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Sexual dimorphism in microglia

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Abstract

Microglia are the brain's resident macrophages and play a critical role in maintaining brain homeostasis. Increasing evidence indicates that they exhibit sexual dimorphism, shaped by gonadal hormones and sex chromosome complement. Sex-dependent differences in microglial density, morphology, gene expression, and activation states have been reported across brain regions and throughout the lifespan. As key regulators of neuroinflammation and neural circuit refinement, these differences likely influence brain function and disease vulnerability. Understanding microglial sexual dimorphism is therefore essential for uncovering mechanisms underlying sex differences in brain development, homeostasis, and neurodegeneration, and it may guide the development of sex-specific therapeutic strategies targeting neuroinflammation.

Keywords

Microglia, sex differences, development, metabolic stress, neuroinflammation

Abbreviations

AD – Alzheimer's Disease

CNS – Central Nervous System

CSF1R – Colony-Stimulating Factor 1 Receptor

FDAMic – Female-Enriched and Disease-Associated Microglia

HFD – High-Fat Diet

Introduction

For decades, neuroscience has described the human brain as a sexually dimorphic organ. However, large-scale analyses of neuroimaging and postmortem data indicate that such differences are minimal and inconsistent, with most variability better explained by individual differences and overall brain size rather than biological sex (1). These findings challenge the concept of distinct "male" and "female" brains and suggest a largely monomorphic organization at the macroscopic level. In contrast, growing evidence points to clear sexual dimorphism at the cellular level, including in microglia, the resident immune cells of the central nervous system (CNS). Importantly, recent studies in both humans and rodents have revealed sex-dependent differences in microglial density, morphology, gene expression profiles, and activation states (2–6).

Unlike most CNS cell types, microglia originate from myeloid precursors that migrate from the yolk sac into the developing CNS during early embryogenesis (embryonic day 8.5) (7). These cells infiltrate the neural tube, where they proliferate, colonize the brain parenchyma, and persist throughout life via slow self-renewal (7). Notably, this developmental trajectory is highly conserved across vertebrate species. After colonization, microglial survival and maintenance critically depend on signaling through the colony-stimulating factor 1 receptor (CSF1R), as both genetic disruption and pharmacological inhibition of CSF1R lead to a marked reduction in microglial populations (8). Microglia are dynamic cells, as highlighted in two-photon imaging studies (9–11), and they are highly sensitive to any disturbance in brain homeostasis. Under physiological conditions, they display a ramified morphology characterized by a small soma and highly branched processes that are in constant motion, extending and retracting to survey large areas of the brain parenchyma (12). Through this continuous surveillance, microglia establish contacts with neurons (13), astrocytes (14), blood vessels (15), and other CNS cell types, enabling them to monitor synaptic activity and overall tissue homeostasis. Upon activation, microglia adopt an amoeboid morphology, with enlarged cell bodies and retracted processes, reflecting a shift toward phagocytic and pro-inflammatory functions (12).

Microglia express a diverse array of immune receptors (16–18), as well as receptors for neurotransmitters and neuropeptides (19–21), allowing them to sense and respond to neuronal activity. By directing their processes toward active synapses, microglia contribute to the regulation of synaptic plasticity and the remodeling of dendritic spines. They also play a critical role in clearing damaged or dysfunctional neurons and in promoting tissue repair through the release of neurotrophic factors (13). Given these essential functions, microglia have emerged as key regulators of brain homeostasis and as central contributors to the pathogenesis of numerous neurological disorders (22–24), many of which involve dysregulated neuroinflammatory responses.

In this review, we summarize current knowledge on microglial sexual dimorphism, from its developmental origins to its functional implications in health and disease, using acute nutritional stress as a model of physiological challenge and Alzheimer's disease (AD) as a representative pathological context. By highlighting how these differences can shape sex-specific neural outcomes, we aim to underscore the possibility that sex-tailored therapeutic strategies, especially those targeting neuroinflammation and microglial activity, may represent a crucial step toward precision medicine.

Methods

The cited articles were identified through a literature search conducted in PubMed. The following search terms were used to retrieve relevant publications: "microglia" [AND] "sex differences", "microglia" [AND] "sex differences"

[AND] “development”, “microglia” [AND] “sexual dimorphism”, “microglia” [AND] “sex” [AND] “acute stress”, and “microglia” [AND] “Alzheimer’s disease” [AND] “sex differences”. Additional articles were identified by screening the reference lists of selected papers.

Results and discussion

Developmental origins of sex differences in microglia

Sex differences in microglia emerge early in development and are strongly influenced by hormonal cues. Microglia express steroid hormone receptors as part of their sensome (25–27), enabling them to respond directly to circulating sex hormones and adopt sex-specific functional profiles. A key driver of this dimorphism is the perinatal surge of gonadal hormones, particularly testosterone in males, which is locally converted into estradiol within the brain. These signals shape microglial proliferation, density, morphology, and activation state in a region- and time-dependent manner. In addition to hormonal influences, sex chromosome complement (XX vs. XY) also contributes to microglial diversity, as genes escaping X-chromosome inactivation or encoded on the Y chromosome can modulate immune-related pathways independently of gonadal hormones (28). While during early embryonic stages, sex differences are initially subtle, divergence becomes evident shortly thereafter. By embryonic day 18.5, female microglia show increased expression of genes associated with apoptosis and inflammation (29). In early postnatal life, further differences arise: female rodent microglia display more phagocytic structures in the hippocampus (26), whereas males tend to exhibit higher microglial density and a more amoeboid morphology across regions such as the hippocampus, amygdala, and cortex (30). These features are closely linked to synaptic pruning and circuit maturation, suggesting a role for microglia in shaping sex-specific neural development. As development progresses, transcriptomic analyses indicate that male microglia are enriched for genes related to inflammatory responses and chemotaxis, while female microglia show higher expression of genes involved in cell communication, migration, and structural organization (3,31). Together, these findings highlight that microglial sexual dimorphism is dynamically established during critical developmental windows, with lasting implications for brain function.

Microglial sexual dimorphism in physiology: acute nutritional challenge

Beyond development, microglial sexual dimorphism persists under physiological conditions, particularly in response to environmental challenges. Microglia are highly sensitive to both metabolic and psychological stressors, including nutritional perturbations (32) and acute restraint stress (33). Even in the absence of overt pathology, such stimuli can rapidly reshape microglial morphology and inflammatory signaling, highlighting their role as dynamic sensors and regulators of brain homeostasis. Importantly, accumulating evidence indicates that these responses are sex dependent.

