Biologically Based:
Brain Rhythms and Biological Theories of Consciousness

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Abstract

Ned Block has suggested that brain rhythms driven by electrochemical processing may be necessary for consciousness, which would rule out AI and perhaps some invertebrates. I am sympathetic, and twenty years ago I argued that brain states are such rhythms against a chemical background. But the rhythms cannot be enough, since slow waves are prominent in deep sleep and under anesthesia, so a biological theory needs a role to say which wave-borne states are conscious. If the role fixes the reference of 'consciousness', the realizer should be described at the grain at which it explains the work the role picks out. I explore the hypothesis that this grain is neither a functional kind nor a physical essence but a medium-bound kind, a kind of mechanism together with the kind of medium it needs to run in. The argument for the medium comes from the work the fluid around neurons does and from what life requires of its liquid. On this grain insects plausibly meet the biological condition, and a machine with the role but not the biology would be a mind without experience. The claims about insects can be tested now, while the test that would distinguish this grain from a coarser one cannot be run yet, but we can say what it might take.

I. Introduction

In a commentary on Anil Seth's case for biological naturalism, Ned Block sketches what he calls a speculative argument against consciousness in AI, and perhaps in some invertebrates (Block 2026b; Seth 2026). "Brain waves driven by electrochemical processing," he writes, "may be necessary for consciousness." If so, no non-biological AI system is conscious, and if the waves consciousness depends on are the coherent, low-frequency, long-range waves that vertebrate brains produce, some invertebrates may not be conscious either.

I am sympathetic. I have defended higher-order theories (Brown 2025), but my sympathies have long been with biological views like Block's and I see no inherent contradiction between these approaches. Twenty years ago I argued that brain states are patterns of synchronized neural firing against a changing chemical background (Brown 2006), and later I suggested that phenomenal consciousness may be nothing but such patterns "against a dynamically changing chemical background" (Brown 2012, 211). Where Block and I come apart is over where the biological line falls, and why. We do not disagree on what kind of thing the realizer might be. I want to go a step beyond the claim that it is some kind of mechanism and say which kind, and why. A theory that starts from a role picks out the realizer of consciousness by what it does, and the realizer

should then be described at the grain at which it explains how that work gets done. The point is one of method, and in the case of consciousness it has surprising implications.

II. Rhythms Are Not Enough

Block's argument starts from the connectome. Most cortical synapses are too weak to bring the next neuron to threshold on their own, so firing depends on population-wide electrical waves, driven partly by ion fluctuations in the fluid around neurons. In Block's words, "These waves make up for the weakness of direct pairwise connections between neurons." He speculates that consciousness depends on electrochemical processing as the rhythms do, in us and then "tout court," which would rule out non-biological AI. His second speculation is that the rhythms depend on low-frequency oscillations, under 20 Hz, which spread over centimeters rather than micrometers and are more prominent in vertebrates than in many invertebrates. Low-frequency firing is affected by myelin, which oligodendrocytes modulate, and Block takes both to be unique to vertebrates (Block 2026b).

But rhythms show up on both sides of the line between conscious and unconscious states, so their presence cannot be what makes a state conscious. Block notes the problem himself. There are slow waves in NREM sleep and under anesthesia, though perhaps of more than one type (Block 2026b). Sorting slow waves into types relocates the problem, since we still have to say which type is required and why, and the answer will be what waves of that type do. 'The waves' covers at least three things. There are global slow oscillations that mark what I call a state of the brain (Brown 2006), rhythms that route content, and the faster synchronized activity that carries it. A biological theory has to say which of these consciousness requires, and lacking low-frequency waves would count against an animal only if they are needed for whatever does mark a state as conscious. That is a question about the role.

III. The Grain

So, a biological theory needs a way to specify what in the brain we are looking for. As I once put it, "uninterpreted brain data is meaningless and interpretation without brain data is blind" (Brown 2012, 211). We have to pick out the activity we care about by what it does, and then we find out what kind of thing does that. The structure is Lewis's (Lewis 1966), but I take the role description (given by a theory of consciousness) as fixing reference in Kripke's sense (Kripke 1980), not as an analysis of our concepts. On this reading, which parts from Lewis where he denies that 'pain' is rigid (see Block 2015), 'consciousness' refers to whatever kind plays the role in us, as 'water' refers to H_2O. That is a hypothesis, and semantic intuition will not settle it.[1]

[1] Block once called it "totally implausible to treat 'consciousness' as a rigid term for a physical essence along the lines of 'water'" (Block 2010), on the ground that we can still ask whether what it is like for Commander Data to

But Block's own argument takes a step of the same shape when it moves from what consciousness depends on in us to what it depends on "tout court," and he marks the step as a further speculation (Block 2026b). Mine is speculative in a similar way.

