

# How we experience pain may unlock the mystery of consciousness

In a recent publication, Professor Richard Ambron of Columbia University in New York, USA, addresses the fascinating topic of consciousness. He reasons that if we can understand the consciousness of pain, we might better understand consciousness in general. He outlines the neurological systems involved in pain and theorises that the consciousness of pain arises through non-physical 'waves' known as local field potentials (LFPs). This, Ambron suggests, could be key to unlocking the nature of consciousness.

Have you ever found yourself pondering philosophical questions like, 'What is consciousness?' In its simplest form, consciousness is our awareness that we exist. But how do we become aware that we exist? The answer lies in solving the mind-body paradox, namely, how does consciousness, a property of our non-physical mind, emerge from the workings of our physical nervous system and brain? This question has puzzled philosophers and scientists for centuries but Emeritus Professor Richard Ambron, from Columbia University in New York, USA, believes that the solution to this mystery is to study how we experience pain. In a recent landmark paper published in *Neuroscience of*

*Consciousness*, Ambron shows how information in our physical nervous system is converted into non-physical electrical signals by a specialised group of neurons in the brain. Neurons are the cells that transmit information throughout the nervous system. He also believes that understanding pain will offer clues to the so-called 'binding/combination problem', which is to explain how inputs from each of our different senses are combined to form a concept of the world around us. Unlike most philosophical theories of consciousness, Ambron describes how his hypothesis can be tested and how it might be the beginning of the journey toward understanding consciousness.

## HOW AND WHY DO WE FEEL PAIN?

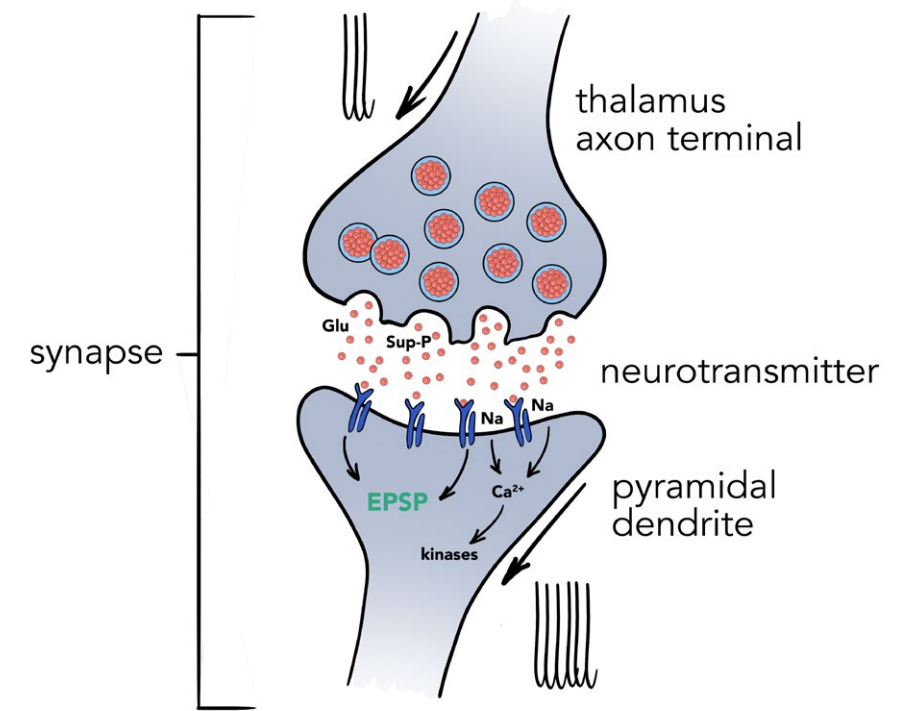
The feeling of pain is needed for survival because it teaches us from an early age about what is dangerous. When present, it receives priority over all other sensations, further indicating its importance to our survival. We already know a lot about pain in terms of understanding the neuronal pathways and processes involved. Pain starts at the site of injury where damaged cells release small molecular compounds that bind to the terminals of neurons in the periphery. The binding results in the generation of action potentials – sparks of electrical activity – that encode the information about the injury. The number and frequency of the action potentials indicate the severity of injury; the more action potentials, the more severe the

injury and the greater the intensity of the pain that will be experienced. The action potentials convey the information to neurons in the spinal cord which, in turn, pass the message to neurons in the thalamus. The thalamus is a collection of neurons located within the brain. It is via the activity of the thalamus that we first become aware that we are injured. Surprisingly, however, we do not experience the onerous or hurtful aspects of the injury. Rather, the suffering associated with the injury arises when the information from the thalamus is communicated to circuits elsewhere in the brain.