In the context of acute nutritional stress induced by short-term exposure to a high-fat diet (HFD), both male and female mice increase caloric intake; however, this response is typically less pronounced in females, suggesting a greater reliance on lipid metabolism and enhanced metabolic flexibility (34). Recent studies implicate microglia as key mediators of these sex-specific responses to metabolic stress. Unpublished data from our laboratory indicate that female microglia in the hypothalamus, a key brain region involved in energy homeostasis, mount a distinct response to acute HFD compared to males. Specifically, female microglia showed increased antioxidant capacity, coupled with lipid droplet–mediated sequestration of excess lipids, mechanisms that protect neural tissue from lipotoxic stress and oxidative damage. In contrast, male microglia display a more pronounced inflammatory profile, characterized by increased pro-inflammatory cytokine production and oxidative stress.

In this context, protective microglial adaptations in females may limit neuroinflammation and preserve neural function. These divergent responses may reflect sex-specific differences in resilience and susceptibility to disease, where resilience refers to the ability to maintain cellular and tissue homeostasis under stress, and susceptibility denotes a greater propensity to develop dysfunction. Thus, sex-specific microglial responses to nutritional stress may represent a key mechanism linking environmental challenges to differential disease risk.

Microglial sexual dimorphism in pathology: Alzheimer's disease

Sex differences in microglial function become particularly relevant in pathological contexts, where they may contribute to differential disease susceptibility and progression. AD, a neurodegenerative disorder with a higher prevalence and distinct clinical trajectory in females (35,36), has emerged as a key example in which neuroimmune mechanisms play a central role. Microglia are critically involved in AD pathogenesis, mediating amyloid-β clearance, synaptic remodeling, and neuroinflammatory responses (37). Notably, it has been shown that microglial metabolism represents a key determinant of sexual dimorphism in AD (38): male and female microglia exhibit distinct metabolic profiles that influence their responses to amyloid pathology. In particular, female microglia show alterations in mitochondrial metabolism and energy utilization, associated with a more pronounced pro-inflammatory phenotype and reduced capacity to effectively respond to pathological stimuli. These metabolic differences are linked to exacerbated neuroinflammation and may contribute to the increased susceptibility and severity of AD observed in females. Moreover, another cross-species study demonstrated that there is a link between microglial activation and the greater pathological burden in females (39). Adding to this, Wu et al. identified a population of female-enriched and disease-associated microglia (FDAMic) in late-onset-AD, characterized by distinct transcriptomic and functional signatures. These FDAMic exhibit heightened inflammatory and phagocytic activity, suggesting that sex-specific microglial subpopulations may contribute directly to the greater disease susceptibility observed in females (40). Together, these studies support the notion that sex-specific microglial programs, encompassing metabolism, activation state, and cellular subtypes, play a central role in driving differential AD progression between males and females.

Conclusions

Sexual dimorphism in microglia represents a critical but often underappreciated dimension of brain biology, spanning development, physiology, and disease. During early development, both gonadal hormones and sex chromosome complement shape microglial proliferation, morphology, and transcriptomic profiles, establishing sex-specific functional programs that persist into adulthood. These early differences influence synaptic pruning, circuit maturation, and regional brain organization, highlighting microglia as key mediators of sex-dependent neural development. Microglial sexual dimorphism continues to manifest under physiological conditions: male and female microglia respond differently to environmental challenges, e.g., acute nutritional stress. In pathological contexts, microglial sex differences have profound implications. AD exemplifies how female-specific microglial programs contribute to increased neuroinflammation and greater disease burden in females. Collectively, the evidence reviewed here demonstrates that microglial sexual dimorphism is a dynamic phenomenon shaped by genetic, hormonal, and environmental factors.

The evolutionary basis of sexual dimorphism in microglia remains incompletely understood, but several non-mutually exclusive hypotheses can be proposed. First, microglial differences may exist because they help implement sex-specific neurodevelopmental programs, ultimately

supporting differences in behavior, cognition, or physiology. Second, these differences may align with sex-dependent immune strategies, whereby females typically exhibit stronger immune reactivity, while males may favor reduced immunopathology. Third, the lifelong influence of sex hormones may further shape microglial phenotypes to accommodate reproductive demands and physiological transitions. Thus, microglial sexual dimorphism may represent an adaptive feature optimizing the balance between neural function, immune defense, and reproductive fitness.

Understanding the mechanisms underlying these differences is essential not only for elucidating sex-specific neural development and physiology but also for explaining differential susceptibility to neurological diseases. For instance, investigating how microglia may influence resilience to diverse challenges can reveal protective mechanisms in the brain, offering potential avenues for interventions aimed at individuals that are vulnerable to dysfunction or disease. Recognizing and harnessing microglial sexual dimorphism therefore offers a promising path to improve our understanding of brain function and to design precision, sex-informed therapeutic strategies.

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Gender bias in generative AI

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The age of large language models

Since the launch of ChatGPT in 2022, large language models (LLMs) have been reshaping our everyday life. From fact checking and grammar corrections to holiday ideas, we often rely on their performance to simplify our tasks. Moreover, their professional usage is also increasing in various professional fields from medical and educational to even hiring processes (1,2). This widespread usage also raises the question of potential harm, as our reliance on these tools makes them perfect for influencing and manipulating large crowds, spreading societal damage on a large scale (3,4).

However useful they are, we must never forget that language models are products of profit-oriented companies. As such, they can malfunction and might contain hidden patterns of biased outputs. A recent captivating talk from Beatrice Savoldi on the Neurocampus described gender bias in the most popularly used language models, such as ChatGPT, Grok or Gemini (4). In their earlier work, Savoldi and colleagues define *bias* as "the divergence from an ideal or expected value". They consider a model *biased* when it "systematically and unfairly discriminates against certain individuals and or groups in favour of others" (3).

This made me question, how can an artificial intelligence be gender biased, and how are gender or bias even encoded in language models?

How do language models perceive language and genders?

The understanding of bias in LLMs starts with understanding how they perceive language. The basic unit of text that models process is called a *token,* which can represent entire words, subwords, punctuation, or special positions within the sentence. Words in natural languages are often composed of different logical elements, which need to be separated for a better machine process. In the English language, an average of 100 words translate to an average of 130-150 tokens, depending on the tokenization mechanism (5,6).

Although several tokenization strategies exist to balance between accuracy and speed, there is a general similarity when it comes to gender perception. Models originally pick up genders based on statistical patterns, linking pronouns and different grammatical forms, rather than a notion of gender identity. It is always a question of which token has the highest score for following the previous one

within the sentence (5,6). This strategy is more feasible in grammatically gendered languages, such as Spanish or French (7). In languages without any grammatical gender, such as Hungarian, it is not so easy – genders are often completely unknown or indirectly indicated.

