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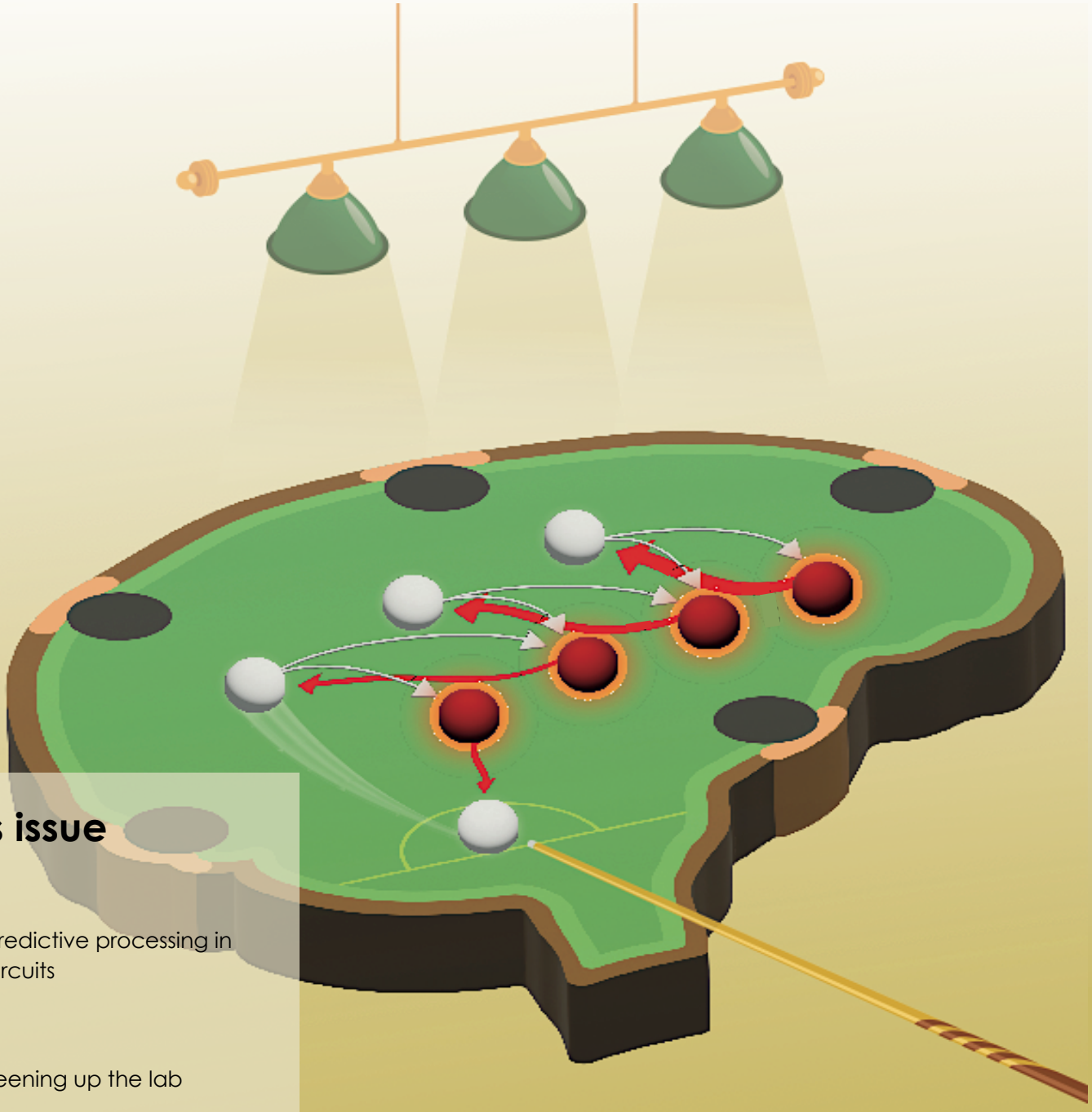

In this issue

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BRAINSTORM STUDENT JOURNAL

REVIEW

Cellular substrate for predictive processing in cortical circuits

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Abstract

The brain can be considered a junction between the external and internal world. Its main function is to receive and process multisensory signals. To be more efficient, neural computation is tailored to novelties diverging from previous input, a theorem that is postulated in the framework of predictive processing. This includes interpreting one sensory modality to make predictions about another sensation. If you hear a car approaching from behind, you will expect it to appear in your visual field. Hosting most sensory processing in the brain, the neocortex has been suggested to play a crucial role in this mechanism. Therein, neurons that encode mismatches between prediction and observation, and neurons that encode internal models of the surrounding were proposed as the cellular substrate. Recently, researchers succeeded in manipulating subject-generated predictions to create mismatches in a laboratory setting. This review overviews the state-of-the-art knowledge of the neuronal circuit architecture underlying predictive processing.

