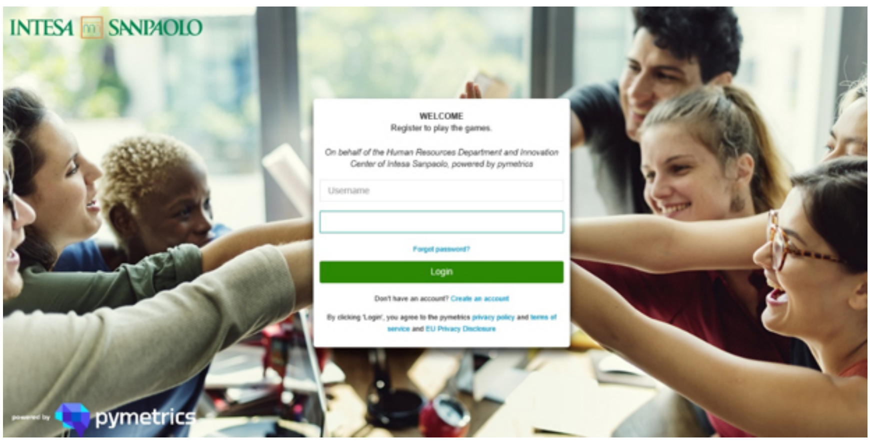
This is a crucial step both, for future research in management science that requires the ability of the man in combining in a fruitful manner all insights coming from different disciplines and for practical application in a business company that increases productivity and competitiveness.

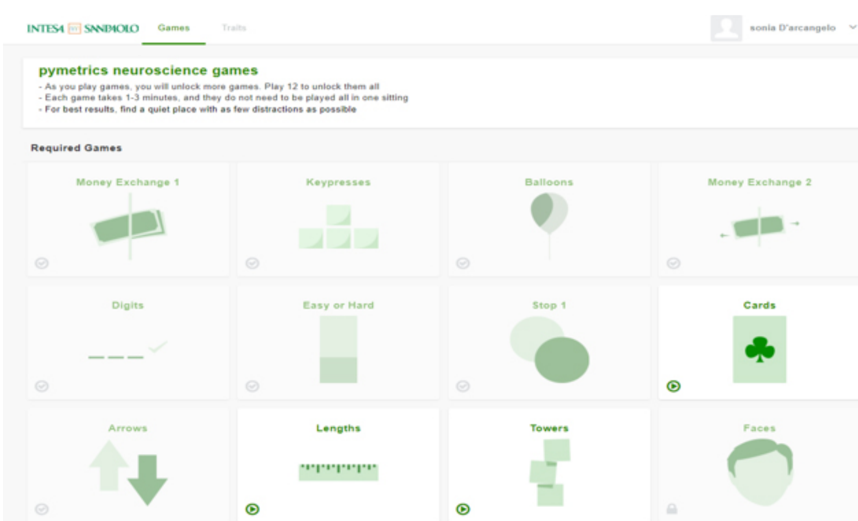
HR and Neuroscience — pymetrics proof of Concept

On this topic **Intesa Sanpaolo (HR Department) and Intesa Sanpaolo Innovation Center** have collaborated in 2017 with an American **startup** named **Pymetrics** in order to embark on a Pilot utilizing the power of neuroscience for recruiting.

The main goal was to explore new methods of digital assessment for candidates, as Pymetrics has developed **neuroscience-based assessment** and prediction technology to transform the way companies hire, retain, and develop their people. The company assesses **cognitive and personality traits** using a series of fun and quick neuroscience games, making it easier than ever to understand where inherent characteristics can lead to success.

During 2017 Intesa Sanpaolo and Intesa Sanpaolo Innovation center have used Pymetrics – tailored for the Bank entity – in a Hackathon with the aim of hiring 30 new colleagues from a pool of 300 participants who just graduated (with mathematics or economics degrees) for the Corporate Department. They have asked the participants to complete the Pymetrics games before the Hackathon in order to have additional insights on them before meeting them in person.