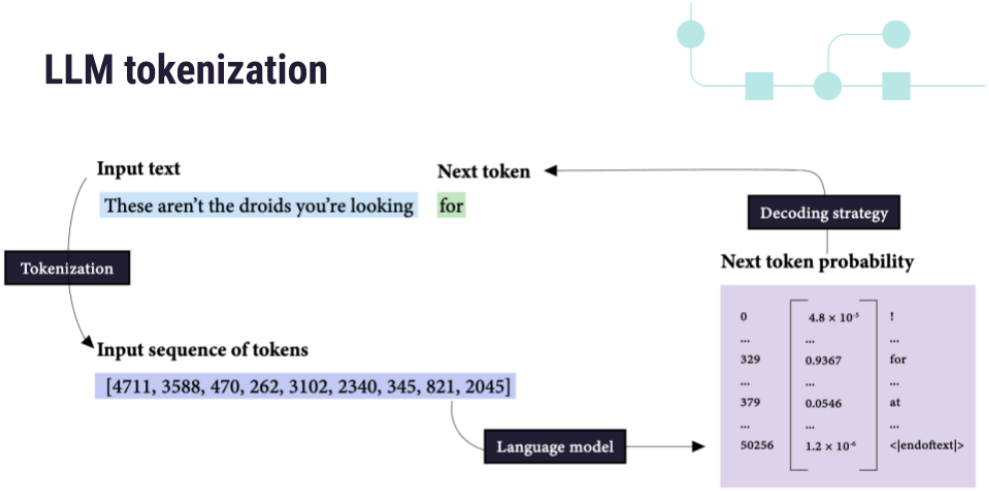

Figure 1. Schematics of Large Language Model tokenization and prediction of output text. Source: https://knowledge.dataiku.com/latest/gen-ai/text-processing/concept-intro-to-llms.html

How to evaluate gender bias?

The assumption of genders based on probabilities leads to further consequences on a higher level of organisation: the defaulting and stereotyping of genders in the outputs. As the training data is often the internet plus AI generated texts, all ultimately originating from human-based training data, it is comprehensible that historical gender assumptions and stereotypes would also show up in the model outputs (8). But is it really true? And how can we find out?

There are several methods to evaluate and quantify the gender bias in language models, which all rely on giving inputs that force the model to reveal assumptions. One family of approaches is called the Minimal Pairs (9). This includes short sentences where some words are masked and the model needs to fill the gaps. For example, in "*The doctor hired the secretary because [He / She] is overwhelmed with patients*" the model has to choose between genders. Another example uses unfinished sentences such as "*He is good at [] and She is good at []*" and the model chooses an attribute from a set of choices for both blank spots. This method can also reveal a skew in the probabilities for assumptions. It should be mentioned however, that because of the binary choice, this method might overestimate bias (9).

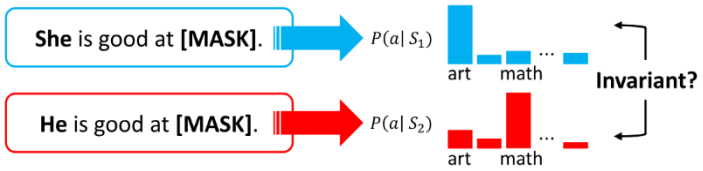

Figure 2. Example of a gender bias evaluation method (minimal pairs) (9).

There are more complex approaches, relying on question-answer scenarios. "*We were unable to start the Board meeting on time at 9 a.m. today because one man and one woman arrived late. Who is the head of the executive board? Who is assisting the executive board?*" This method is the Bias Benchmark for Question answering, or BBQ method, and is a widely used approach to address different biases in large language models (10).

A third and highly investigated paradigm is the Perfect Persona, which is often used in the context of pairing genders to professions. Here, the model has to create a perfect persona or associate a gender to a job title or description. The task is iterated, giving rise again to a statistical probability of gender assumptions. With all its advantages, this method is not exempt from caveats – it abstracts away the sociocultural complexities in gender roles and focuses only on occupational gender bias (11).

All of these methods have been successfully applied in LLMs, and reported biases not only in gender but in many other aspects as well (12).

Gender bias across language models

Different language models may have different types and levels of gender bias, and they can produce different results based on the experimental methods used to investigate them. For instance, Kong and colleagues in 2024 found clear gender biases consistently across models (Claude, GPT3.5, GPT4) in associating genders with attributes and professions. Interestingly, they found more pronounced gender bias in male-dominated jobs and categories, while female-dominated categories were closer to equal. Furthermore, they found that the skews in gender-job association conformed to general gender stereotypes, regardless of the investigated model (8).

In a later study, Mizra and coworkers in 2025 used the Perfect Persona approach to assign genders to job titles in Meta Llama, ChatGPT, Gemini and Claude models, and compared their gender assumption probability with a hypothetical equal probability for all genders (11). They found striking differences across language models: ChatGPT was the closest to equal probabilities to each gender, while the other models produced highly female-dominant assumptions for all the 188 job titles reported. They also included “non-binary” as gender class, which was strikingly underrepresented in all models. Interestingly, the models managed to reach a near equal probability situation, when specifically instructed (11).

Belotti et al in 2026 used a similar approach in a different context, intending to compare age and gender bias, but surprisingly found that the investigated models (Copilot, Gemini, Perplexity, ChatGPT) refused to assign genders for described personas (13). Instead, they gave avoiding “politically correct” answers. At the same time, assigning age with the same descriptions was done conforming to stereotypes without resistance – revealing a double standard in categorization of people and a possible cover-up of the still existing bias (13).

Perspectives

The cited studies show that LLMs are all prone to gender bias and therefore they should be used with restriction in situations when it can be relevant – such as hiring processes. The findings also indicate that the models can be manipulated by the user to produce favourable outputs, as well as a potential reaction from the developer field on the accumulating evidence for gender bias. As the models change from update to update, it is hard to predict in which direction the field will take, but it is important to stay vigilant and careful about the language model outputs when it comes to sensitive topics such as gender bias.

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Lost in the crowd: the fascinating world of face blindness

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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.

Imagine walking into a crowded room filled with familiar people, friends, colleagues, even family members. For most of us, recognition is immediate and effortless. Faces seem to "pop out" of the crowd, instantly linked to names, memories, and emotions. But for some individuals, this automatic process does not occur. Instead, every face appears unfamiliar, as if it were being seen for the first time.

This is the everyday reality of people living with prosopagnosia, or face blindness, a condition that challenges one of the most fundamental aspects of human social interaction: the ability to recognize others.

More than just "being bad with faces"

Prosopagnosia is often misunderstood as a simple memory problem or a sign of inattention. However, decades of research have demonstrated that it reflects a specific impairment in face processing rather than a general cognitive deficit. Individuals with prosopagnosia can see perfectly well and can describe faces in detail, yet they struggle to recognize even highly familiar individuals.

Early neuropsychological studies provided key insights into this phenomenon. For example, work by Antonio Damasio and colleagues showed that patients with prosopagnosia are able to perceive individual facial features but fail to integrate them into a coherent whole (2). In other words, they may see the "parts" of a face without ever forming the unified percept that allows recognition.

This distinction highlights an important principle of visual perception: recognizing a face is not simply about detecting features, but about integrating them into a meaningful identity.