Keywords

Cortical computation, layer 2/3, mismatch neurons, predictive processing

Abbreviations

ACC: anterior cingulate cortex

FR: firing rate

M2: secondary motor area

MM: mismatch neuron

nMM: negative mismatch neuron

O: observed value

P: predicted value

pMM: positive mismatch neuron

SOM+: somatostatin interneuron

Introduction

Imagine yourself standing on a patch of sand near the beach playing volleyball with friends in the summer. At some point, one teammate of yours that is at the net calls the signal for setting the ball in your direction to perform an attack. You prepare yourself to strike the ball and try to score a point. You lift off from the ground, timing your movement to meet the ball at the net. Suddenly, the ball is caught by a gust of wind which alters the direction. Fortunately, you are an experienced player and able to adapt in time. You eventually made it: the ball found its way to the other team's side.

Although it seems trivial, performing this kind of action necessitates enormous computational power. As a first step, this involves receiving many sensory cues: the teammate's signal, the ball's movement, and the player's movement towards the net. Those are integrated to make a prediction of the events to happen, in this case, the trajectory of the ball. A prediction is then compared with the observation of new events, i.e., the divergence of the ball, which leads to an adjustment in case of mismatch. This type of computation has been postulated as predictive processing and is considered the blueprint for treating information in the neocortex (1, 2). It evolved around the idea that primary cortical areas integrate multisensory input to the effect of creating internal models of the environment. This representation of the surrounding is constantly updated by comparing the predicted value (P) of an event with the observed value (O) of the same event. In the previous example, P would be the trajectory of the ball, and this would be compared with O, the position of the ball.

The theoretical framework of predictive processing has been put forward in the last century, but due to technical caveats, it was not investigated for long on a cellular level. In the last 20 years, researchers have made advances in understanding the cellular architecture and functional organization of the neocortex that have allowed overcoming the technical limitations (3). It was shown that sensory inputs were not restricted to one primary cortex, providing the first key evidence for the possibility of predictive processing (4). The field evolved equally on a methodological level, allowing for recordings of multiple neurons in behaving animals with techniques like calcium imaging or multichannel recordings (5). The development of virtual reality as a controllable variable of visual input finally allowed researchers to generate mismatches between P and O experimentally (6, 7).

This review aims at presenting recent evidence on the cellular basis of predictive processing to give an overview of the current understanding of cortical computation in the field. Additionally, it provides an outlook towards the next questions that need to be investigated.

Methods

For this review, articles were first selected based on a database search (Google Scholar and PubMed) using a combination of different keywords: cortical AND computation, cortex AND mismatch AND signal, cortical AND prediction, mismatch AND prediction AND signal, prediction AND mismatch AND neurons AND visual AND cortex, predictive AND coding. The identified primary literature was filtered for relevant publications addressing the question of the cellular substrate and/or neural circuit for prediction processing. Due to the larger number of studies on prediction error neurons, this review will focus on those.

Results

A theoretical framework for mismatch neurons

Two neuronal subpopulations were postulated to be necessary for predictive processing; neurons that encode internal models and neurons that compute the difference between P and O, so-called mismatch neurons (MM) (1). According to the theoretical framework, the prediction-coding neuronal network seems to be strictly hierarchical. P would be conveyed from higher-order neurons (top-down), and O signaled by lower-order neurons (bottom-up). The comparison of both signals would subsequently update a higher-order internal model neuron for each network layer (1). Three potential scenarios were postulated for the comparison of P and O, which taking the example in the introduction are as follows:

- P = O: the volleyball appears at the expected location.
- P > O: volleyball does not appear at the expected location, negative mismatch.
- P < O: the volleyball appears without expectation, a positive mismatch.

In other brain areas where prediction-error processes had been revealed earlier, i.e. the dopaminergic reward system (8), one neuronal population was shown to integrate all three information respectively by basal, decreased or increased firing rate (FR). Conversely, for the cortical network, due to lower basal FR, it was expected that two neuronal subpopulations would separately represent negative and positive mismatch (1).

