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Growing Evidence that Perceptual Qualia are Neuroelectrical Not Computational

Abstract: *Computational neuroscience attributes coloured areas and other perceptual qualia to calculations that are (as recently argued) realizable in multiple cellular forms. This faces serious issues in explaining how the various qualia arise and how they bind to form overall perceptions. Qualia may instead be neuroelectrical. Growing evidence indicates that (1) perceptions correlate with neuroelectrical activity spotted by locally activated EEGs, (2) the different qualia correlate with the different electrochemistries of unique detector cells, (3) a unified neural-electromagnetic field binds this activity to form overall perceptions, and (4) this field interacts with sensory circuits to help attentively guide perception. The coloured areas in images may thus be seated in the electrochemistry of unique cells, while constancy mechanisms and other multiply realizable computations just help refine these images behind the scenes. This theory is ultimately testable.*

1. Computationalist Approaches to Minds

Classical computationalism claims that minds are abstract computing systems realized in diverse ways. The mind does not just resemble a computing system — it literally is an abstract computing system that is realizable in multiple hardwares (Rescorla, 2015).

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Inspired by the computer revolution, computationalism's seminal ideas — including that computers can think and neural connections can be modelled computationally — were developed by Turing (1936), McCulloch and Pitts (1943), Newell and Simon (1956), and many others. Computationalists have long disagreed about what computations are, yet examples are the operations of modern computers, neural networks, and Turing machines (theoretical machines using a table of rules to manipulate symbols on a tape). They also disagree about how computational, psychological, and neural views of mental activity are related.

By the 1960s, computationalism was replacing behaviourism, which proposed that science study overt behaviour and explain it via stimulus–response chains. Computationalists turned from overt behaviour to inner representations (thoughts, percepts, etc.). This paralleled functionalism's rise in the 1970s, where pain, for example, was characterized in terms of its causes and effects, both overt and internal. Pain's substrate was this causal structure, which is abstracted from the multiple hardwares that realize it.

Most computationalists also adopted multiple realization. Their mind-as-computer view thus rejected mind-as-brain views of the 1950s, which identified pains with neural pain-detector activity. Arguably, such identities are improbable, for they must hold across all species in evolutionary history (Putnam, 1967). Many others later argued that mental tasks can be executed by multiple brain structures due to neural plasticity in learning or injury. Yet multiple realization has not gone unchallenged (see §5.3 below).

Another argument supporting mind-as-computer over mind-as-brain views was that no pictorial images are found in brains, so images cannot be neural events. Images must by default be encoded in information non-pictorially (Sperry, 1952). Again, this has been challenged (§5).

Computational neuroscience (CNS) sticks to computations in neural systems. It explains consciousness in terms of global workspace and integrated information, for example.[1] This paper focuses on CNS's

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[1]   Examples of Tononi's integrated information account appear below. Examples of other accounts are the many works tied to Llinás's thalamic hub (Llinás *et al.*, 1998), Edelman and Tononi's dynamic core (2000), Varela's brainweb (Varela, Lachaux and Martinerie, 2001), and Dehaene's neural accounts of global access (Dehaene, Changeux and Naccache, 2011). Despite their differences, this latter group of authors relies on

empirical issues with perceptual qualia. These qualia are the pains, colours, odours, tastes, sounds, and other qualities in our sensory experience. One's qualia are inaccessible to other people (private) and they involve a point of view (subjectivity). They are unified in that various qualia can be experienced together as a whole, as when sipping a cappuccino. CNS's main empirical issues here concern how it encodes these various qualia and their unification (binding) into overall percepts.

CNS has other issues too. To start with, its total focus on neural versus computer science may seem contrary to multiple realization. But arguments by Aizawa and Gillett (2009) show that CNS and multiple realization aren't easily separable, for multiple cells often perform the same neural operation. Since realizing the same sensory computation in multiple hardwares thereby abstracts it from the hardwares, non-empirical issues arise concerning how sensory experiences are abstract computations, and how percepts are related to brains (weaker claims that abstract computations and perceptions are similar, not identical, face the latter issue).

This paper shows how a neuroelectrical approach may avoid these computational issues.