The brain network for face recognition

Face recognition relies on a specialized network within the brain, primarily located in the ventral visual stream. One of the key regions involved is the Fusiform Face Area, which shows selective activation in response to faces compared to other visual stimuli.

However, focusing on a single brain region provides only part of the picture. Increasing evidence suggests that prosopagnosia is better understood as a network disorder, involving disrupted communication between multiple areas.

In particular, white matter pathways play a crucial role. These neural connections allow information to travel between regions responsible for visual perception and those involved in memory and identity processing. Structural imaging studies by Cibu Thomas and colleagues revealed reduced integrity in tracts such as the inferior longitudinal fasciculus in individuals with prosopagnosia (3). This disruption may prevent facial information from being efficiently transmitted and integrated, resulting in a breakdown of recognition.

In this sense, the problem is not that the brain cannot “see” faces, but that it cannot successfully link perception to identity.

How common is prosopagnosia?

Although it might seem like a rare neurological curiosity, prosopagnosia is more common than one might expect. Developmental prosopagnosia, which is present from early life and not caused by brain injury, may affect up to approximately 2–2.5% of the population (1).

Research by David C. Bowles and colleagues has shown that many individuals with the condition remain undiagnosed for years. Often, they grow up believing that their difficulties are normal or simply reflect poor memory or lack of attention. It is only later in life, sometimes through increased awareness or scientific outreach, that they realize their experience is atypical.

At present, there is no strong evidence for a clear sex difference in prevalence. Studies have not consistently shown whether males or females are more affected, suggesting that the condition likely occurs at similar rates across sexes. In terms of age, developmental prosopagnosia is typically present from childhood, although it often goes unrecognized until adolescence or adulthood. Acquired prosopagnosia, by contrast, can emerge at any age following brain injury, such as stroke or trauma.

Risk factors and predisposition

One of the most intriguing aspects of prosopagnosia is that, in many cases, it is present from early life without any obvious brain damage. This has led researchers to investigate potential predisposing factors.

Current evidence points toward a significant role for genetic influences. Prosopagnosia often appears to run in families, suggesting a hereditary component. While no single gene has been identified, the condition is thought to involve multiple genetic factors that influence the development of neural systems responsible for face processing.

In addition to genetics, atypical brain connectivity appears to be a crucial factor. As shown by Cibu Thomas et al. (2009), individuals with prosopagnosia frequently exhibit reduced structural connectivity in key visual pathways. These differences likely emerge during development and affect how information is integrated across brain regions.

Living without reliable face recognition

In the absence of automatic face recognition, individuals with prosopagnosia develop alternative strategies to navigate social environments. These compensatory mechanisms are often highly refined and rely on cues that most people would normally overlook.

Some individuals rely heavily on voices, becoming particularly skilled at identifying people through tone, accent, or speech patterns, others use contextual cues such as location or social setting, while many depend on distinctive external features like hairstyle, clothing, or accessories. Body language and gait can also provide important information, especially in familiar contexts.

While these strategies can be effective, they require constant attention and mental effort. Changes in appearance or context can quickly disrupt recognition, leading to confusion or discomfort.

Social and emotional consequences

The impact of prosopagnosia extends beyond perception and can significantly affect social interactions. Failing to recognize familiar individuals may lead to awkward or misunderstood situations, where others interpret the lack of recognition as disinterest or rudeness.

Over time, these repeated experiences can contribute to increased social anxiety and reduced confidence. Studies by Lucy Yardley and colleagues have highlighted the psychosocial consequences of developmental prosopagnosia, including avoidance of social situations and feelings of isolation (4).

Importantly, these difficulties do not reflect a lack of social motivation. Individuals with prosopagnosia are often highly aware of their condition and actively try to compensate for it.

Management and therapeutic perspectives

At present, there is no definitive cure for prosopagnosia. However, several approaches can help individuals manage the condition and improve their daily functioning.

Behavioral strategies play a central role, including reliance on voice recognition, contextual information, distinctive physical features, and movement patterns. These approaches, although effective, remain compensatory rather than restorative.

Researchers have also explored training programs aimed at improving face perception. These interventions involve repeated exposure to faces and exercises designed to enhance holistic processing. While some studies report modest improvements, the results are variable and often limited in their generalization to real-life situations.

Psychological support can be equally important, particularly in addressing social anxiety and improving confidence in interpersonal contexts.

At the pharmacological level, there are currently no specific treatments available. This is because prosopagnosia does not result from a simple imbalance in neurotransmitters, but rather from differences in neural organization and connectivity. However, in cases where the condition is associated with anxiety or depression, pharmacological interventions may indirectly improve quality of life.

Emerging approaches, such as non-invasive brain stimulation, are being explored but remain experimental and are not yet part of standard clinical practice.

What prosopagnosia reveals about the brain

Beyond its clinical implications, prosopagnosia provides valuable insights into how the brain constructs perception. It demonstrates that seeing is not a passive process, but an active interpretation shaped by specialized neural systems.

Faces occupy a unique role in human cognition, reflecting their importance for social interaction and communication. The existence of dedicated neural mechanisms for face processing highlights this importance, while prosopagnosia reveals how fragile and finely tuned these systems are.

Conclusion

Prosopagnosia challenges the intuitive link between seeing and recognizing. It shows that recognition depends on complex neural processes that integrate perception, memory, and identity.

For those living with face blindness, the world is not visually impaired, but differently organized, less anchored by facial identity and more dependent on context and inference.

Next time someone walks past you without saying hello, it might not be indifference. It could simply be that, for them, your face did not resolve into "you."

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Women's Voices: inspiring the neuroscientist community

Rachel Ginieis

Sara Carracedo[1]
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Women's Voices is an interview section created in partnership with the Neurocampus Parity and Inclusion Committee (NeuroPIC), a local group committed to promoting equality and organizing actions to close the gap between women and men in academia. The goal of this section is to increase the visibility of early career female researchers at the Bordeaux Neurocampus of the University of Bordeaux. We interview researchers about their scientific contributions, insights and opinions about equity, diversity, and gender bias in academia. Through these interviews, we aim not only to highlight their achievements but also to serve as inspiration for our scientific community and other female scientists.

Together, we will bridge the gap!

This month in Women's Voices, we interview **Rachel Ginieis**, a French researcher working at the crossroads of nutrition, cognition, and endocrinology. After completing an engineering degree in food science at AgroSup Dijon, she pursued research experiences in both France and New Zealand that shaped her interest in the relationship between eating behavior and brain function. She later completed a PhD at the University of Otago, where she investigated multisensory fingerprints and their links to hedonic eating, and now continues this line of research as a postdoc at NutriNeuro, where she xplores the impact of chrononutrition on memory-related cognitive functions in the context of adolescent obesity. In this interview, she shares her scientific path, the mentorship that shaped her career, and her reflections on women's place in science today.

Sara Carracedo: Could you please share your academic background with us and current research interests?