The neuroscience tasks adapted into the Pymetrics game battery are designed to evaluate interesting and unique aspects of candidates, for example:

Iowa Gambling Task

The task allows participants to select cards from four decks displayed on-screen. Participants are instructed that the selection of each card will result in winning or losing money. The objective is to attempt to win as much money as possible

→ **decision making and risk seeking**

Ultimatum Game

A social interactive bargaining task that measures social preferences via the degree to which participants accept unfair and unequal offers

Tower of London

Participant must rearrange a set of three colored balls arranged on pegs, in the fewest possible moves, to match a specified configuration

→ **fast performed tasks**

BART

Balloon analogue risk task

→ **decision under uncertainty**

Digit Span

A task in which participants are presented with sequentially presented digits and are then asked to recall the items

→ **working memory**

Go/No Go

A task in which stimuli are presented in a continuous stream and participants perform a binary decision on each stimulus

→ **Accuracy and reaction time are measured for each event**

Eriksen Flanker Task

A task in which participants view stimuli (typically arrows) presented one at a time and to which they must make a simple lexical response. These stimuli are surrounded by either distracting or facilitating items

→ **Spatial selective reponse**

pymetrics.com

Pymetrics video

Pymetrics

Pymetrics applies proven neuroscience games and cutting edge AI to reinvent the way companies attract, select, and retain talent.
The new human resources selection process is based on an assessment of company's DNA: Existing employees play pymetrics neuroscience games - pymetrics analyzes trait data and trends are identified - pymetrics builds custom algorithms representing success and audits for bias - candidates play games and match to opportunities. pymetrics uses assessment tools developed by the global neuroscience community based on decades worth of research. They are widely considered the gold-standard of neuroscience research, and measure established building blocks of cognitive and emotional functioning, akin to the DNA of cognition + personality. We capture these traits by measuring behavior on an objective scale, rather than asking people to answer questions.

pymetrics

Total Funding $16.6 Mln

Last Round September 2017
Series B

INTERVIEW

Frida Polli
CEO Pymetrics and Neuroscientist at MIT

Why have you thought to create a startup like Pymetrics using neuroscience games?

After a decade as an academic neuroscientist at Harvard and MIT, I got a fellowship to go to the Business School at Harvard, which is where I came up with the idea for pymetrics.

There were two main experiences that led to the idea - the first was personal, and the second was through my peers. I was a 30-something year old woman with a 30-something page resume, but I had no idea what to do next with my life. I knew I didn't want to stay in academia but I wasn't sure the best way to translate my skill set into an industry job. I couldn't believe that people were still telling me to take the Myers Briggs to figure out what to do with my life — a tool that was developed decades earlier when we had much less neuroscience knowledge, much sparser datasets, and much less sophisticated recommendation engines to process data.

The second 'aha' moment was watching my peers — at HBS nonetheless — "drop their resume" for any jobs they heard about around campus, and often times, never hearing back. It seemed random which people got interviews and who ended up getting offers. There were countless websites to find job listings and candidates, but none that were actually matching people to the right jobs for their personality and skills.

In a time where Netflix can give you personalized movie recommendations, Spotify can give you personalized music recommendations, Amazon personalized product recommendations, why could nobody understand our individual traits and give us personalized recommendations for our most important decision - what to do with our lives?

That's when I realized I could take the neuroscience research I had been doing in a brain imaging lab for the past decade, merge it with data science, and create a consumer-grade product experience to tackle this problem.

How Corporations could gain advantages by using neuroscience games for recruiting?

Neuroscience-based games and AI are revolutionizing the way people get hired. Previously, people's qualifications for a job were determined by a recruiter manually scanning a resume. This process was riddled with failure – 30 to 50% of first year hires fail – and bias against women, minorities and people from lower socioeconomic backgrounds. Neuroscience-based games and AI have made this process obsolete.

Gameplay is bias free, and does not know someone's gender, race or socioeconomic status. We then apply AI to predict job performance based on the complex neuroscience data collected through gameplay. We do this by determining if there is a match between a candidate's gameplay, and the algorithms we've built using a company's top performers' gameplay. If so, the person is immediately moved onto an interview. If not, we are able to recommend hundreds of other jobs to the candidate based on matching them to algorithms we've built. The candidate experience is vastly improved, made streamlined, instantaneous, and containing personalized feedback.