Experimental design to reveal MM in vivo

Empirical evidence that confirms the theoretical postulates were put forward by recordings of cortical pyramidal neurons in rodents during locomotion-coupled virtual reality exploration (6, 9, 10). Rodents were head-fixed to ensure stable recordings but placed on a freely moving ball (spherical treadmill) that allowed self-generated forward and backward movements by the animal. Running initiated the visual flow of gratings (virtual reality) simulating the passage of a virtual corridor (Fig. 1A). Likewise, if the rodent stopped moving, the visual flow would also halt. In the framework of predictive processing, locomotion (motor-driven P) would be a top-down signal. Conversely, virtual-reality flow (visual-driven O) would be a bottom-up signal. If the visual flow is coupled to locomotion, P equals O, which should not alter FR of MMs. The working hypothesis for the following experiments was that manipulating the coupling of locomotion and visual flow, i.e. halting the virtual corridor while active running (mismatch, P > O), would reveal the existence of MM neurons (**Fig. 1 B**).

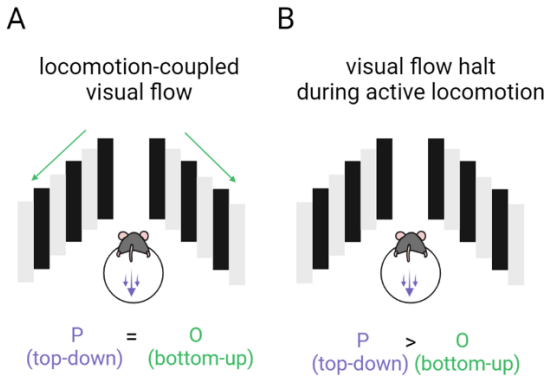

Figure 1. Experimental paradigm to reveal MM. A rodent is head-fixed on a movable ball (white) which allows back and forward-directed movement within a virtual reality while neural activity is recorded simultaneously. (A) The visual flow of a virtual corridor follows the locomotion of the rodent (P = O). (B) Visual flow halts although the rodent keeps moving (P > O), putatively inducing a mismatch response.

Empirical evidence of two subpopulations of MM in the neocortex

The first experiment investigating the cellular substrate of predictive processing used two-photon imaging (6). Researchers revealed a subpopulation of pyramidal neurons in cortical layer 2/3 that specifically responded to visual flow halt (negative mismatch) with increased calcium transients after habituating rodents to locomotion-coupled flow. This was the first evidence of the existence of MMs in the cortex. Because they responded specifically to negative mismatches these neurons are called negative MM (nMM). Further research using optogenetic methods (9) confirmed that nMMs receive both bottom-up (visual-driven GABAergic afferences) and top-down (motor-driven excitatory afferences) inputs (Fig. 2A). An additional study (10) showed that top-down input to nMMs originated in the anterior cingulate cortex (ACC) and adjacent secondary motor areas (M2). Bottom-up input was shown to be conveyed by local visual-driven somatostatin (SOM+) interneurons (9).

Without mismatch (P = O) excitation and inhibition are equal, resulting in baseline firing of MM neurons. During negative mismatch (P > O), nMMs would receive stronger excitatory top-down and weaker inhibitory bottom-up input leading to increased firing (**Fig. 2A**). According to the theoretical framework, another subpopulation of positive MM (pMM) should increase firing during positive mismatches (O > P). Unlike nMMs, this would suggest that they receive excitatory bottom-up (O) and inhibitory top-down input (P). Therefore, during a negative mismatch they should be hyperpolarized. This was shown in experiments performing whole-cell patch clamp recordings during visual flow halts (11). As expected, nMMs responded to halts with membrane depolarization (Fig. 2B, left) while pMMs responded with hyperpolarization during mismatch (Fig. 2B, right). This experiment confirmed the notion of two distinct populations of MMs postulated earlier.