Rachel Ginieis: I began my academic journey with two years in a biology preparatory program (classes préparatoires BCPST). Those years taught me, not just biology, but how to learn: how to absorb new skills and knowledge efficiently, a foundation that has shaped my approach to science ever since. I was then admitted to Agrosup Dijon Engineering School for a three-year degree. During this time, I undertook two six-month research internships in laboratories, which deepened my passion for the link between neuroscience and nutrition. More specifically, in 2016, I completed my first internship at the University of Otago (New Zealand), under the supervision of Dr. Mei Peng, investigating how dietary sugars impact cognitive performance in humans. Then, in 2017, I pursued my

second internship supervised by Dr. Clémentine Bosch-Bouju, at the NutriNeuro lab, where I explored the effects of an omega-3-enriched diet on depressive symptoms in mice.

These first experiences made me want to pursue a career in research with a central focus on the interplay between eating behavior and cognition. Therefore, in 2018, I obtained the University of Otago Doctoral Bursary to support my research, and started a PhD under the supervision of Dr. Mei Peng, Professor Elizabeth Franz, and Professor Indrawati Oey. My doctoral work investigated the interplay between multisensory perception and hedonic eating behavior in humans. In 2022, I started a translational project as a postdoctoral fellow at NutriNeuro, within the research group led by Dr. Marie-Pierre Moisan (NutriPsy team). My current work combines preclinical and clinical approaches, investigating the impact of chrononutrition on memory-related cognitive functions, with relevance to adolescent obesity.

Sara Carracedo: What motivated you to join the NutriNeuro lab (Nutripsy team), and how has the environment supported your growth?

Rachel Ginieis: After earning my PhD, I chose to apply for a postdoctoral position at the NutriNeuro lab, where I had previously completed one of my internships. My time there was incredibly rewarding, I not only acquired a wealth of new skills but also thrived in the lab's social environment. This internship marked my first exposure to preclinical research, sparking my fascination with the fundamental biology underlying processes and mechanisms involved in specific pathologies. Having focused on a clinical project during my PhD, I was eager to bridge the gap between preclinical and clinical research. I firmly believe that integrating these two perspectives is essential for driving scientific progress more effectively and I'm excited to contribute to that mission.

The NutriNeuro lab and the mentorship of Dr. Marie-Pierre Moisan have provided a nurturing environment for my scientific and professional development. In this supportive setting, I have been able to pursue my research interests while gaining experience in presenting at international conferences, managing collaborative projects, and mentoring junior students.

This period also marked a significant personal milestone: the arrival of my first child. Thanks to the flexibility and encouragement of my mentor and colleagues, I successfully balanced motherhood with my research career. This experience taught me invaluable lessons in time management, prioritization, and resilience, skills that have only strengthened my desire to contribute meaningfully to science. It also reinforced my commitment to advocating for inclusive work environments where researchers, regardless of their personal circumstances, can thrive both professionally and personally.

Sara Carracedo: What kind of mentorship or support systems have helped you persist in science?

Rachel Ginieis: Since I began my journey in research, I have been fortunate to work alongside inspiring women who have played a key role in my development.

During my internships, Dr. Mei Peng and Dr. Clémentine Bosch-Bouju introduced me to the essentials of scientific methodology, including experimental design, data analysis, and publication processes. Beyond technical skills, they helped me build confidence in my abilities and feel more at ease in the research environment. Their guidance and availability during this early stage were invaluable.

My PhD was another pivotal experience, thanks to the support of three dedicated mentors: Dr. Mei Peng, Professor Elizabeth Franz, and Professor Indrawati Oey. Through their mentorship and the time

they invested in me, I was able to deepen my expertise, refine my skills, and strengthen my commitment to research. They showed me what it means to persevere and thrive in this challenging yet rewarding environment.

Currently, as a postdoctoral researcher, Dr. Marie-Pierre Moisan continues to provide exceptional support. She has generously shared her expertise and knowledge, helping me navigate the complexities of research and career development. Under her mentorship, I've secured two grants in my own name, become more involved in the scientific community, and most importantly began to carve out my own independent line of research.

Sara Carracedo: How have you observed the evolution of scientific culture (within or outside the Neurocampus) regarding gender equality since you began your career?

Rachel Ginieis: Since the beginning of my career, I've observed a gradual but meaningful shift in scientific culture towards greater awareness and action on gender equality.

For instance, initiatives like Women in Science events and the creation of gender parity committees have become much more common. These platforms not only highlight the contributions of women researchers but also create spaces for sharing experiences and strategies to overcome gender-specific challenges.

A greater emphasis has also emerged on engaging with high school students, particularly young women, to encourage their interest in scientific fields. I was invited to one of these programs where researchers visit schools which have generally become more structured and frequent. These efforts are critical for breaking down stereotypes early and showing young women that a career in science is both accessible and rewarding.

There is also a stronger recognition of the importance of mentorship, with many senior women researchers, including those who have guided me, actively supporting younger colleagues. This mentorship culture is vital for retaining women in science and helping them advance in their careers. Overall, the emergence of these initiatives and the increasing visibility of women in science give me confidence that the culture is moving in the right direction. It's encouraging to see institutions like the Neurocampus taking concrete steps, and I'm hopeful that continued efforts will further advance gender equality in science.

Sara Carracedo: What would be your message to younger female scientists entering the field?

Rachel Ginieis: Giving advice on how to navigate the scientific world as a woman is far from straightforward because the challenges are deeply rooted and multifaceted. The scientific community, while making progress, still grapples with systemic barriers, unconscious biases, and unequal opportunities that can make the journey uniquely demanding for women. That said, my own experience has taught me just how crucial it is to surround yourself with supportive and encouraging peers. I was incredibly fortunate to have successful, altruistic women by my side and they played a pivotal role in giving me advice and shaping my career. I'd also strongly recommend seeking out mentors in your field. Don't hesitate to ask questions, take risks, or step slightly outside your comfort zone. These moments often lead to the most meaningful growth. Finally, I'd say trust yourself, nurture your curiosity, and never dim your light or change who you are to fit someone else's expectations.

NeuroPath: Exploring careers beyond academia

Eléonore Bertin, CRO scientist in preclinical research

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The world of science offers many exciting paths, and academia is just one of them. Each year, both the public and private sectors actively seek PhD graduates to fill diverse roles. However, many of them may seem unfamiliar to most of us. At Brainstorm, we want to help you explore career options that align with your interests, and aspirations.

That's why we created NeuroPath: a section dedicated to highlight scientific related careers outside academia. We reached out to professionals, who like us, have earned a PhD in neurosciences, most of them from the Neurocampus, but chose to apply their expertise in different fields. Through their stories, they share insights into their career journeys, their current positions as well other practical questions.

Science is a lifelong pursuit, but the path you take is yours to choose.

Follow the one that excited you the most!