2. Neuroelectrical Approaches to Minds

Neuroelectrical approaches to minds appear in the numerous works of Kohler, Libet, Popper, Lindahl, Århem, Charman, Pockett, John, McFadden, Fingelkurts, Maxwell, and Jones (bibliographies appear in Jones, 2013). These authors seat minds in the electromagnetic (EM) fields generated by neural impulses. These electrical currents cascade along membrane channels in neurons' axons, then initiate synaptic signals to other neurons. The former come in bursts that make field strengths oscillate. Fields are strong locally, near these currents, but weaken with distance exponentially.

Intriguingly, these fields resemble visual images. Images pictorially resemble electrical activities in retinas — and in brain areas mapped onto retinas. Also, both images and fields seem incorporeal. Further, both arguably arise from discrete neurons and reach across space in a continuous, unified form.

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synchronous binding, often with feedback loops from higher cortex, and often on behalf of a global workspace.

A prominent example of field theories of mind is McFadden's panpsychist view that information is conscious at all levels (2002). The discrete consciousness of fundamental particles is isolated and limited. However, as neural particles unite in a field they create a unified field consciousness across the brain. When these global fields affect motor neurons, the brain's consciousness is no longer epiphenomenal, for the field can communicate with the world. This access consciousness resembles Baars' (1988) global workspace, where specialized processors compete for access to global, conscious processing (McFadden, 2006).

As this last level stipulates, there is recent evidence that the fields generated by neurons can affect the firing of other neurons and help guide brain activities (Anastassiou and Koch, 2015; McFadden 2013). Field–nerve interactions occur largely when fields are strong due to synchronized firing in regularly aligned nerves, or when nerves are myelinated and bent relative to field isopotentials (McFadden, 2002). This affects neurons poised near firing thresholds, which proliferate when we're undecided (McFadden, 2006).

Many other field theories are reviewed in Jones (2013). My own field theory adopts their idea that minds are seated in neural EM fields. It parallels Lindahl and Århem's (2016) dualist field theory (which is the culmination of classical field theory). They offer a sophisticated dualist defence of mind–brain interaction. Similarly, my theory adopts mind–brain interaction and non-reductionism. But its materialism lacks dualism's transcendent minds (see §3).

My field theory, which adopts Bertrand Russell's realism below, is called 'realist field theory' (RFT). RFT differs from most other field theories mainly in that it avoids their claims that the mind's unity comes from global fields pervading large brain areas, and that minds are seated in information carried by these global fields. These global, computationalist field theories face two problems which RFT will try to avoid.

First, why don't strong external fields from MRIs and other sources unify experience between brains? After all, external fields from transcranial magnetic stimulation affect neural activity. Global field theories offer various replies, but these still raise serious questions (see Jones, 2013, §5). RFT will offer a clearer reply below in which highly localized EM fields unify consciousness along each brain's circuits, while fields between brains are far too weak to unify their consciousness. These local fields don't pervade brains like global fields — they're confined along the membrane currents of neuronal

circuits. They reach along these circuits to unify consciousness across the brain.

   Second, how are visual images created? Based on extensive EEG studies such as Freeman (1991), Pockett (2000) argues that neural fields create unique spatio-temporal patterns that correlate with the various qualia. But if the field's spatial patterns are used to specify the colours in visual images, then what is left to specify the colours' spatial locations in the images? This is part of the larger problem of how non-pictorial computations yield pictorial images. RFT will offer a non-computationalist account of pictorial images. It accepts that brains are massively computational, but adds that perceptual qualia, such as the coloured areas in images, are seated in arrays of unique neuroelectrochemical substances, while constancy mechanisms and other multiply realizable computations just help refine these images behind the scenes.[2]

3. Avoiding Computationalist
Issues with Perceptual Qualia

CNS faces various kinds of issues in explaining perceptual qualia. For example, how do circuits process colours and their shapes, how do both bind together, and how does this processing yield actual qualia such as conscious red spots? The paper argues that RFT avoids these binding, qualia, shape, and consciousness issues. How it avoids each issue is briefly sketched here in §3, then fully explained in §§4–7.