Block leaves open whether our consciousness "depends directly on the computational, on the subcomputational properties, or both," and his meat hypothesis is that it "does depend directly on the subcomputational properties, even if it also depends on the computational properties" (Block 2026a, 299). That is the hypothesis I explore, and my question is what kind of thing the subcomputational realizer is. Which theory specifies the role I also leave open. Any computational theory of consciousness, the higher-order theory I have developed included (Brown 2025; 2026), can be read in the reference-fixing way. The computational description picks out what does the work, and what it picks out need not be computational.

Whatever kind that is should be described at the grain that explains how the work gets done. Water is H_2O wherever it is found because the molecule is what explains what water does. Nothing finer, such as its isotopic makeup, and nothing coarser, such as being a clear liquid, explains it as well. So the question is which features of our brains explain the work, and which are the way a brain of a given size implements it.

There are three candidate grains. A functional kind is individuated by a pattern of causal relations among states, whatever produces the pattern. Money is the standard example, and computational kinds are the limiting case, where any medium with enough degrees of freedom will do (Piccinini 2015, 122). A physical essence is individuated by composition; nothing that is not H_2O is water. A mechanism is individuated by how it does its work, by the kinds of physical effect through which the pattern gets produced. It is finer than a function, since a carburetor and a fuel injector do the same job by different mechanisms, and coarser than a composition, since a titanium fuel injector and a steel one are the same mechanism (compare Polger and Shapiro 2016, 64).

The difference between the first and the third is the one that needs an argument. A causal role is fixed by the pattern alone, and a kind of physical effect is fixed also by which physical magnitudes do the causing. Kinds of the third sort are familiar. Sound is a pressure wave in an elastic medium. It is not a composition, since air, water or steel will carry it. It is not a role either, since a radio signal with the same waveform has the pattern and is not sound, and a role

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have 'pain' is like what we have when we are in pain. I agree that semantics cannot answer that question, and which identity holds is an empirical question. What makes the reading available is that a state and the feel by which we pick it out can come apart, as I have argued pain and painfulness do in dental fear and pain asymbolia (Brown 2010, 58–61). And the kind I go on to propose is not a physical essence. In the same exchange Block granted that the nature of a biological kind can in general be presumed to be functional, adding that consciousness "may be anomalous in this as in so many other respects." His recent work locates the anomaly in realizing mechanisms rather than in stuff (Block 2026a, 300), and so do I.

specified finely enough to rule the radio signal out has to mention pressure, at which point it is the mechanism under another name. The medium belongs to the kind, since its density and stiffness set the speed of the wave, though no particular medium does.

Call a kind of mechanism together with the kind of medium it needs to run in a medium-bound kind. The medium belongs to the kind when it carries part of the work. Cao's example is nitric oxide, which signals by diffusing freely across cell membranes (Cao 2022, 7–8). Diffusion is not something the medium permits; it is something the medium does, at a rate its properties set. No particular chemistry belongs to the kind, and here I follow Block. He suggests that fluctuations in the ions of the soup between neurons may be a mechanism of consciousness, and that the particular ions are not necessary, since "other ions could function in this way"; by a realizer he means "realizing mechanisms, not just material composition, not just realizing stuff" (Block 2026a, 300). So the medium enters through what it must do, which is to dissolve ions and let them move, carry diffusion, support chemical transmission and sustain the fields the activity generates, and not through what it is made of.

The nearest view on the other side is Cao's. She is a functionalist, though not a computational one, and she argues that the brain's functional organization, fully specified, is unlikely to be realizable in anything but biologically similar stuff, so that functionalism "is more like an iron cage" (Cao 2022, 25). A function specified that finely includes what the medium does, so she and I can agree on every actual case and differ only on why (compare Cao 2022, 26 n. 42). A functionalist of her kind can hold that a system that reproduced the function would be conscious, and her bet is that nothing non-biological can. Block separates two ways the biology could be required. Either there is only one way to implement the role and it requires the biology, which "is actually compatible with functionalism being true," or the biology is "the ground of the conscious qualities" (Block forthcoming, 347). Cao's view is of the first sort. On the view I am exploring, which is of the second, the function is how we find the kind, so a system that had the pattern by other means would have the role and lack the realizer.