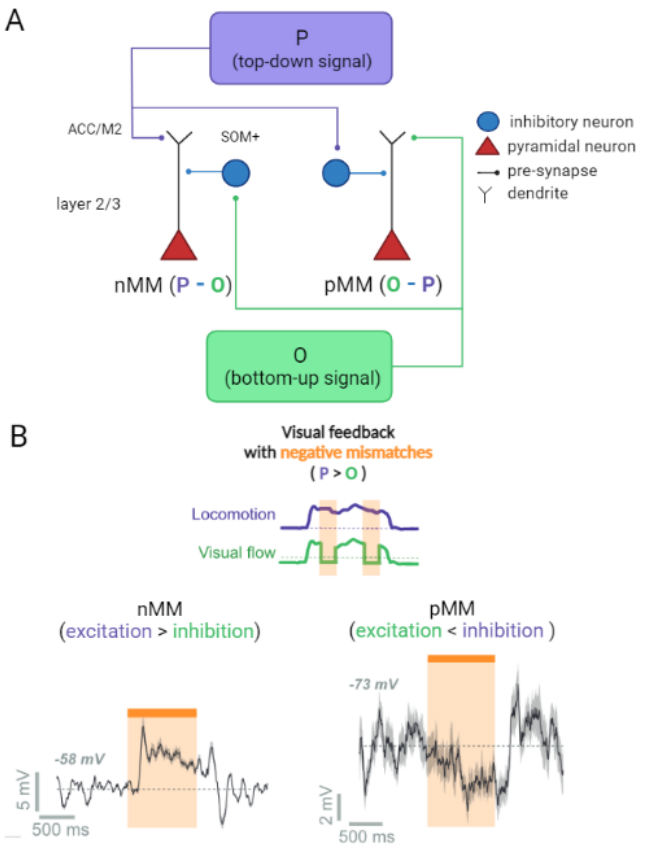

Figure 2. Empirical evidence for the theoretical framework of predictive processing, adapted from (1, 10). (A) Cortical excitatory MM in layer 2/3 receives both top-down (P) and bottom-up afferences (O). (B) nMMs receive inhibitory bottom-up (SOM+ interneurons) and excitatory top-down input (ACC/secondary motor area) thus increasing firing if predicted sensory input does not occur (P > O). pMMs receive inhibitory top-down and excitatory bottom-up input thus postulated to increase firing if sensory input occurs without prediction (O > P).

Predictive mismatch neurons could also be shown to be present in cortical areas outside of the visual cortex. In the primary sensory cortex, researchers investigated locomotion-generated tactile stimulation. During mismatch events between locomotion and touch, they could show that layer 2/3 neurons decreased activity (12). Another research group provided evidence that auditory cortical neurons respond stronger to unexpected sounds (P < O) after a lever press that was previously coupled to an expected sound (13), confirming the notion of pMM. However, one recent study provides a different explanation for a neuronal response towards mismatch (14). Therein, researchers used a virtual grating drift uncoupled to

animal movement. Mice were head-fixed and could run ad libitum on a treadmill while visual cortical neuron activity was recorded with a multi-electrode array. The drift was halted to induce mismatches to which a specific group of neurons responded. Instead of receiving less bottom-up input during drift halt, researchers argue that neurons show increased firing due to intrinsic tuning towards lower grating flow frequencies, which they call feature selectivity. One of the major arguments was that they did not find a significant difference in the number of halt-responsive neurons in previously exposed vs. naïve mice, which made them argue that there was no predictive component in the neuronal response (14). Conversely, for neurons recorded by members of the Keller team, it was shown that MMs of previously exposed mice responded stronger than MMs of naïve mice and that mismatch response increased proportionally to the divergence between P and O (15). This stresses the possibility that not all neurons that respond to a mismatch correspond to a MM population.

Conclusion

Extensive research in the last decade provides convincing evidence for predictive processing as a theme for cortical computation. Researchers confirmed the notion of two distinct types of prediction error neurons, nMM, and pMMs, found in cortical layer 2/3 of rodents. A potential confounder known as feature selectivity has been described and should be considered in future studies. In the following years, further research is necessary to better understand the underlying circuit architecture of predictive computation in the cortex. So far, most experiments have focused on negative mismatches (visual flow halt) where the bottom-up input was nullified (P > O; O = 0). Conversely, knowledge on positive mismatch response (P < O) is limited to only some studies. Additionally, how would MMs respond to negative (or positive) mismatches that are less pronounced (O < P and O > 0)? This would be the case if the visual flow did not halt but slowed down compared to the locomotion. Perhaps, this would reveal a threshold value for mismatch responses in MMs. Further, knowledge of top-down and bottom-up input, as well as downstream targets of MM is still limited. Notably, identifying the internal model representing the unit would complement the search for the cellular substrate of predictive processing. Putative candidates are excitatory neurons in cortical layer 5 (16) which do not respond to negative mismatch on a single cell level (9). The major pyramidal cell types in layer 5 are intratelencephalic (IT) and extratelencephalic (ET) neurons, also known as slender-tufted and thick-tufted neurons. They seem fitting to integrate all the relevant signals. IT and ET both extend dendrites along the entire length of the cortical column and receive bottom-up, top-down, as well as layer 2/3 input. Finally, increasing the efforts to study other cortical areas (auditory, primary sensory cortex) will be helpful in comparing mechanisms and postulating a canonical motive. On a side note, intensifying the search for molecular markers of MMs (17) will be very instrumental.

