RESEARCH INSIGHTS FROM COGNITIVE NEUROSCIENCE FOR EVERYDAY ECONOMISTS

BATRANCEA LARISSA
ASSOCIATE PROFESSOR, BABES-BOLYAI UNIVERSITY CLUJ-NAPOCA, FACULTY OF BUSINESS, ROMANIA
e-mail: larissa.batrancea@ubbcluj.ro

Abstract
The article details on known and less known information about the human brain, growndbreaking discoveries across the history in terms of the structure of the human brain, cutting-edge noninvasive and invasive research techniques used in cognitive neuroscience studies, which aim to identify the neural bases of cognitive processes. The article also gives account of the role played by the most renown patient in neuroscience for understanding brain functioning. In addition, the study emphasizes meaningful inputs from cognitive neuroscience research with the purpose of improving economic decision-making during day-to-day economic activities.

Keywords: *cognitive neuroscience, human brain, cognitive processes, noninvasive techniques, invasive techniques, economic decision-making*

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1. Introduction and general context

Talking about the brain, Paul Allen – businessman, investor, philanthropist and co-founder of Microsoft – stated that it “is the most complex, challenging scientific puzzle we have ever tried to decode”. On the same topic, Jeffrey Bezos – the founder and CEO of the company Amazon – asserted that “the human brain is an incredible pattern-matching machine”. More than a century ago, the Nobel Prize winner Santiago Ramón y Cajal voiced that “the brain is a world consisting of a number of unexplored continents and great stretches of unknown territory”.

If one were to ask what these three personalities have in common, the answer would be straightforward: they all acknowledged the complexity of the human brain and the fact that there are still numerous unknowns regarding the way it processes information and drives the decision-making process.

The following paragraphs will comprise some of the known details regarding the human brain and some of the aspects that still need extensive investigations.

Known and unknown facts about the human brain

It is known that the adult human brain weights around 1.5 kg and it is made up of 75% water. Despite the fact that it represents about 2% of the body weight, the brain imposes an extensively high metabolic demand on the body since it uses 20% of the oxygen in the blood and 20-25% of the body glucose resources. Supplies of oxygen and glucose are carried via blood vessels, which represent around 20% of the whole brain volume [28: 3]-[35]. This being the case, the aforementioned energy demand is perfectly reasonable because it is also known that human brains are always active during one’s lifetime, without breaks. This important brain characteristic of uninterrupted activity was unraveled especially through the so-called resting-state studies [16], which will be briefly mentioned in section 3.

There are two main categories of cells in the human brain: a) *neurons* or nerve cells; b) *glia*. Neurons are the fundamental information-processing units of the nervous system, which communicate via electrical and chemical signals. Glia cells communicate via chemical signals, create a structural and nutritional support system for neurons and play important roles in different neurodegenerative disorders such as multiple sclerosis, epilepsy, Parkinson's and Alzheimer's diseases etc. [32].

Although the exact number of cells in the human brain is still a puzzle, it is estimated that the adult human brain has around 100 billion neurons and 10 times more glia cells [1]-[19]. Moreover, one neuron can purportedly be connected with approximately 10,000 other neurons.

When it comes to dividing the surface of the brain into different areas, the most well-known proposal was launched in 1909 by the German neurologist Korbinian Brodmann. The scientist divided the human brain into 47 areas based on cell structure (i.e., cytoarchitecture), taking into account criteria such as size, type and distribution of neurons in a specific region. Nowadays, these divisions are referred to as "Brodmann's areas".

Scientific research studies have constantly reported that specific brain areas are associated with extremely specific cognitive functions [20]. Moreover, if a certain brain area incurs a damage, this does not impede the normal functioning of other brain areas, as long as the damage was not severe. For instance, people may possess a high IQ or EQ and still suffer from face blindness (i.e., prosopagnosia) after a stroke or brain trauma [37]. Therefore, it could be stated that another puzzling reality consists in that brain areas, while being connected with other brain areas, maintain a certain autonomy.

In the category of *unknown facts*, one could include the following main aspects:

- the specific activities of all types of neurons and other brain cells;
- the role of every area in the brain;
- the manner in which brain areas are connected and communicate with one another;
- the manner in which brain areas contribute to triggering different types of behavior, including the economic one that we try to understand.

With the advent of cognitive neuroscience almost 30 years ago, many puzzling questions related to the brain have found an answer. Nevertheless, the quest for decoding the brain puzzle (as Paul Allen mentioned) continues as scientific research methods become more and more advanced.

The present article gives an account of how insights from cognitive neuroscience studies can inform economists, who generally aim to make the most efficient decisions in terms of economic activities [4]-[9]. Starting from these scientific results elicited via state-of-the-art research techniques, economists can grasp the "why" behind the irrational decisions people make on the market in their everyday activities.

The structure of the article is the following. Section 2 briefly presents some of the most important discoveries regarding the human brain across time. Section 3 describes how cognitive neuroscience research may guide everyday economic decision-making. Section 4 comprises concluding remarks.