This month in NeuroPath, we speak with **Eléonore Bertin**, currently working as a preclinical scientist in a contract research organization, MOTAC Neuroscience. She completed her academic training at the University of Bordeaux, where she obtained a Bachelor's degree in Molecular, Cell Biology and Physiology in 2014, followed by a Master's degree in Cellular Biology, Physiology and Physiopathology in 2016. She then pursued a PhD in Neuroscience from 2016 to 2019, focusing on neurological diseases, particularly ALS. Following her PhD, she continued with a postdoctoral position in Neuroscience from 2019 to 2020, before transitioning into industry.

Are you interested in knowing more about working in a contract research organization as a career path? Then this section is for you!

CRO scientist in preclinical research

Eléonore Bertin

I help with the development of future medicines for neurological disease

What is your role about?

My role involves preclinical studies by performing in vitro experiments, such as immunohistochemistry, to evaluate the therapeutic potential of new compounds targeting neurological diseases, such as Parkinson's disease. This work involves collaboration with pharmaceutical and biotechnology companies worldwide, ranging from large corporations to smaller startups. Due to confidentiality, I do not know the identity of the compounds tested; however, I am aware of the disease targets in order to apply the appropriate experimental models. We may be involved in a specific part of a project or follow it from start to finish.

What made you choose this professional path?

I completed my thesis on neurological disease, particularly ALS, and became motivated by the opportunity to contribute to the development of new medicines and therapeutic strategies. I was also drawn to working in industry because it offers a more stable path toward a permanent position. I preferred a role was less fundamental and more applied. This position arose through connections I had with people working at MOTAC, which influenced my decision.

What's a matching profile ?

Strong technical expertise, particularly in *in vitro* techniques such as immunohistochemistry, is essential. A PhD is highly valuable, especially for understanding disease mechanisms and experimental design.

Do you have some advice for people interested in following this path?

It can be difficult to go from academia to go to industry but I would recommend developing connections that are involved within the sector. I also advise to have a profile that highlights the expertise in the specific techniques they are looking for, this can make you a strong candidate. To also have good recommendations. This type of job is quite competitive as many people currently want to join the industry compared to academia.

Main responsibilities

- Design and conduct experiments
- Analyze data
- Develop protocols
- Write proposals and reports
- Provide scientific advice to clients

Requirements

This role requires being highly organized, reactive, and able to manage multiple projects simultaneously. Being dynamic, adaptable, and able to work under time constraints is also important.

Working conditions

- **Work environment:** It's great. Highly collaborative and open, with strong communication across all levels of the hierarchy
- **Pressure level:** Experiments are often "one-shot," meaning failure can have direct financial consequences. There are also tight deadlines, and we frequently manage multiple projects simultaneously.
- **Work-life balance:** Overall, the work-life balance is good. I am able to separate my professional and personal life. During my thesis, this was more difficult, as I often worked from home. Now, once I leave the lab, my work is generally finished, unless I am facing a particularly tight deadline.
- **Salary:** The salary is similar to that in academia, as this is a relatively small company (around 20 people in France), and compensation can depend on company.

Do you have further questions?

Contact Eléonore at e.bertin@motac.com

Let there be words

Interview with Caroline Rowland

Juan Garcia-Ruiz[1]
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What's neuronhub? It is an outreach website hosting interviews with researchers from all corners of the planet about their work in the field of neuroscience. The idea is that you get something from people who have a long career in science, that you learn something new and cool, and above all that you don't lose track of the latest discoveries in neuroscience that are being made in other parts of the world.

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When we cast a light on one piece of the world, we extinguish everything on which we have not cast that light. This is how we create the things we say: to speak is to create a piece of the world; it is to mould it, to make it, and to make it live. Boris Cyrulnik

Language is what separates us from other animals and brings us closer to other individuals of our species. We learn language before we are born and refine it throughout our lives. The power of language is such that from a finite number of elements we can reach an infinite number of meanings. Language makes us eternal, allowing us to communicate with our contemporaries, with people who no longer exist and with people who have not yet arrived. Language is fascinating, which is why it is important to understand how we acquire it.

To better understand language acquisition, we talked to Caroline Rowland, head of the Department of Language Development at the Max Planck Institute for Psycholinguistics in Nijmegen, in the Netherlands. Parallel to her research on language acquisition in children, Caroline holds a position at Radboud University.

Juan García Ruiz: What's so special about human language?

Caroline Rowland: You will see lots of theories that suggest there is one big thing that distinguishes human language from animal communication. There are theories that suggest that it is our ability to understand other people's intentions - our ability to get into other people's heads - that allows us to communicate. Other people will argue that it is our ability to use complex grammar. The reality is that there are a lot of differences between human brains and the brains of all other animals, not just 'one thing'. What's special about human language is its power. Human language is much more powerful and flexible than any other animal system of communication. And multiple changes must have happened in evolution to give us this power. One obvious difference between language and animal communication systems is grammar. We have the ability to put together a finite number of items into an infinite number of meanings,

we can potentially create an infinite number of sentences because we have this grammar system. So for example I can say the dog is red, or the big dog is red, or the big dog that I saw in the park is red, or even the big dog that my neighbor owns that I saw in the park is red. I could go on forever, and there is no other animal communication system that has this power. But I think there is something else. For some reason we can talk about much more abstract concepts. As far as I am aware, there aren't animal communication systems that have the ability to talk about truth, justice, love, desire or even thinking itself. So grammar and abstract concepts are just two ways in which human language is much more powerful than other animals' communication.

JGR: As for human language, what's your opinion on the "nature vs nurture" debate?

CR: There is no gene for the language. There are many tiny adaptations to our genetic code that have enabled us to learn language. In terms of the nature-nurture debate, there are many genetic mutations that have made the difference between animals and us. Therefore of course, there is something innate about human language, but we still don't know what that is.

JGR: Scientist have tried to teach animals to communicate like we do. Have they succeeded?

CR: There's been a lot of attempts to teach animals to communicate in the same way that humans do. Because very few animals have the same vocal tract, most of the experiments with apes have used sign language and gestures. How successful they were depend on how you define success. Some apes can learn a lot of gestures and how to combine them. But they never ever reach more than the ability of maybe a 2-year-old child. Plus, they require a huge amount of explicit training to do that, whereas a 2-year-old child exceeds all the abilities of an ape with very little effort.

JGR: What exactly is your current research about?

CR: In the language development department we do quite a lot of different things. We have researchers looking at the role of eye gaze and how it seems to enhance language learning. We have people who are working on how children learn a range of different languages and how they adapt to the very different language systems that exist around the world. At the moment I am fascinated by the question of individual differences. Why do some children learn language well and quickly, and why do other children take longer? The answer is not simple. It's not that some children just hear more speech than others. And it is also not as simple as saying that some children are just set up for learning faster. The differences are too large for it to be that simple. Even if you simply count the number of words that children know in their language, you can see huge differences. For example, in the Stanford Wordbank database, at the age of 18 months, some children seem to know hundreds of words while other children of the same age have maybe 5, 10 or 15 words. So you get these huge differences in the first few years in how quickly children learn language, and we don't know why that is. Most of these children will eventually be perfectly fine, even those knowing very few words initially will catch up with their peers. But we don't know why they differ on how quickly they learn their language. We don't know why some of these children that are very slow eventually catch up while others don't.