Whether consciousness falls at this grain depends on how the work gets done in us, and here we can follow Block's own reasoning. On his account the rhythms are driven partly by ion fluctuations in the fluid around neurons. Earl Miller and colleagues, who argue that consciousness depends on the organization of the waves, add that the fields the activity generates feed back on spiking (Miller, Brincat, and Roy 2026). There is evidence of both in the mammalian cortex. Neuromodulators shift the ions of the fluid around neurons, and in sleeping mice a change in that ion mix is enough to convert local cortical activity to the waking pattern (Ding et al. 2016). Imposed fields no stronger than those the activity itself generates shift the timing of spikes in slices of rat cortex (Anastassiou et al. 2011) and in awake monkeys (Krause et al. 2022).

These results suggest that the chemical background I located in the neuromodulators in 2006 works partly through the ions of the fluid. The more one studies neurons the larger the role of ions seems to become. In addition, the fluid does some of the work itself. It helps hold the brain in the state in which the role can be played, as a variable the brain sets and not a supply like oxygen, and it carries part of the coupling that coordinates the activity. The medium is in the kind only because it does this work. If it turned out to do none, with the wave pattern doing all of it however the pattern is produced, I would drop it, and what remains is the claim that it is some kind of mechanism.

That is a live possibility, and these results do not tell against it. In each the medium acts by changing the pattern of activity, and a view on which only the pattern counts predicts that too. Miller and colleagues conclude from anesthesia, where agents with different molecular targets have similar large-scale electrical effects on the cortex, that "consciousness depends less on specific receptors or cell types and more on the integrity of large-scale wave organization." They do not ask whether a machine could be conscious, but their view points to a coarser grain than mine, wave organization in any medium that can carry it, liquid or not, and the argument for it has the same form as mine about the ions, that what can vary while the work goes on in the same way is not part of the kind. What would decide between the two grains is a manipulation that alters the medium, the mix of its ions for instance, while the measured organization stays in place, with subjects' reports as the measure. If reports change, the medium does work that the wave pattern does not capture, though a functionalist of Cao's kind could say that the organization that counts is finer than the one measured, so the test bears on where the line falls more directly than on why. If nothing changes unless the organization does, the coarser grain is right. A chemistry that no other ion or molecule could replace would push the other way, toward composition.

No experiment I know of alters the medium while holding the organization in place. A change in the ion mix or an imposed field works by changing the pattern, so the pattern would have to be put back by another route while the medium stayed altered, in a subject who can report, and I do not see how to run that test in us yet. A first step like that could possibly be taken in animals. We know that in monkeys held under anesthesia, stimulating the thalamus partly restores wake-like cortical activity and signs of arousal (Redinbaugh et al. 2020; Bastos et al. 2021), but the ions were not measured. If they stay where the anesthetic put them, what comes back does so without them, which would count for the coarser grain; if they move back with the pattern, nothing is settled.

IV. What Life Requires

Still, isn't all of this a careful balancing act just so we can choose something to keep computer chips out? I do not think so. There is a principled argument for the position, and it comes from what life requires. It runs from life to the liquid it needs, and from that liquid to the kind of mechanism just described. Life seems to need a liquid for its chemistry, and one recent survey finds that only protonating liquids, those whose molecules have protons to hand over, meet all of the chemical requirements, and that of these only water and concentrated sulfuric acid are likely to be abundant on rocky planets (Bains, Petkowski, and Seager 2024). Even in the acid, nineteen of the twenty biogenic amino acids are unreactive or modified only in their side chains after four weeks (Seager et al. 2024). Both liquids are strongly polar as well, and a liquid that is both pulls salts apart into ions and keeps them apart. A large dipole moment is not enough. Acetone has a larger dipole moment than water (Rumble 2023) and is a poor solvent for most salts, because it has no proton to offer an anion in a hydrogen bond and it screens the charge between ions less well. Methanol does have such a proton and would do the jobs, though less well than water. The survey sets it aside because it would not accumulate on a rocky planet, not because of what it can do (Bains, Petkowski, and Seager 2024, sec. 3.11). So the liquids that life can use are liquids that can also do the jobs the mechanism needs.

Life puts its liquid to that use from the start. Every known cell holds an ion gradient across a membrane, most use it to make ATP (Lane 2015), and most of the energy the brain's gray matter uses goes to pumps that restore the ion gradients that signaling runs down (Attwell and Laughlin 2001). A nervous system is that machinery put to work for coordination, so wherever life builds a nervous system the medium is already in place. The biological condition could also be met by an engineered system in which the right dynamics run in the right medium, such as memristive devices whose signals are carried by ions in fluid-filled channels (Kamsma et al. 2024; compare Godfrey-Smith 2026 on hardware with something like cell membranes). It is not met by a digital computer, which is engineered so that what it computes does not depend on the physics of its parts. 'Biological' is shorthand for a medium-bound kind in life's kind of medium, not for being alive. All of this is an induction about life, and the step to consciousness has to be taken in us.