Ultimately, the goal is to transfer the knowledge of predictive processing from animal studies to a human context. Results from recent studies investigating the cortical architecture of the human brain suggest that predictive processing themes could be more pronounced in the human cortex. Layer 2/3 of the cortex was shown to be more developed in humans than in rodents and macaques (18) and its complexity seems to correlate with IQ (19, 20). This also includes the investigation of disease-related alterations in the cellular substrates of predictive processing. It was previously shown that mismatch responses were altered in an early stage of an Alzheimer´s disease mouse model (21). A better understanding of putative pathological imbalances would potentially improve treatments against neurological diseases such as schizophrenia (P > O) and autism spectrum disorders (O > P), which have been suggested to shift predictive processing towards opposing edges of the spectrum (1).

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BRAINSTORM STUDENT JOURNAL

LETTER

Greening up the lab - research and sustainability

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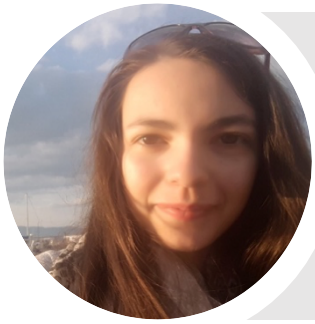

Maria Fakitsa

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Laboratories, the heart of the research and a space with enormous carbon footprint. Sustainability is imperative in all aspects of our lives, including the work in the labs. In this letter, I would like to share my personal perspectives on this global issue and the practices that can make a greener lab.

Scientists are doing their best to gain and share knowledge, but are they doing all they can in their daily lab operations to improve lab sustainability? Their work is along the lines of the future of humanity, but laboratory research itself has a significant impact on the environment. In recent years, the threat of climate change has moved to the center of global conversations, and it has become critical that they take place in laboratories to encourage more and more scientists to play an active role. Scientists around the world recognize the need to reduce their negative impact of research activities. Solid proof of this transition in their position is the increasing number of articles in the literature with the main topic the managing of the environmental impact of research. This reflects their willingness to take into account the sustainability in research design and execution.

Lab sustainability has been bubbling under the surface worldwide. However, over the last decade there has been a mounting interest in adopting more sustainable practices. Universities devote time to increase the awareness of the benefits of sustainable living and working by promoting the 5R's rule "Refuse, Reduce, Reuse, Repurpose, and Recycle" (1). Each year, "green-lab" programs are introduced at research institutions across the world. They are providing a redundancy of activities that focus on the reduction of the waste, with emphasis on plastic, and energy consumption in labs (2). However, there is often a misconception that having a sustainable focus will drive up costs, that can be translated to cost of scientific integrity. The last, should be ensured as it is a pillar of research. It can be ensured with the establishment of environmental transitions commitment charter for the units and platforms

of the research departments, as in case of the University of Bordeaux (3). So, the good organization of those practices is the key for a greener lab without the cost of a non-valid research. Instead, implementing sustainable changes can bring a wider multitude of benefits, including the financial ones.

Regarding the last aspect, Dr. Bistulfi points in a Nature article "Implementing ecological awareness at the bench has saved up to 40% of my research funding over one year" (4). This is just an example, but we can also think the energy of the buildings, the business trips and a lot more. Adopting the 5R's rule can save money that can found the research. A simple example is the reuse of single-use plastic or its substitution with glass, when is possible. This small change can reduce dramatically the yearly cost for plastic of a lab, money that can be used for research or just for a lab retreat to move closer to the environment. Environmental-friendly practices, including the above one, do not have a cost but require a change in the mindset of the organization of everyday lab-life. Yet, the adoption of an environmental policy tends to be controversial, because of up-front costs and there is the perception that they do not provide visible benefits. Sustainability takes time, that's true (5). However, the difference will be obvious in the near future, first at the bank accounts and then at environmental level. For these reasons, it is necessary to undertake a detailed cost-benefit analysis of every change that is introduced to truly illustrate the advantage of this effort (6,7).