2. Brain facts across the history of mankind

The human brain has always represented an engaging research topic for worldwide scientists activating in different fields [12]-[13]-[27]. From ancient times until nowadays, details regarding the functioning of brain cells have enriched the overall knowledge. The following section will briefly list some of the paramount breakthroughs regarding the human brain:

- A medical text found on a papyrus dating back to Ancient Egypt (approx. 1700 BC) seems to contain the first written mentioning of the brain. The word "brain" was depicted by a hieroglyph made of four signs, namely: "vulture", "reed", "folded cloth", an end suffix meaning "little" [36: 10];
- Around 430 BC, the Greek physician Hippocrates, known as the "father of medicine", wrote the first book on epilepsy and correctly described it as a brain disease, contrary to popular beliefs [39];

- The Greek physician and philosopher Claudius Galenus (131–192 AD) examined the brain through observation and experiments [25];
- In the 11th century, Hasan Ibn al-Haytham, known as "father of modern optics", wrote a seven-volume treatise on optics, in which he inserted the first drawing of an optic nerve and was the first to state that visual perceptions occurred in the brain [33];
- In 1873, the Italian physician and pathologist Camilo Golgi discovered a method of staining nerve tissue (i.e., "Golgi method" or "black reaction"), which unraveled the network-type organization of the brain;
- In 1889, the Spanish neuroscientist and histologist Santiago Ramón y Cahal used Golgi's method to show that the brain comprises individual units called neurons, which are connected. Nowadays, this came to be known as the "neuron doctrine";
- In 1906, despite certain scientific disputes between the two, Golgi and Ramón y Cajal shared the Nobel Prize in Medicine "in recognition of their work on the structure of the nervous system" [38].

Important advances into understanding the human brain emerged towards the end of the 19th century due to Phineas Gage, deemed to be the most renowned patient in terms of studying brain lesions. His case study has been extensively discussed in neuroscience and related fields [11]-[15]-[23]-[40]. The storyline behind his fame was as follows. Phineas Gage was an American railroad construction supervisor in Vermont, who was in charge of a team that cleared the road with dynamite in preparation of future train tracks. As method, the team of workers led by Gage drilled holes into rocks and boulders, filled them with gun powder and sand and managed controlled explosions. On September 13, 1848, when Gages was 25, he suffered an accident while at work: an iron rod of 110 cm entered and exited his skull and brain, following an instant of distraction during a controlled explosion. He survived, nevertheless with physical consequences: Gage lost his left eye sight and the left frontal brain lobe was destroyed (i.e., he lost about 11% of the white matter and 4% of the grey matter in the brain). Phinenas Gages died 12 years later after the accident because of epilepsy. Nowadays, his skull and the iron rod that caused the brain injury can be seen on display at the Warren Anatomical Museum within the Harvard University Medical School in the USA.

Scientists' interest in the case of Phineas Gage rose mainly because of the psychological and behavioral consequences triggered by his brain injury. After the accident, Gage underwent a massive behavioral change, which lasted about 2-3 years. Namely, he became capricious, impulsive and disrespectful, risk-seeking, being unable to maintain his job. The numerous studies carried out later on his damaged skull coupled with details regarding his life after the accident provided important insights in terms of brain plasticity, or the capacity of the brain to reorganize itself in response to internal or external stimuli. It also opened new understandings on how rational decision-making works and affects economic outcomes [11].

3. Cognitive neuroscience and everyday economic decision-making

Among the scientific fields that focus on the brain, cognitive neuroscience is an emerging young discipline of about 30 years that aims to identify the neural bases of cognitive processes using different advanced techniques [2]-[17]-[18]-[30]. The main types of investigations carried out in cognitive neuroscience and other economic sub-fields with which it partners, such as marketing, finance, management, are task-based studies and resting-state studies. During a task-base study, participants perform an explicit task (e.g., reading product descriptions, memorizing management techniques, mentally computing financial ratios, imagining, observing, comparing prices, assessing company performance) as indicated by the researcher and they are exposed to a certain stimulus while their brain activation is being tracked via a neuroscientific technique. Consequently, researchers can establish whether the levels of brain activation during the task and in the presence of a stimulus differed significantly from the brain activity in the absence of the stimulus. In resting-state studies, participants do not perform any explicit task while their brain activity is being tracked. In other words, participants "rest" from any purposeful mental action and wait until brain activity is being recorded. As mentioned before, the brain operates all the time and these particular resting-state studies can capture the functional connectivity of different neural networks [24].

Cutting-edge research techniques

Taking into account the complexity of the brain, human cognition and economic decion-making, the study of neural activity calls for the use of cutting-edge research techniques into different economic sub-fields, which can be noninvasive and invasive [34: 10]. The following paragraphs will briefly list the most well-known techniques without focusing on the multitude of operating details (these being outside the scope of this article).