## THE BRAIN'S 'CENTRE OF PAIN'

The key region for experiencing the hurtfulness of pain is the anterior cingulate cortex (ACC). This region receives direct input from the thalamus and brain imaging shows an increase in the activity of the ACC in patients suffering from pain. Interestingly, it is not only physical pain that increases activity in the ACC; but also psychological pain, such as that from extreme grief. Thus, the ACC is involved in suffering from both physical and psychological causes. Action potentials from the thalamus that are conveying the information about pain activate a select group of neurons within the ACC that are organised into a complex neuronal circuit. Circuits are composed of several different types of neurons and their interconnections that are designed to process a specific type of information. The most important components of the ACC circuits involved in pain are the pyramidal neurons. The cell body of these neurons is triangular in shape that has a long dendrite with many branches that are vital to experiencing pain because they receive input from the thalamus. At the other end of the pyramidal cell body is an axon that transmits information to other areas of the brain (Figure 2A).

The axons of the thalamic neurons form what is known as a chemical synapse with the pyramidal dendrites (Figure 1). There is no direct contact between the axon and dendrite, but a narrow gap that is bridged by a small molecular neurotransmitter that is released when the action potentials reach the axonal endings. The neurotransmitter binds to the dendritic ending, resulting in action potentials in the pyramidal neurons and the initiation



**Figure 1.** An illustration of the synapse between an axon from the thalamus and a dendrite from a pyramidal neuron. Action potentials from the thalamus cause the release of neurotransmitter molecules and the activation of processes in the dendrite that induces a long-term potentiation.

of enzymatic events that have a profound effect on the transmission of information.

When there is prolonged activity at the synapse in response to a serious injury, the synapses become 'hyperresponsive' and strengthened. This strengthening, called long-term potentiation (LTP), sensitises the synapse so that it takes fewer action potentials to cause pain. This is why even a gentle touch to the

pain. In addition to housing circuits for pain, the ACC also contains circuits that are involved in attention, as well as circuits that receive information from other regions of the brain. For example, inputs from neurons in the amygdala can increase the intensity of the pain due to anxiety or fear, whereas those from the nucleus accumbens will reduce the pain if the reward for bearing the pain is considered worthwhile. Thus,

## How does consciousness, a property of our non-physical mind, emerge from the workings of our physical nervous system and brain?

site of an injury will hurt. Prolonged LTP causes adaptations in neural circuits and researchers believe that the occurrence of the LTP in the ACC might contribute to chronic pain. Interestingly, studies of chronic pain patients who learned to control the activity of the ACC found that when they purposely decreased activity in this region, they experienced less pain. Such studies add to the evidence that these centres in the ACC are needed for experiencing the consciousness of

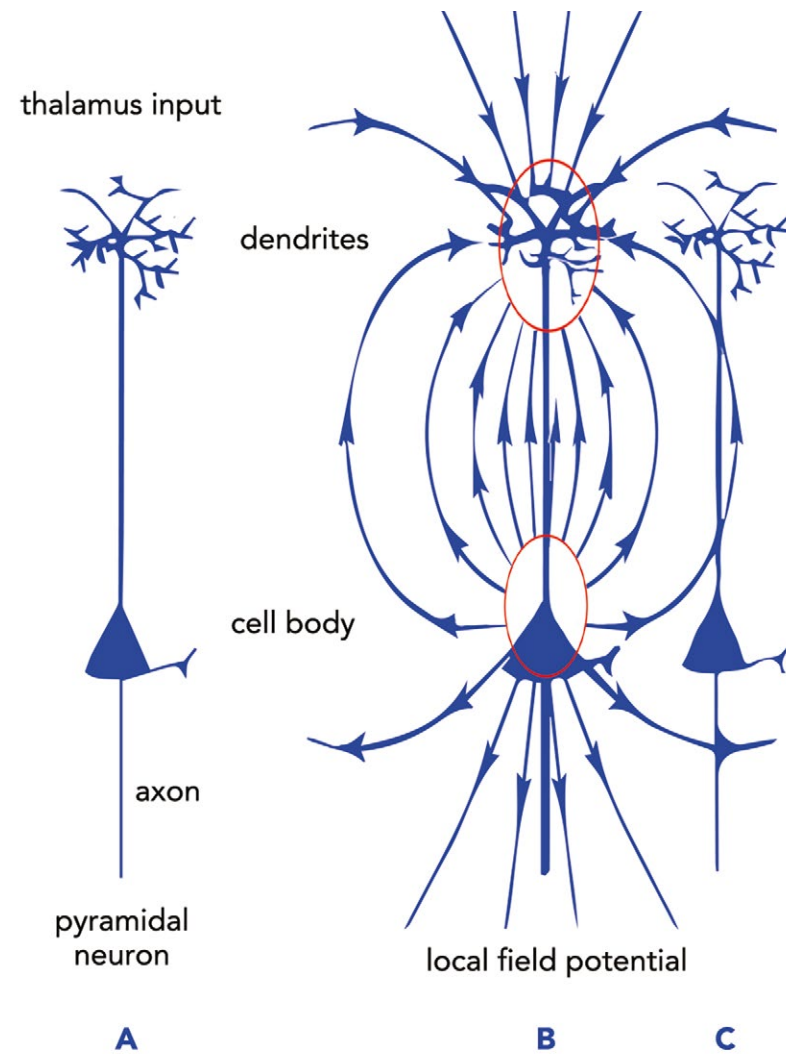
what we experience as pain depends on interactions between several areas of the brain. Ultimately, however it is the development of the LTP in the ACC that is most important.