There are a number of changes that can make significant improvements and can be categorized into 4 main axes (8):

a) The green-lab programs, engagement among scientists and other institutional stakeholders that engage in discussions on how to introduce and implement the 5R's rule into the research community

b) Sharing of resources and equipment

c) Procurement of laboratory purchases for research

d) Motivating research funding bodies to call for sustainability

Here, between the University of Bordeaux (UoB) and Bordeaux Neurocampus, there seems to be a strong sense of responsibility towards the environment (9). University of Bordeaux is taking transformative actions to meet the environmental and the economic challenges of present times. There is an ambitious challenge by UoB ongoing from 2021 to reduce the up to -40% the energy-related greenhouse gas emissions by 2030. More specifically, regarding the University and the research units, there is a sustainability labs charter that specifies the commitment to sustainability and will be signed before the end of the year 2023. While now, there is the "Energy challenge" ongoing among the UoB and the research units that shared within the Research Commission, in June 2022 meeting. The University is organizing it to test actions to reduce environmental impact up to 3 months in 3 axes (energy-digital-mobility) on March-April-May. Among the teams, one represents the Bordeaux Neurocampus.

Bordeaux Neurocampus, following the University's general trend for green-labs, actively follows the 5R's rule. At this moment, there is a coordination between the green-committees in all labs towards an environment-friendly Neurocampus. The reduction of the energy usage of the buildings, that concerns the carbon footprint of the buildings, is partially taken into account at this moment but there is a strong motivation and collaboration with the University to improve it. On top of that, there are plenty of actions that are taken individually or by some institutes and others that are more spread in the Neurocampus. Recycling is well organized by the majority of the institutes, focusing on polypropylene. However, as recycling is the last option, labs tend to refuse to purchase wasteful and instead, buy items you can reuse multiple times or that can use for a new propose (reproposing) and save them from trash. Additionally, other practices, including composting, mobility habits for travel from home to work

or a plan to reduce the energy from ultra-low-temperature freezers, are adopted less in Neurocampus research community. Don't you think is time to change? The agreement between the Neurocampus and the University of Bordeaux towards the sustainability may be a key solution and all these practices will be adopted by all research units.

Now that we know the importance of sustainability in research, you ought to consider it and include small practices that will make a big change in the final impact on the environment. Through changes from universities, research units and individuals, we can ensure that sustainable practices will become the norm, rather than the exception, with great benefit to the planet and science.

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DISSEMINATION ARTICLE

Why are we still lacking Amyotrophic Lateral Sclerosis biomarkers?

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This section has been created in collaboration with the Maison du Cerveau, an association that brings together all those involved with diseases from the nervous system. Our goal is to increase visibility and to provide information about these pathologies, treatments, and research advancements for the general public.

Amyotrophic lateral sclerosis (ALS) is a rare neurodegenerative disease characterized by the motor neuron loss in the brain and spinal cord. These neurons are crucial in our daily life since they carry the information from the nervous system to the muscles to cause movement. The symptoms of this disease include cognitive impairment, motor weakness and breathing troubles. Eventually as the disease progresses, a severe respiratory muscle paralysis can cause the patient's death within 3 to 5 years following diagnosis. In Europe, ALS has an incidence rate of 2 cases per 100.000 people. In France, between 1000 and 1500 new cases are diagnosed each year (1).

The main cause of ALS apparition is unknown. However, some protein mutations have been found related to motor neuron loss in ALS patients. The most relevant ones are Super Oxide Dismutase (SOD1), Fused in Sarcoma (FUS) and TAR DNA-binding Protein 43 (TDP43). However, the percentage of ALS patients carrying these mutations do not exceed the 10%. The reminder 90% of ALS cases consist of sporadic and multifactorial forms of the disease (2). Thus, the fact that we don't really know what caused most of the cases makes diagnosis and treatment impracticable. Currently, the diagnosis of ALS takes almost a whole year from the apparition of symptoms. Considering ALS patients' short life expectancy, these late diagnoses based on symptoms narrow the window for therapeutic opportunities.

The discovery of new molecules that allow to detect the apparition of the disease, also known as biomarkers, could lead to a diagnosis improvement and may allow the implementation of early efficient therapies to rescue the motor neuron death. Indeed, biomarkers can also be used to monitoring the diseases and track the response to the therapies (3).

To identify these molecules, several body secretions can be used, including peripheral blood, cerebrospinal fluid, and urine. In ALS, molecules such as p75ECD from urine or Phosphorylated Neurofilament Heavy in cerebrospinal fluid have been already identified as diagnostic and prognostic biomarkers. However, these biomarkers have low specificity for ALS as they can be found altered in several diseases (4).