Among the **noninvasive** ones, the "oldest functional brain imaging technique" is *electroencephalography* (*EEG*), invented by the German neurologist Hans Berger in 1929, which measures the electrical impulses generated by neurons via electrodes placed on the human scalp [10]. Since it captures electrical impulses of firing neurons, EEG provides a direct measure of brain activity. A direct measurement is also provided by a newer technique called *magnetoencephalography* (*MEG*), which captures the magnetic field naturally produced by the electrical activity of neurons. One of the most advanced techniques is *functional magnetic resonance imaging* (*fMRI*), which measures changes in blood flow accompanying neural activity. For this reason, the metrics provided by fMRI are indirectly liked to the firing of neurons. *Transcranial magnetic stimulation* (*TMS*) uses magnetic fields to stimulate neurons in certain brain areas. Last but not least, stemming from the early discoveries on visual perceptions of al-Haytham, *eye tracking* supports the measurement of eye movements through various metrics, be they gaze position, fixation duration, number and order of fixations, pupil dilation. Much just like the brain, the human eye is in continuous motion, meaning that it registers 3-6 fixations per second, 10-15 blinks per minute and an overall of 100,000 fixations per day. Eye movements are captured with a device called eye tracker, which can be screen-based ("remote"), head-mounted ("mobile") or built in a virtual reality headset. Due to their noninvasive nature, these techniques are regularly used by cognitive neuroscientists and economists on a large scale. It goes without saying that the combination of two noninvasive techniques (e.g., EEG and eye tracking; EEG and fMRI; TMS and fMRI) provides more support for empirical results and conclusions related to economic decision-making [22].

In terms of the **invasive** techniques available, the literature reports results from *positron emission tomography* (*PET*), which uses radioactive materials to produce 3D images of the brain, and from *single-cell recordings*, which measure brain activity by inserting electrodes into neurons. Because of their invasive nature, such methods are used only in clinical studies.

Insights for everyday economic decision-making

Based on the aforementioned details regarding the human brain and special research methods of tackling cognitive processes, the question that naturally arises would be the following: How can cognitive neuroscience help people with their everyday economic decisions?

First and foremost, the main benefit provided by cognitive neuroscience to economic decision-making is that scientists, professionals, public authorities and laypeople have now access to information in people's brain that support economic actions and that cannot be otherwise obtained through conventional methods (e.g., questionnaire, interview). For example, for marketing purposes, instead of asking people how they rate a certain TV advertisement, scientists can perform an fMRI brain scan while participants watch the advertisement and can conclude whether people liked it or not by analyzing the most activated brain regions. Moreover, the aesthetic appeal of a beauty product container (e.g., deodorant, makeup, lotion, perfume) can be quickly investigated via eye tracking and any shortcoming amended before the product is even launched on the market, thus saving resources of time and money. Second, as opposed to traditional economic studies that may employ thousands of participants in representative samples, investigations using cognitive neuroscience techniques need far less participants (i.e., a couple of dozens) since human brains function in the same manner.

One of the many interesting insights from cognitive neuroscience studies that can be useful for economic decision-making is that specific brain areas are associated with extremely specific cognitive functions [14]-[21]. For instance, face perception is the most important visual function for normal social interaction among humans. Studies using fMRI, MEG, TMS and PET have shown that the brain comprises regions that process faces more than other objects and body parts (e.g., fusiform face area, occipital face area, posterior superior temporal sulcus). Consequently, marketing companies put a particular emphasis on faces (either human or non-human) when creating advertising campaigns in order to appeal to this propensity of the human nature for face perception. Other specialized regions in the brain process scenes and places (parahippocampal place area), numbers (number form area) or letters (visual word form area). These types of studies can play an important role in designing company vision and mission statements, company logo, strategies for efficiently managing human resources. These studies are also of paramount importance for reading, understanding and analyzing financial statements of companies or banks and improving the operating, investing and financing decisions of managers [3]-[5]-[8]-[26].

Regarding the insights provided by eye tracking studies, besides the classical marketing investigations in which companies test a specific logo, packaging, media advertisement, travel destination, new product ready to be launched in order to identify and meet consumer preferences, this techniques can also be used to determine the effectiveness of official websites administered by public authorities (e.g., national tax administration; national education system; local authority; various public ministries, etc.). This way, authorities can identify potential shortcomings in the functioning of the websites (e.g., design; user-friendliness of the interface; quality of information provided), improve them and help citizens comply or get easier access to public information [6]-[7].

4. Conclusions

The present article drills into relevant cognitive neuroscience research studies [29]-[31] and results in order to identify insights that can assist economists during the everyday process of making the most appropriate and efficient decisions for their economic activities.

One by one, state-of-the-art techniques used in cognitive neuroscience studies such as functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG), electroencephalography (EEG), transcranial magnetic stimulation (TMS) and eye tracking are mentioned. Moreover, applications of empirical results to economic decision-making within the economic sub-fields of marketing, management, finance, are also emphasized.

Considering the rapid advancement of neuroscience technologies, the unceasing drive and enthusiasm of researchers, the growing penchant for interdisciplinary studies and the remaining uncharted territories of the human brain, it stands to reason that future research endeavors will enrich the extant literature with important findings, beneficial for both the scientific community, economists, business people and laypeople alike. At the end of the day, as the American inventor and head of research for the General Motors company Charles Kettering used to say, "research means that you do not know, but you are willing to find out".

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