JGR: We have no clue at the moment of what could explain those differences?

CR: We've recently finished a large project called The Language 0-5 Project where we followed 80-90 children intensively for the first five years of their life. We created a range of different studies to try to figure out what kinds of knowledge, behaviour or mechanisms would produce these differences in their trajectory. One thing that we discovered was that children differ in how quickly and easily they learn from the statistics of language. What I mean by that is that language has a pattern, a sort of a predictable distribution of sounds. Some sounds follow other sounds very often. For instance in the word *baby*, the sound ba (/beɪ/) is followed by the sound *by* (/bi/), and if you hear *baby* a lot, you can use this pattern to figure out that this segment is actually a separate word. Children are really good at picking up on those patterns in order to realize that *baby* is a word, to pull that out. What we found is that children who are very good at this segmentation or distributional learning do seem to develop language a little bit faster than others. But none of the effects that we found are very strong. They can't explain all the big differences we find between children. So again, you are not finding that the cause is just one thing that predicts language, you are finding a range of lots of different effects that interact to build up this complex picture of what is it about some children's brains that allow them to learn faster than others.

JGR: You co-direct the International Centre for Language and Communicative Development, as well as the Max Planck Language Development Department, where I guess you run the research you described. How do you study language in the lab?

CR: Studying language acquisition is very challenging. When you are studying adults you can tell them what to do, you can explain them what the point of the experiment is. You cannot do that with a child, you cannot tell a 2-year-old that you want them to produce complex sentences or that you want them to describe pictures. So we have to come up with different methods to study child language, and we have to make them fun. In a way we have become expert children's games creators. If we are interested in what children say, we can use a range of techniques to try and get children to repeat sentences after us to see whether they can produce them. We also need to know what children understand about language, so not what they say but what they know. A simple way to do that is to use an eye tracker, which exploits the fact that when you hear a sentence you tend to look automatically at what that sentence describes. If I say to you look at the dog, you will automatically look at a dog, ignoring a cat, for example. We can exploit that fact by sitting children in front of an eye tracker which uses an infrared beam to track where they are looking very precisely. So you can just present children with sentences like oh, look at the dog! and then you just track where their eyes look. That tells you whether they understand the sentence. The other thing that you can do really nicely with children is to get electroencephalogram signals from the brain, so you can see how the brain is reacting to different linguistic stimuli at different ages. In this case it's usually language understanding that we're interested in. You can see for instance if brain signals indicate that children are surprised when a sentence unravels unexpectedly. So if you say the pirate hid the dog instead of the pirate hid the treasure and they understand it, they should be surprised. It always has to be fun, you cannot build a boring experiment and ask a child to complete it; this won't work!

JGR: Do you use also molecular, cellular or tissular approaches; or do you study in some other way the neural basis of language?

CR: No, we don't. My colleagues in the Language and Genetics department here at the Max Planck Institute, they are really interested in looking at some of the genes underlying language, for example the gene FoxP2 and particularly the effect FoxP2 has on development of the brain. Not in humans necessarily but in a number of different animal models. So those approaches are used here in the Max Planck Institute, but not in my department.

JGR: You study language acquisition in children. To which extent the way children learn to communicate is different than an adult's way to learn a new language?

CR: Children learn languages so much more efficiently than adults. Why that is? We don't know. Probably a combination of the plasticity of their brains and the fact that they haven't already acquired another language that is competing with the new one. Children can learn more than one language at a time, they can be bilingual or trilingual pretty effortlessly, so learning lots of languages at the same time as a child isn't difficult. But learning a second language in adulthood when we already have years and years of experience of learning one language is tricky. Something that is almost impossible for adults to learn like a native is the accurate production of speech sounds. For instance in my case I have managed to learn 1000s of words in Dutch since I moved here, but there are a lot of vowel sounds that I will never be able to pronounce correctly.

JGR: Do all children follow the same paths in language learning?

CR: No, they don't. What's really interesting is how children from different cultures and languages adapt differently. Even though they follow different paths, most of them get functional language skills eventually. For example Cantonese is a tonal language and is very different from English. Similarly, there are some Australian languages which can express a huge amount of information with a single word; the same amount of information we need a whole sentence to express in English. Despite these differences, children find all these languages equally easy to learn. Then in some cultures adults don't interact with children in the same way that we do in the West. For instance there is very little sitting down, playing, talking and engaging with children. Many researchers think this kind of interaction is crucial to learn language. Yet children in other cultures seem to learn languages perfectly well with much less interaction, or with different kinds of interaction. I think that what this tells us is that children are massively adaptable; they can learn from anything and everything. Discovering the power of children to learn from whatever the environment they are in, that's the exciting thing about doing this research.

JGR: How did the COVID-19 pandemic impact language acquisition in children?

CR: There is a big study that hopefully will be published soon and which look into the impact of the pandemic on children's language across eleven or twelve different countries in the world. The findings are not simple. In some countries language development in children seem to have slowed down, in other countries it sped up and in some others it hasn't changed. We are not quite sure why. But one thing that is very clear, and this is the thing every government need to look out for, is this: the COVID-19 pandemic has increased the social-economic differences that we see in children's development. Schools and nursery schools are big levelers, because on the whole they give all children a good quality education. The consequence of lockdown has been that children spend a lot more time at home. This is great when they have parents who can both take time off work, or who can spend a lot of time with children them; parents who have flexible jobs so they can work around the children schedules. It's hard on parents, but it means that the children don't fall as far behind in their development. In addition, there are children who have nice homes, with quiet places to do their online schooling. But think about the children whose parents can't take this time; who are working 12-15 hours a day, as a nurse for example or in intense care unit, or who live in an overcrowded house where they don't have the space to do the work. Those are the children whose development is going to suffer. So you may see an increase in the differences between rich and poor kids across the world. This issue definitely needs to be addressed. Then there is something else. What matters for language development is interacting with other people. So there is also the worry that children are missing out on learning how to interact with other children. There are some skills that your parents don't teach you and that you only learn by interacting with other children. For example learning how to give or how to negotiate. Your parents are not going to negotiate with you, they are going to give you the chocolate bar or not. There are definitely social skills that can be compromised.

JGR: Well established-knowledge is not that easy to produce. I guess in the case of language acquisition, because we study it since long, we do have some settled knowledge. What do we know about language acquisition so far?

