Do neuroscientists dream of electric fish?

In pursuit of a better understanding of how neural coding contributes to the detection and discrimination of sensory inputs, **Dr Gary Marsat**, Assistant Professor of Neuroscience at the Department of Biology in West Virginia University, is using electric fish as a model for sensory input coding. By describing how their evolved mechanisms are similar across species, and how these mechanisms transform the signals, he is helping to uncover the general principles underlying how sensory inputs guide complex behavioural responses.

Since childhood, Dr Gary Marsat has been fascinated with discovering how the world works. He describes his high school discovery of the study of the nervous system as "a subject of endless complexity" and something he would never get bored studying. As a researcher, he became particularly interested in describing how specific neurons transform the signal travelling along a pathway and how they influence other parts of the circuit. This formed the direction of his research career.

A CHILDHOOD DREAM

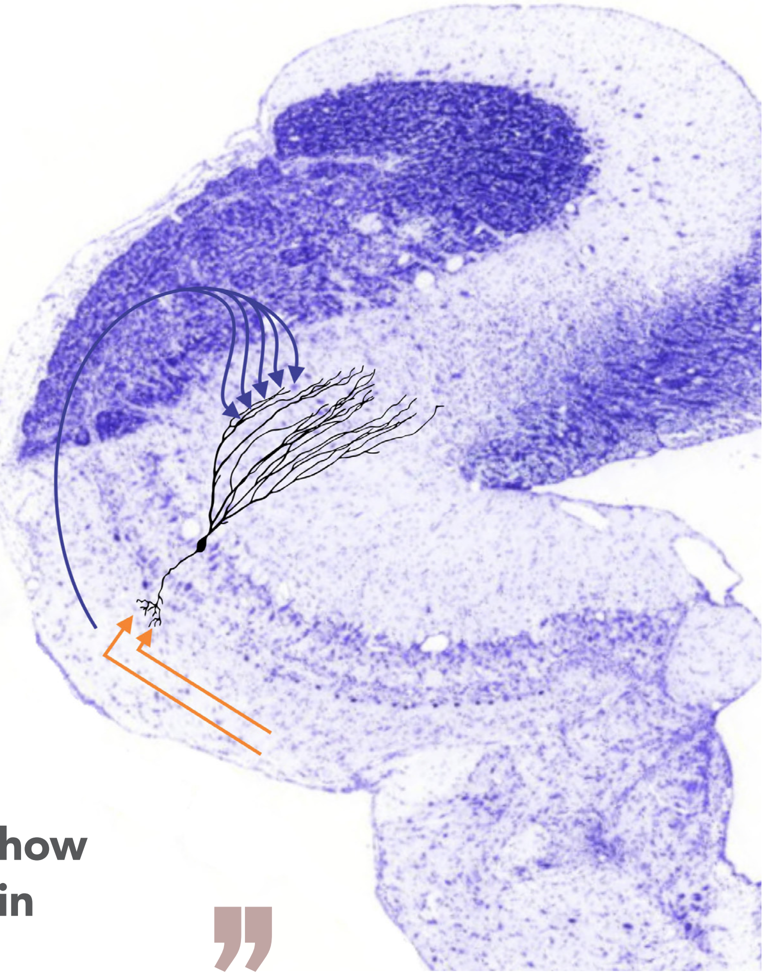
Early research in Dr Gerald Pollack's lab at McGill University in Canada, investigating how crickets detect and localise the mating calls of other crickets and the ultrasound sonar of preying bats, found that specific neurons were effectively 'tuned' to the different ranges of rhythms found in these stimuli. This allows for the rapid detection of (and hence a quick behavioural response to) danger signals, whilst allowing for finer discrimination of other inputs, such as the location of mating calls. Through this research experience, Dr Marsat could finely delineate a goal: cracking the neural codes.