Cerebrospinal fluid, the liquid found within the tissue that surrounds the brain and spinal cord, is seen as the major warehouse of potential ALS biomarkers (5). However, the extraction of these liquid requires an invasive intervention called lumbar puncture, which allows its collection but becomes impracticable at later disease stages because of the danger it poses. In addition, the use of imaging techniques such as Magnetic resonance imaging becomes complicated to perform in advanced stages of ALS due to the patients' breathing troubles. Thus, the use of these techniques to diagnose ALS is possible only on early stages of the disease, but, as previously mentioned, the diagnosis usually comes too late.

The biological heterogeneity of ALS is extraordinarily complex. This is the reason why ALS still lacks from specific biomarkers and efficient treatments. The impact of ALS is deeply felt by families and relatives. ALS tops the list of pathologies regarding requests for assisted suicide (3). Despite immense efforts in research, none of the candidate molecules has reached routine applicability in clinical practice. Today, several clinical trials are focusing on ALS. Hopefully, soon a new generation of biomarkers will give rise to an early diagnosis and development of efficient therapies for fighting ALS.

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Neurogame:

Which cell type of the nervous system are you?

Sara Carracedo, 2nd year PhD student at the IMN

Answer the following answers to discover which cell match with your personality!

1. How do you typically react when faced with a problem that you don't know how to solve?

a) I'll try to research and gather information to come up with a solution

b) I'll reach out to others for help and collaborate on a solution

c) I'll procrastinate and hope the problem resolves itself

2. What do you think is your biggest strength in your personal life?

a) My intelligence and ability to solve problems

b) My ability to connect with others and build relationships

c) My creativity and willingness to take risks

3. What type of work environment do you prefer?

a) A quiet and organized space where I can focus on my tasks

b) A collaborative and social environment where I can work with others

c) A fast-paced and challenging environment that keeps me on my toes

4. How do you typically respond when someone you care about is going through a difficult time?

a) I offer practical solutions and help them to problem-solve

b) I provide emotional support and listen to their feelings without judgment

c) I become overwhelmed by their struggles, and I don’t cooperate

5. What type of food do you typically buy at the supermarket?

a) I focus on buying whole, nutritious foods that will support my health

b) I tend to buy food that are easy to prepare and don't require much effort

c) I tend to buy highly processed, high-sugar or high-fat foods as a way to cope with stress or emotions

6. You're scheduled to give an oral presentation at a prestigious scientific conference, and you're feeling nervous. What do you do to calm your nerves?

a) You practice your presentation in front of a mirror or with a trusted colleague and prepare extensively to ensure you're fully prepared.

b) You pop a few anti-anxiety pills and hope for the best.

c) You envision the audience in their underwear and imagine yourself as the star of a blockbuster movie, delivering your talk with confidence and charisma.

7. You've been up all night with your supervisor working on your analyses, and you're feeling confident about the data you've collected. However, when you show it to your supervisor, he doesn't like it. What do you do?

a) You take a deep breath and ask your supervisor for specific feedback on how you can improve your data.

b) You throw a tantrum and storm out of the room, vowing never to work with your supervisor again.

c) You pull out a bottle of tequila and suggest that you both take a shot every time your data is criticized, turning the criticism into a drinking game.

8. How do you typically cope with difficult emotions, such as sadness or anxiety during your PhD?

a) I seek support from friends and family, and practice self-care techniques to manage my emotions

b) I distract myself with friends, and try to avoid thinking about the difficult emotions

c) I may overreact to the difficult emotions, turning into unhealthy substances habits

9. You've just realized that your experiment has failed, and it's already late at night. What do you do?

a) You curse the gods of science and call it a night, ready to try again tomorrow.

b) You cry into your lab coat and consider quitting science altogether

c) You turn on some 90s power ballads after performing a voodoo ritual and you go to a bar

10. Your thesis supervisor has informed you that you can't take any time off this summer. What do you do?

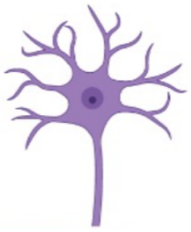
a) You negotiate with your supervisor to find a compromise that allows you to take some time off without falling behind on your work.

b) You plan a secret getaway anyways, and hope that no one notices your absence.

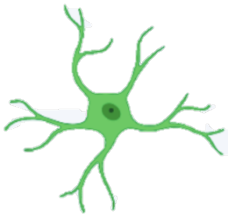
c) You take your laptop and research notes to the beach, and work on your thesis while soaking up the sun.