3.1. Binding

RFT may explain unified experience without neuroscience's issues. For example, it is often assumed that unified, conscious images appear once computations by colour and shape circuits bind into an integrated form. Yet these circuits do not synapse or synchronize systematically, even via feedbacks. So how is binding encoded? RFT will instead draw on evidence that images correlate with electrical activity revealed by local EEGs. Unlike computations, this field is a

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[2] RFT avoids a third problem often directed at field theories, namely that visual images cannot be neural fields because experiments have shown that test animals could still run mazes after mica inserts blocked cortical fields. RFT attributes images to *localized* fields, so that these inserts create local blind spots yet do not block overall images. Also, maze learning uses many sensorimotor abilities. If one is impeded, others are used instead.

continuous, unified substance that can bind circuits across space. The field is continuous in that quanta in a strong field form a probability cloud of continuously high energy. Such a field could thus bind the minimal consciousness in cells to form overall perceptions. As this flux density wanes, field continuity and conscious unity deteriorate, and percepts dissolve (see §4).

3.2. Qualia

RFT may explain qualia without neuroscience's difficulty in explaining why qualia are experienced so differently but processed so similarly. Neuroscientists also create difficulty by encoding qualia in global, integrated cortical information, for this conflicts with evidence that qualia appear at lower levels in preattentive images. RFT will instead draw on growing evidence that different qualia come from different sensory-detector electrochemistries. Qualia will be attributed to these specific electrochemical substances, not multiply realizable computations (§5).

3.3. Shapes

RFT may explain the shapes that qualia exhibit in images without neuroscience's issues. For example, neuroscientists often assume that integrated shapes appear when high-level detectors have sufficient information to decide which objects are present. While such detectors do attentively monitor objects, none monitor the entire visual scene — which is often preattentive — to decide what shapes are present altogether. So how do we see entire scenes? RFT will try to show how images can arise in pictorial form from electrical activity in neural maps without need for computationalism's problematic spatial codes (§6).

3.4. Consciousness

CNS faces issues in explaining not only how qualia, their shapes, and their binding are encoded, but also in how these abstract codes yield the conscious areas of colour in pictorial images. RFT may avoid this mind–brain issue by using realist ideas from well-known philosophers such as Locke, Russell, and Strawson. In their realism, we access our own consciousness directly, yet we access matter indirectly through instruments, reflected light, eyes, etc. Here, matter exists beyond what

we observe of it, yet we cannot know its underlying nature beyond its sensory appearances.

Russell (1927/1954) further argued that, since we cannot access what brain matter is really like apart from our perception of it, our consciousness could, for all we actually know, be this underlying reality of our brain matter.[3] We just see this conscious substance as grey matter because of the light reflected from it into our eyes. Similarly, Strawson (2016) added that the underlying reality of all matter-energy could conceivably be consciousness (which would posit an identity between consciousness and matter-energy, or between qualia and neural events).[4]

This theory is thus exceedingly simple. Sceptics cannot reject it as inconceivable, for (as Russell noted above) they have no way of knowing underlying reality's true nature. Strawson's realism is well-known in neurophilosophy. It is arguably materialist, for consciousness is the real nature of matter-energy. It may avoid reductionist and other mind–brain issues facing CNS (§7).

These binding, qualia, shape, and consciousness issues will now be covered in greater detail, starting with binding.

4. Binding

4.1. Neuroelectrical binding

How do anatomically separate neural processes produce unified sensory representations in brains? How do these representations yield the unified, conscious perceptions we experience? Not all neuro-scientists address both topics (Revonsuo, 1999). But fully explaining perception involves both, so both are addressed below. A key issue is that colour, shape, and motion pathways operate separately and lack systematic synaptic connections (Zeki, 1993, p. 115). So how do

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[3]   This contrast between observable matter and its underlying reality is not dualist, for only the underlying matter is real. Observations of matter are just appearances in our perceptions.