LIVING THE DREAM

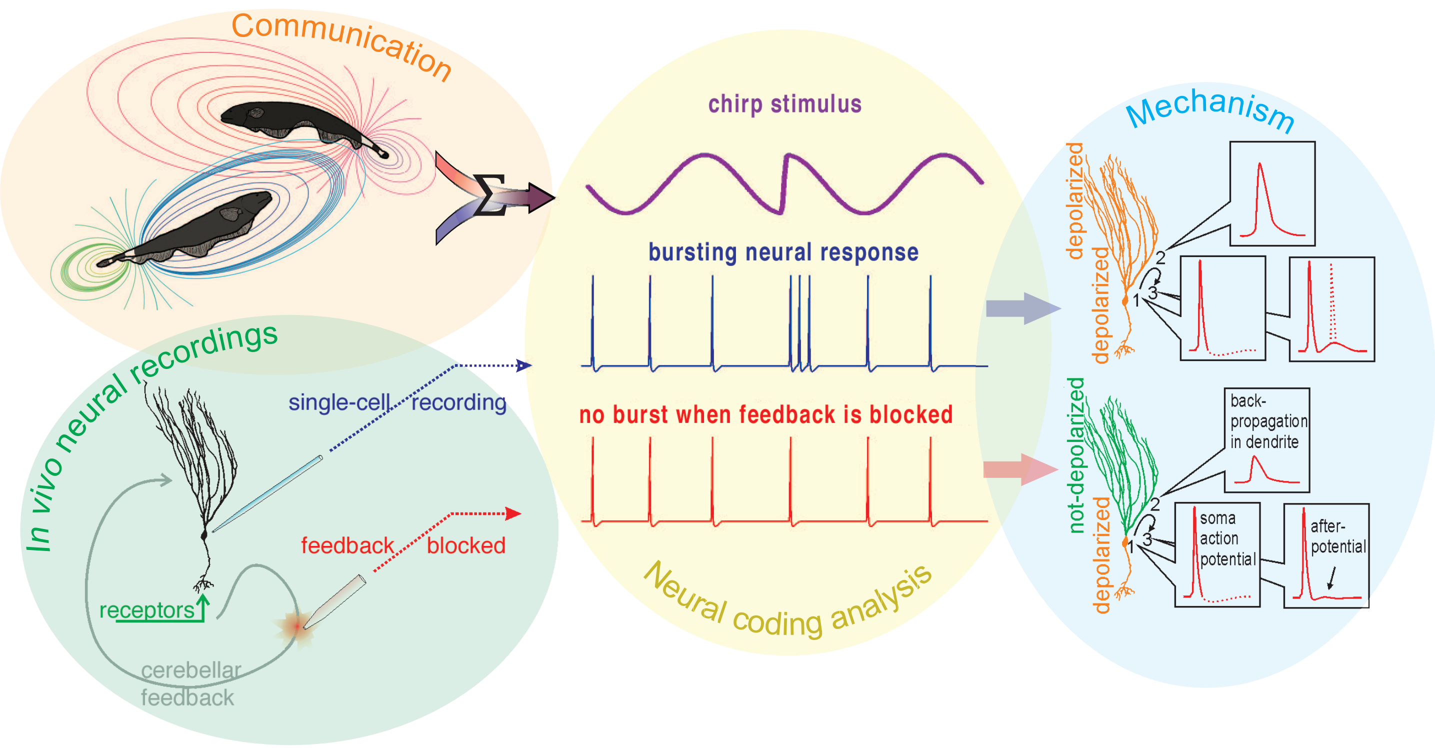
An important feature of the neural coding associated with behavioural responses is the 'bursts' of action potential (the rapid change in membrane potential of a neuron which generates a signal). These are only observed in response to predator signals in Dr Marsat's cricket research. From this, he was inspired to look for them in other sensory systems to understand what relates this neural code to the signal and behavioural task.

Recent research in electric fish had provided significant insight into how bursts are used. Bursts are an ideal neural code for detecting behaviourally urgent signals because they transmit, in a short time, a clear indication that an event happened. For Dr Marsat, this was a turning point in his research. He said: "The fact that these two widely different organisms used similar strategies to solve similar problems pushed me to continue seeking general principles underlying nervous systems." So, he traded his crickets for electric fish and never looked back.

Dr Marsat's research focuses on sensory processing, combining *in vivo* neural recordings, computational analyses and behavioural assays to uncover how sensory information is encoded in the nervous system, transformed at the different stages of processing and how the cellular and network properties shape these transformations. He uses the weakly electric fish (Gymnotiformes) as a model organism, whose electrosensory system is ideally suited to investigate how sensory information is processed in sensory systems. By investigating the various elements of sensory processing, from the cellular, structural and functional elements of neuronal populations to the relationship between neural codes and perceptual



Dr Marsat's research focuses on sensory processing, uncovering how sensory information is encoded in the nervous system



abilities, his group aims to understand how sensory information is acquired and packaged in a format that allows higher brain areas to make decisions and trigger behavioural responses.

STILL DREAMING

The lab is currently pursuing this research focus by comparing the signal processing mechanisms in several closely related species of electric fish; each species is subtly different in how their brains encode the chirps they use as communication signals. Using neurophysiological experiments, behavioural assays, and signal analysis, the team will seek to understand how brain mechanisms are optimised to these species-specific signal properties. They hypothesise that the structure of communication signals and the patterns of neural responses are matched efficiently enough to enable effective detection and discrimination.

So far, the team has discovered that different neural codes are used for communication signals based on the perceptual task they involve. Stereotyped strong responses across many neurons are observed in response to signals that are behaviourally detected, whereas graded and heterogeneous responses are used for signals in which the detailed features can be identified. Using a computational analysis of the information carried by the neural responses, Dr Marsat and his team determined the efficiency of these coding schemes.