Neurogame Solution:

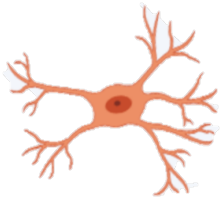
In this game, you have answered 10 questions, each with 3 possible answers. The first answer gives 1 point, the second answer gives 2 points, and the third answer gives 3 points. The total number of points you get will correspond to the type of cell you are most like.



If you have a **score below 13**, you are a **Neuron**. Neurons, like their human counterparts, are logical thinkers and problem-solvers. They're focused, task-oriented, and excellent at communicating their ideas. They're like the dependable and detail-oriented colleague who always has a plan.



If you have a **score between 14 and 21** you are an **Astrocyte**. Astrocytes are like the friendly and empathetic person who tries to help everyone. They're compassionate, reliable, and have a natural ability to connect with others. They excel at building relationships and thrive in environments where they can support and assist those around them.



If your **score is above 22**, you are a **Microglia**. Microglia, is like the person who is constantly in "fight or flight" mode, are always ready to jump into action. They're energetic, passionate, and always on the lookout for potential threats. They can be intense and sometimes quick to react, but they're fiercely protective of their loved ones and will do whatever it takes to keep them safe.

Share your result

SCAN ME

You will know the most common cell at the Neurocampus in the next issue!

Editorial board

Simon Lecomte

Simon is originally from Lyon, France. He did his Bachelor's of Psychology from Strasbourg, after which he did the International Master of Neuroscience from Bordeaux. He is a PhD student studying how the Fragile X Syndrome impacts the presynaptic mechanisms at the DG-CA3 synapses from which one can guess that his interests lie in memory, synaptic communication, and the hippocampus. He also runs a blog "Astrocytes et traumatismes crâniens juvéniles".

Khadija Inam

Khadija is a Pakistani student currently pursuing a training as a Clinical Research Associate at the University of Bordeaux. She graduated with a Bachelor's degree in Applied Biosciences from the National University of Sciences and Technology, and later the NeuroBIM Master's degree in Neurosciences from the University of Bordeaux. Her research interests are in the scope of pharmacology and neurological disorders.

Louise Eygret

Born in Gien, France, Louise did her Bachelor's in Life Sciences followed by the NeuroBIM Master's in Neurosciences. Currently, she is pursuing a PhD focused on the neural substrates underlying odor modulation of food intake regulating neuronal circuits. Her research interests are primarily in nutrition, olfaction and hypothalamus.

Juan Garcia-Ruiz

With two Bachelor's degree, in Psychology and Biochemistry, and the NeuroBIM Master's degree in Neurosciences, Juan is now pursuing a PhD where he is focuses on the role of lactate in basal synaptic transmission, which allows him to combine his research interests in biochemistry, electrophysiology and neurometabolics. Although he speaks near-perfect French, Juan comes from Huelva, Spain. He is also the co-founder of neuronhub (www.neuronhub.org).

Sara Carracedo

Sara is a PhD student at the Neurodegénératives Diseases Institute (IMN). She comes from Pontevedra, Spain and holds a Veterinary Bachelor's degree from the University of Santiago de Compostela, Spain and she did the NeuroBIM Master's in Neurosciences. Her PhD is focused on understanding the role of P2X4 receptor in ALS pathogenesis in which she is interested in neuroglia interactions and receptor trafficking.

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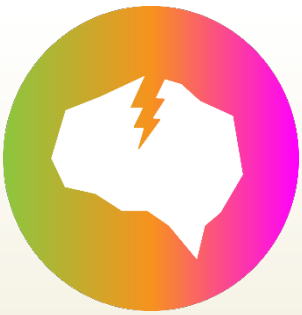
BrainStorm, a journal by students and for students

Are you a MSc or a PhD student in neuroscience? Then you are more than welcome to participate in our journal.

You can write either a short-review on a topic of your choice, or a one-page letter (a reflection, a project or an insight you would like to share with the scientific community), a dissemination article about clinical neuroscience (neurodegeneration, neurodevelopmental or psychiatric disorders…) with the aim to reach a more general public, or a neurojoke.

Don't start to worry, you won't be alone! You will work hand-by-hand with our editors and we will send you guidelines and a template to make your life easier. Perhaps you would like to know that the best review will get a special prize by June 2023.

If writing is not your thing and you prefer to express yourself through art, we have a place for you too! For each issue we recruit an artist to design the cover page illustration. And remember that microscopic images are also a form of art!



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