INTERVIEW

The company outcome is also vastly improved. Here are some results we've seen from clients:

Candidate Quality

1. 100% increase in quality of candidate: CPG firm went from hiring 1 of 3 people to 2 of 3. This was from offer extension increasing from 50% to 80%, and offer acceptance increasing from 64% to 80%.

Retention

1. 33% increase in first year success rate for a multinational institution (70% to 80% retained).
2. 60% increase in first year success rate for a global consulting firm (75% to 91% retained).

Efficiency

1. 75% reduction in time to hire: 4 months to 4 weeks
2. 75% reduction in recruiter time.
3. 6x improvement in applicant to offer yield: went from 150 resumes to fill 1 role to only 25 resumes at a global financial institution.

4.3x improvement in interview to offer yield: baseline of 8.5% improved to 25% for global consulting firm.

Gender diversity

1. 18% increase in female technical hires (33% to 39%)
2. 150% increase in female applicants for financial role (20% to 50%)
3. 39% increase in female applicants (31% to 43%), and 29% increase in first round female interviewees for financial service role (34% to 44%).

INTERVIEW

Ethnic diversity
1. 20% increase in minority interns hired into technical roles for financial service firm.
2. 16% increase in minority hires across 7 different roles at large multinational firm.

Socioeconomic Status diversity
1. Financial service client went from 12 all-Ivy League campuses to 115 campuses.
2. CPG client got applicants from 2,500 US campuses and hired people from community college, and first-time generation college students for the first time.

INTERVIEW

The future of Neuroscience and HR together. What is your vision about?

My vision is for pymetrics to create workplaces where the right people people are in the right roles where they are most likely to succeed. Imagine if people loved their jobs so much they never had to quit, and if companies never had to fire people? Imagine if we could give people a fair shot at all opportunities, regardless of their background? If we can use neuroscience and AI to match people to the right jobs, I believe pymetrics can create that future.

GLOSSARY

FOCUS ON: HUMAN RESOURCES

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Conditional cooperators
Contribute to the public good only if they expect other group members to do so as well.

Inequity aversion
Human resistance to inequitable outcomes, which occurs when people prefer fairness and resist inequalities.

Neuroleadership
A term coined by David Rock, founder, and CEO of the NeuroLeadership Group focuses on applying neuroscience to leadership development, management training, change management education and consulting, and coaching.

Non-conscious processes
Make up the most interesting psychological aspects of our lives and define all the processes people are not consciously aware of.

Organizational neuroscience
Explores the implications of brain science for workplace behavior.

Social neuroscience
The science behind intergroup relations, social networks, altruistic behavior, social learning, and self-biases.

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Conclusion

Through this report dedicated to “Neuroscience Impact”, Intesa Sanpaolo Innovation Center firmly boosts the vision that Neuroscience will bring value in the field of business and into people’s lives.
Indeed, the study of the neurosciences arouses a deep interest in the scientific world, among the insiders and public opinion and has enormous implications of an economic nature, which concern the diagnosis, treatment and neurological rehabilitation, but also involve ethical choices.
The development of large international projects, for which the growth of neuroscience represents a fundamental driving force for economic development, is a proof of this interest. The United States, the European Union, Chinese and Japanese agencies fund independent multibillion projects (e.g., “Human Connectome Project”, “Human Brain Project”) about brain, all with a common goal: to decipher the intricate neural circuit of the brain for realizing a simulation of the complete functioning of the brain and for improving the understanding of human brain physiological and pathological functioning, but also for the health and well-being of people, community and business.
Furthermore in an age of digital and technological acceleration where machines will work and interact with men, it is certainly fundamental for **Intesa Sanpaolo Innovation Center** to study and to deeply analyze how neuroscience could represent an essential lever to increase people’s potential, the way they could learn better and faster, and interact more effectively with each other.

Conclusion

For that reason, in Intesa Sanpaolo Innovation Center we have decided to launch a dedicated Lab named **Intesa Sanpaolo Innovation Center Lab Neuroscience** with the aim of investigating how neuroscience can bring value within the banking group, exploring innovative patterns to problems and challenges that do not find standard solutions covered by big players or start-ups.