V. Insects

Block has said that focusing on the realizer rather than the role "favors consciousness in simple animals" (Block 2026a, 302). His second speculation would take some of that back, for animals without the coherent low-frequency waves of vertebrate brains. Asking which features explain the work gives a different verdict. On Block's own account the waves make up for weak synapses. Their reach is a fact about large brains. Across mammals, brain volume varies some 17,000-fold while the hierarchy of rhythms stays much the same, and what keeps the timing in

larger brains, Buzsáki, Logothetis, and Singer (2013) argue, is large-caliber, myelinated, long-range axons. So long reach and myelin are how a large brain implements the rhythms, not part of what makes them work. Nor is myelin a vertebrate specialty. Myelin-like sheaths evolved independently in annelids and some crustaceans, and lampreys and hagfish, which are vertebrates, have none (Hartline and Colman 2007).

On Block's own earlier account the core neural basis of at least one kind of visual experience is a recurrent loop between visual areas (Block 2007), and the size of the brain sets how far such a loop has to reach. A honeybee brain is about a cubic millimeter (Menzel and Giurfa 2001), and its rhythms do the same kind of work in the same kind of medium. Blocking odor-evoked synchronization impairs a bee's discrimination of similar odors (Stopfer et al. 1997), and a spontaneous oscillation at about 18 Hz biases the timing of spikes within and between the hemispheres of the bee brain (Popov and Szyszka 2020). Godfrey-Smith (2024) argues on comparative grounds that large-scale dynamic patterns of the kind linked to experience in us are conserved across arthropods, cephalopods and vertebrates.

One might reply that the dependence of neurons on population activity is itself the mark of the kind. In cortex, firing "depends on the joint action of populations of neurons," whereas there is "a tendency in invertebrates towards synapses that are stronger because axons link to only a few dendrites or even one dendrite" (Block 2026b, text and Figure 1; see also Block 2026a, 305).

It is not clear that this is true for insects. There is some evidence that insects have these properties as well. In the locust, each Kenyon cell of the mushroom body is contacted by about half of the 830 projection neurons, each input is worth on average less than a tenth of a millivolt, and about a hundred must arrive together to fire the cell (Jortner, Farivar, and Laurent 2007). The inputs arrive together because oscillations synchronize them (Perez-Orive et al. 2002). In the fruit fly a Kenyon cell has only a handful of inputs and still spikes only when several are active together (Gruntman and Turner 2013). So the difference is not in the mechanism, and it is not reliably in the numbers either. How many inputs a neuron needs is a parameter of size and circuit, not a mark of the kind.

So insects plausibly meet the biological condition. That is not yet a reason to think them conscious, since rhythms contribute to unconscious processing too. A positive reason has to come from the role and the jury is out on that question.

VI. Minds Without the Biology

Suppose AI systems lack the biology. Then on the hypothesis I explore they are not phenomenally conscious.[2] They would have fool's consciousness, as XYZ is fool's water. That is not the end of the story for AI, though. If a system can fill the role without the realizer, it is not an imitator. Its states do the work the role picks out, without what makes that work phenomenally conscious in us. If it also represents itself as having experiences, using concepts it learned from us, that representation is false, and illusionism would be the right account of it, though not of us (Brown 2026).

Whether the biology makes a difference has to be settled in us first, since we are where the role and the reports come together. Markers in a machine cannot settle it. A system that only computed the pattern would show the markers of consciousness either way, because the markers come with the role. Block's question, whether a sophisticated organic creature with only electrical synapses would show markers of consciousness (Block 2026a, 306), is a different kind of case and the right kind of next step. Such a creature varies one part of the biology and keeps the rest, so the question is whether chemical transmission belongs to the kind or is one more way of implementing it. And if wave organization rather than the medium turns out to do the work, the line would fall between systems organized by physical waves in a medium and systems that compute digitally. Current AI is on the second side, though some future analog hardware might not be.

VII. Conclusion

Block and I agree that consciousness may well depend on something biological, and that rhythmic activity in an electrochemical medium is the best candidate. We part over where the biological line falls, and why. On the grain I have explored, a kind of mechanism in the kind of medium it needs, insects plausibly meet the biological condition, and a machine with the role but not the biology would be a mind without experience. All of this is speculative, as Block says of his own view, and I still split my credence between a biological and a functionalist reading of the role (Brown 2025, 48; 2026, §VIII).[3]

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[2] Chalmers's fading and dancing qualia arguments say otherwise (Chalmers 1995). I argue elsewhere that results on change blindness and subjective inflation make their consequences less bizarre than they seem from the armchair (Brown manuscript).

[3] This paper benefited from drafting, editing, suggestions, and discussion with Claude.

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