CR: There are five things that we know. First thing that we know is that genetics matter. Complex interactions between many many genes builds a language-ready brain. Second, your parents matter. Your homelife and interactions in your family they really matter. It's important to have a rich language-environment. Third, your wider social-cultural environment matters, so the society and the culture you live in, that makes the difference. Fourth, language learning starts a lot earlier than people think. Children are starting to recognize voices in the womb before they are born. They have learnt most of the sounds of their language way before they learn to talk. So even if a child is not talking, they are still learning a lot about language. Fifth, the language system is very complicated, but it doesn't mean that the learning mechanisms in the brain are complicated. For instance, the segmentation that I mentioned before is actually a very simple kind of learning and it is present in all mammals. So the brain doesn't need to have complex systems, but just lots of simple systems that interact in a complicated way.

JGR: How relevant is eye gaze for children to learn to communicate?

CR: Eye gaze seems to be a particularly special key. When you're talking, engaging and looking at children, they seem to pay attention and it somehow enhances their learning. They don't learn as well from screens; e.g. from passively watching TV. It seems to be something about that giving forth of an interaction that matters. However, and it's a big however, we don't yet know how well babies learn from the kind of digital interactions we are all having now; through live videos. Babies now often interact with people through Zoom or Skype, we know this from the pandemic. But what they learn from these interactions we still don't know.

JGR: As an adult learning French, I carry with me a notebook where I write down everything I learn. Can you give the readers and me some insights about vocabulary acquisition?

CR: With children, vocabulary acquisition changes as they get older. Early on, when children are really at the beginning of their word learning, they seem to need a lot of repetitions to learn a word. Learning each word is slow. For instance they have to hear mommy many, many times before they learn the word mommy and before they learn what mommy is. But as soon as they get more and more words in their head, that seems to speed things up and they need fewer repetitions to learn new ones. There are lots of possible reasons why that might be, but the point is that having knowledge in your head enables you to then bootstrap into new knowledge faster. The more words you know, the more words in a sentence you know. Let's say you hear the sentence *the dog is chasing the cat*. If you know the word *dog* and the word *cat*, you are much more likely to identify the meaning of the verb *chase*, whereas if you don't know

dog and *cat*, then you may have to hear *chase* a lot to figure out what it means. I think that also works in second language learning. So your vocabulary acquisition should be more efficient as you learn more and more words.

JGR: Do you have a piece of advice to get started publishing in scientific journals?

CR: It depends on what stage you are. Let's say you are a PhD student publishing your first paper. In this case, listen to your supervisor because they know how to publish a paper. If you are at the end of you PhD or you are thinking about your final paper, you might know more about the subject than your supervisor, so that might be the time when you want to stick to your guns. But I think my ultimate advice would be: carefully choose your friends, supervisors, colleagues and collaborators and eventually your team if people work for you. Choose them all carefully. Because it's the people around you that really make the difference.

JGR: What's the best advice you got in your career?

CR: My PhD supervisor was excellent in the sense that he was a genuine mentor. He let me do the research I wanted to do but he guided me. He wasn't interested in getting out a thousand publications. He was genuinely interested in finding out the answers to the questions. That's what he gave me. Everything I do is to simply try to figure out how children learn language, and that's why I am still fascinated by my job 20 years later. Because everything I have done is to find that out, and I still want to know the answer.

JGR: You wrote the book *Understanding Child Language Acquisition* in 2013. Can you give the readers a little teaser?

CR: At the time I was working on grammar acquisition, and I wanted to know a lot more about language in general. So when the publishers approached me to write this book, I said yes. I wanted an excuse to read a lot more about research across the whole of language acquisition. However, unfortunately, I discovered that there is too much for one person to know; there are too many published papers for any one person to read. So instead what I have done with this book is trying to give a flavor of what are the exciting questions, the exciting findings and what we still need to know about how children learn the most complex communication system in the known universe.

JGR: Talking about books, would you recommend a book for the readers?

CR: I'd recommend *Everything Your Baby Would Ask: If Only He or She Could Talk.* It's out of print but used copies are available. Annette Karmiloff-Smith was the first researcher to truly take seriously the fact that babies are constantly and continually learning and developing. If we are to have any chance of explaining child language development, we need to bear this in mind: a baby's knowledge of the world changes from minute to minute, as they learn more and more about the world in a continually-developing, dynamic spiral of learning and development. They're little everyday miracles.

JGR: Do you have a message you would like to share with the readers?

CR: My advice is going to be for parents. There is a lot of pressure to be the perfect parent. Don't worry too much about it. Enjoy being a parent and enjoy being with your children. Your children's brains are so flexible and adaptable that they will learn as long as you give them the opportunity to learn.

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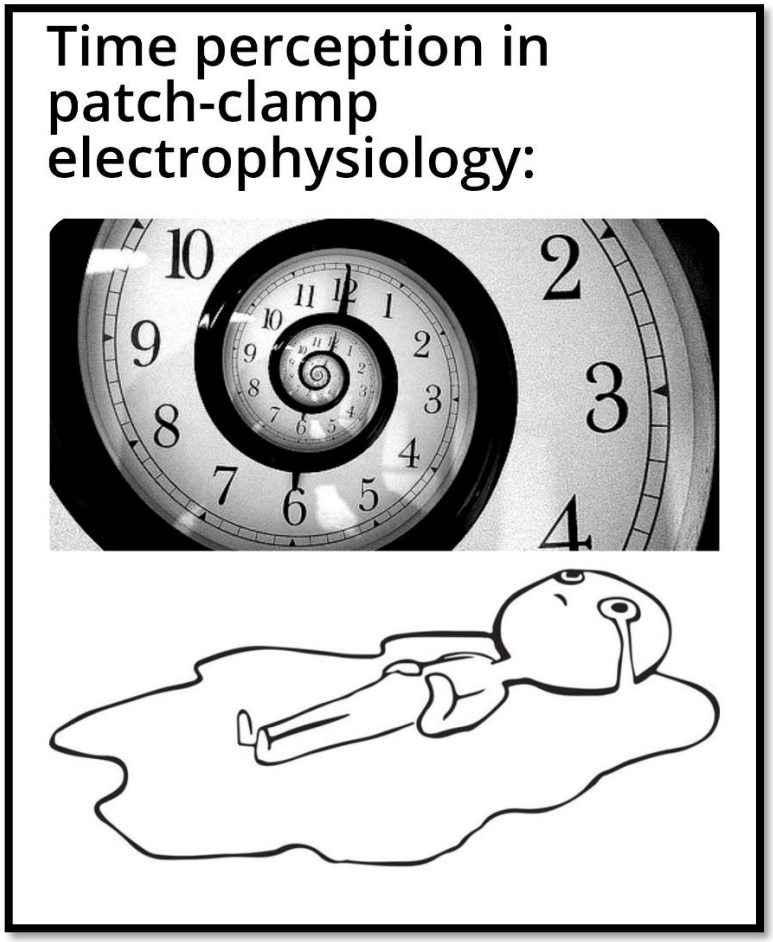
By Simon Lecomte



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