So at the end Innovation Center Lab Neuroscience has the main goal to attract the best talents for the realization of complex challenges concerning defined «industrial» issue and to **encourage «cross-contamination» and transfer of know-how** through dedicated physical spaces, facilitating the meeting of knowledge with partners, thus **reducing time and complexity of development**.

Sonia d'Arcangelo

Intesa Sanpaolo Innovation Center

Exploring the business models of the future to discover the new assets and skills needed to support the long-term competitiveness of its customers and of the Group as we become the driving force of the New Italian Economy, this is the mission of Intesa Sanpaolo Innovation Center which aims to create the assets and develop the necessary skills that guarantee the competitiveness of the group and its customers through the promotion of new technology use and the support of corporate transformation projects where responsible business models can reconnect business and society.

Intesa Sanpaolo Innovation Center supports the growth of start-ups in domestic and international markets through programs in acceleration and networking and has created laboratories and Competence Centers to generate know-how and develop new assets and businesses. Intesa Sanpaolo Innovation Center invests in start-ups with its Corporate Venture Capital NEVA Finventures to encourage new business growth and to support the champions of tomorrow.
Intesa Sanpaolo Innovation Center: the country's driving force for future-proof change.

Editors & Contributors

Maurizio Montagnese
Chairman

Mario Costantini
General Manager

Matteo Colombo
Head of Competence Center

Sonia D'Arcangelo
Head of Neuroscience Lab

Daniele Borghi
Senior Innovation Analyst

Massimo Milone
Network & Promotion of Innovation Culture

IMT School for Advanced Studies Lucca

The IMT School for Advanced Studies Lucca is a public graduate school and research center that focuses on the analysis of economic, societal, technological and cultural systems. IMT is one of the six Italian Schools of Excellence, together with Scuola Normale and Scuola Sant'Anna (Pisa), IUSS (Pavia), SISSA (Trieste) and the Gran Sasso Science Institute.
Since its institution by ministerial decree of November 18th 2005, the School distinguished for the quality and innovativeness of its research and doctoral program and its interdisciplinary nature, characterized by the complementarity and discourse between methodologies drawn from economics, engineering, computer science, applied mathematics, physics, archeology, art history, management science, cultural heritage, and, more recently, neuroscience and psychology.
The fusion between tradition and innovation is even reflected in the School state-of-the-art campus, mainly located in the newly restored convent of San Francesco. The Campus, originally started in 1228 and place of theological and philosophical studies, now includes spaces for research and laboratories, courses, living and recreation for teachers and PhD students. The Campus with its own life is completed by the IMT Library, which offers a plethora of resources and additional working spaces to the IMT community and, more in general, to the city of Lucca.
The IMT School offers two PhD Programs. The Cognitive and Cultural Systems Program examines the methodologies applicable to the study of the brain, mind and behavior, human activities and productions, as well as their material and symbolic functions and representations. The Program in Systems Science relies on proficiencies in the development of predictive quantitative models for the analysis of economic, technological and social systems.
Starting from the overlying fundamental principle of scientific rigor and excellence, which applies to all areas and levels of the IMT research community, the School distinguishes itself through its interdisciplinary model to develop innovative research and acquire greater international perspective.

Authors & Contributors

Pietro Pietrini
Professor – Research topics: Social and Clinical Neurosciences, Psychiatry

Nicola Lattanzi
Professor – Research topics: Strategy and Business Behavior, Business Administration

Emiliano Ricciardi
Professor – Research topics: Cognitive Neuroscience, Neuroimaging

Andrea Patricelli Malizia
Senior Research Collaborator, Innovation Center Lab-Neuroscience

Giulio Bernardi
Guest Researcher in Neuroscience

Guido Caldarelli
Professor – Research topics: Scale-free networks, Complex Networks and Systems Biology

A further contribution has been provided by the following faculty and research members: Luca Cecchetti, Davide Bottari, Andrea Leo, Monica Betta, Alessandra Rampinini, Mirko Garasic (visiting professor), Giulia Avvenuti, Evgenia Bednaya, Giacomo Handjaras, Laura Sophie Imperatori, Giada Lettieri, Alice Martinelli, Laura Muscatello, Paolo Papale, Francesca Setti, Ilaria Zampieri.