The same neurons can switch back and forth between different coding strategies to match the perceptual demands of different tasks. Through a series of experimental and theoretical studies, Dr Marsat has identified a feedback pathway as one of the key mechanisms operating this change in neural coding properties. Furthermore, through an extensive literary analysis of the various sensory systems, he and his team realised that the same principles relating these coding schemes to perceptual tasks could be identified in a wide range of species.

A DREAM COME TRUE

From this, the group gathered strong evidence to suggest that neural codes were precisely matched and shaped to suit the signals and perceptual tasks. In order to prove that this match resulted from the evolutionary pressures shaping neural codes, Dr Marsat and his collaborator – Dr GT Smith of Indiana University – embarked on a comparative study; comparing closely related species could provide the same insight Charles Darwin found during his study of the shape of finches' beaks, relating form to function.

Dr Marsat believes that the different elements of the sensory system must co-evolve in line with the demands for communication within species. By analysing the signals, comparing the coding strategies and testing their influence on behaviour, the project links all of these strands together. This gives the project the potential to open a new direction in the study of the evolution of communication systems, revealing how the complex elements of species-specific signals and sensory systems are interlinked.

Dr Marsat's goal of improving neural code understanding can benefit technologies that interact in a sophisticated manner with the nervous system

Dr Marsat's dream of improving understanding of or 'cracking' neural codes has never been more relevant as in today's fast-paced technological world. Various technologies, such as new generation prosthetics, require communication with the nervous system and therefore an understanding of how nervous systems encode information is essential.

Not only that, but the use of electric fish, with their fascinating 'sixth sense', also gives the project an extra dimension and the ability to engage public interest. This unusual creature has the potential to shape future technology and inspire the next generation of neuroscientists, but for now, Dr Marsat and his group are showing just how much this humble organism can bestow on neuroscience today.

Q&A

What most fascinates you about neuroscience?

Besides the complexity of nervous systems that makes for a good challenge, neuroscience has this visceral pull on me because our neural system is what defines us as humans: not biological creatures, but minds capable of highly abstract thinking. It is what sustains and mediates the "self" with its personality, philosophies and a past made of memories. Yet, it is made of molecules. It is the true frontier between the material and the immaterial.

How did you come across the electric fish as a model for sensory processing?

As I finished my BSc and was looking for a neuroscience lab to pursue graduate studies, I did a research project in a neuroscience lab in my department, liked it, and continued in this lab for grad school. As I was doing my PhD project, an electric fish lab was publishing results that were strikingly similar to mine. Electric fish might seem like an eccentric model system to many but in fact it is a well-studied and convenient model system. Since my questions are system-independent, I jumped at the opportunity to pursue similar questions to ones asked during my PhD work.

Why not just use another sense such as vision or sound in mammalian models?

My key goal is not understanding any specific neural network. In fact, I don't really care that much about understanding how electric fish neurons work per se – I seek general principles. If everybody worked on mice, we would understand… mice. By studying a wide range of model systems, we can better understand the core principles common across species and across sensory modalities. Electric fish was simply a convenient system to ask the specific questions I had when I started and I now look for specific questions that are best answered in this system.

What is the relationship between bursts and chirps?

The specific type of chirps we are talking about here have a structure that makes them hard to discriminate but easy to detect and, behaviourally, we know the fish does not distinguish between different variants of these chirps. Therefore, the relationship we see, and that can be seen in many sensory systems using bursts, is that bursts are used for detecting signals in a very efficient way when fine discrimination is not crucial. For example, consonants elicit the same type of responses and we know that we perceive consonants categorically rather than finely discriminating them along a continuum. Vowels are not encoded and perceived the same way.

Which came first, the chirp or the means to detect it?

The capacity to detect electric field is a very ancient sense that far pre-dates the capacity to generate electric fields. For example, lampreys, sharks and platypus detect electric fields.

Detail

RESEARCH OBJECTIVES

Dr Marsat and his lab's research determines how sensory information is encoded in the nervous system, how it is transformed at the different stages of processing and how the cellular and network properties shape these transformations.

FUNDING

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COLLABORATORS

- Dr Gerald Troy Smith (Biology Dept, Indiana University)
- Dr Cheng Ly (Dept of Statistical Sciences and Operations Research, Virginia Commonwealth University)
- Dr Steve Kinsey (Psychology Dept, West Virginia University)
- Dr Andrew Dacks (Biology Dept, West Virginia University)

BIO

Dr Marsat received his BSc in Biology from McGill University in 2001, prior to studying a PhD there until 2007. He later became a postdoctoral fellow at the University of Ottawa before joining West Virginia University as an Assistant Professor in 2012. He has remained there ever since.

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