## ARE LFPs THE ANSWER?

The induction of the LTP begins when action potentials from the thalamus arrive at the synapses with the pyramidal dendrites. This results in the release of the neurotransmitter, which crosses the gap to bind to receptors on the



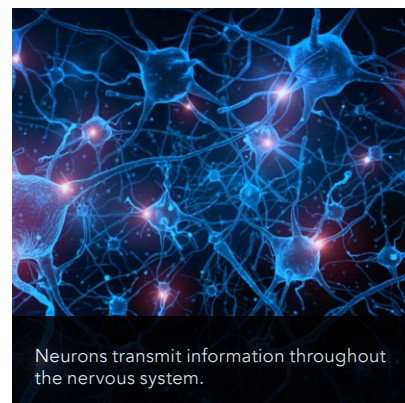




**Figure 2.** A) A single pyramidal neuron with extensive dendritic branches that contain synapses with thalamic axons. Injury-induced action potentials arriving at the synapses results in the movement of ions into and out of the neuron. B) The result is the generation of a local field potential (curved lines) shown super-imposed in the external space around the neuron. The movement of the ions creates waves that now contain the information about the injury that had been encoded in the action potentials. C) If the LFP is sufficiently strong, the waves can influence the activity of nearby pyramidal neurons, such as those that contribute to attention.

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dendrites (Figure 1). The binding causes an influx of negative ions into the dendritic terminals that are located far from the cell body (Figure 2A). To maintain electro-neutrality, there is an efflux of positive ions from the cell body that results in the formation of a local field potential (LFP) and the creation of electric waves in the space around the pyramidal neurons (Figure 2B). These waves now contain the information about the pain that was previously encoded in the action potentials.



In other words, the information was transferred from the physical brain to the non-physical waves. The waves generated by extreme pain could extend considerable distances and could influence the activity of nearby circuits, such as those for attention (Figure 2C). In addition, if information from our other senses is also transformed into waves, it would help answer the binding/combination problem because integrating the information from all the waves could create, in the words of Ambron, 'a unified, coherent version of the world.'

So how do we prove that LFPs are indeed needed for the consciousness of pain? Ambron proposes that two aspects of his theory require confirmation in experiments. The first is to show that following an injury, the LFPs arise from the pyramidal neurons. Since the generation of the LFPs depends on coordinated biochemical reactions in the pyramidal dendrites, the application of inhibitors that block these reactions should prevent the development of the pain. Second, is to show that the waves are necessary to experience pain and he details experiments in which blocking pain waves are delivered into the centre for pain. The outcome of these experiments will be highly anticipated. We are still learning about these centres, how they function individually, and how they are interconnected. If LFPs are proven to be necessary to experience pain, this could be an important key to unlocking the nature of consciousness.

Ambron is also exploring the role of electromagnetic (EM) waves as non-physical packets of information. EM waves also appear in the extracellular space around the pyramidal neurons after an injury. Currently unpublished, he proposes that, like the LFPs, the characteristics of EM waves specify information about their origins, and they too can affect neighbouring neurons and neural circuits. Could such EM waves also contribute to consciousness? Ambron believes this is an exciting area of research because these waves can exit the skull and travel in space, meaning that conceptually this information may be 'out there in the universe.' While currently speculative, such thought-provoking concepts offer clear insights into the mysterious realm of consciousness.



# Behind the Research

## Professor Richard Ambron

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### Research Objectives

Professor Ambron examines the neurological systems involved in pain.

### Detail

#### Bio

Richard Ambron, PhD is emeritus professor of cell biology, anatomy, and pathology at the Vagelos College of Physicians and Surgeons of Columbia University, where his laboratory identified a kinase that contributes to chronic pain. He was co-director of the Clinical Anatomy Course and was selected Teacher of the Year ten times.

### References

Ambron, R, (2023) Toward the unknown: consciousness and pain. *Neuroscience of Consciousness*, 1, niad002. [doi.org/10.1093/nc/niad002](https://doi.org/10.1093/nc/niad002)

Ambron, RT, Sinav, A, (2022) *The Brain and Pain; Breakthroughs in Neuroscience*. New York: Columbia University Press. [cup.columbia.edu/book/the-brain-and-pain/9780231204873](https://cup.columbia.edu/book/the-brain-and-pain/9780231204873)

### Personal Response

**You've clearly described how your hypotheses regarding the importance of LFPs in the consciousness of pain can be tested in mice. Will your laboratory be conducting these experiments and how else will you take this work forward?**

|| I am retired and no longer have a laboratory. I am hoping that publicising my findings will prompt other labs to carry out the proposed experiments and there are many groups that have the requisite expertise. ||