[4]   Here consciousness is arguably the underlying substance of the universe (the stuff the universe fundamentally consists of). For example, pain is electrochemical activity that occupies space and exerts forces that EEGs detect. Physicists cannot object, for they depict this electrical activity by its observable effects on charges, so its underlying nature — which actually moves the charges — is up for grabs. (EM, gravitational, nuclear, and Higgs fields can thus be consciousness that deflects particles in these fields. The charge, mass, etc. from these fields are properties of consciousness.)

unified conscious images arise? Also 'there is no single cortical area to which all other cortical areas report exclusively, either in the visual or in any other system' (*ibid.*, p. 296). So how do perception, thought, and emotion bind to form overall experience?

This binding problem in CNS may be dealt with by RFT. When the neural EM field is strong and localized, it is a continuous, unified substance, as explained above. It can thus reach along pathways, and even across nearby pathways, to bind colour and shape features, and thereby form unified percepts. For example, visual cells activated by a spot of moving long-wavelength light could be united in a neural EM field to form an image of a moving red spot. (This principle also applies to uniting areas for perception, emotion, and thought into a single consciousness.)

This view aligns with various lines of evidence cited below, including long-standing evidence that perceptions correlate well with EM activity tracked by local EEGs. This view is also ultimately testable and has been partly verified (§5.3). While it is partly speculative, it is no more so than existing binding theories — whose problems it avoids.

4.2. Avoiding issues

Three alternatives to this RFT approach are listed below. These three standard binding accounts address Zeki's challenges too. But they raise issues that RFT avoids (for fuller versions of all this, see Jones, 2017).

(1) One standard account of binding argues that Zeki ignores how feedbacks from higher cortex into lower cortical maps can indirectly bind colour and shape (e.g. Kawato, 1997). But to encode detailed images, feedbacks must systematically connect shape and colour features point by point all across lower cortex — a daunting task indeed. In contrast, fields can bind features simply by (for example) reaching between them when they are nearby, as in the primary visual cortex (V1).

(2) In another standard account, synchronized firing of sensory cells binds them into a unified, conscious form (e.g. Gray and Singer, 1989). But this binding code has well-known issues. Binding can occur without synchrony, and synchrony can occur without binding or conscious unity during seizures, anaesthetized states, and NREM sleep (Koch *et al.*, 2016). By contrast, locally activated EEGs (which detect localized EM fields) track perceptions much better than synchrony

(*ibid.*). This supports claims that it is local EM fields that bind per-
cepts together.

RFT can avoid synchrony's issues above by explaining the merely
partial correlation between synchrony, binding, and consciousness as
follows: (a) EM fields can bind neuronal activity while synchrony just
plays an indirect role by reinforcing neuronal fields, that is, by making
peaks and valleys in field oscillations align (McFadden, 2013;
Fingelkurts, Fingelkurts and Neves, 2010); (b) binding can occur in
RFT even if pathways are not fully synchronized, so long as fields are
strong (for example, where colour and shape pathways are nearby in
cortical maps); (c) RFT explains why unified consciousness is lacking
during seizures, anaesthesia, and NREM sleep. Fields cannot bind
sensory features in these hypersynchronous events. The cortex fires in
a jumble and the long pauses between firings disrupt the continuity of
conscious fields.

(3) In another standard account, focal attention binds perceptual
features into a unified, conscious object, as when we suddenly spot a
friend in a crowd (Crick and Koch, 2003). But binding can occur
without attention. Subjects report mistaken combinations of colour
and shape in objects if their attention is diverted — and this involves
binding, despite the mistakes (LaRock, 2007). Further experimental
evidence for preattentive awareness appears in Tsuchiya and Koch
(2008). For example, Fei-Fei *et al.* (2007) found that subjects can
glean the gists of scenes that are flashed too fast for attentive
scanning. Even ordinary experience shows that we are not unaware of
surrounding people while focusing attention on a friend. Nor are we
unaware of coloured shapes while staring without focus or attention at
scenes during fatigue. All this offers evidence that *we can pre-
attentively experience images with coloured shapes*.

RFT thus ends up with two binding levels. (a) *Raw images* arise as
visual feedbacks from higher, attentive levels of the cortex create
strong firing in lower-level cortical maps. This reinforces fields and
binds sensory detectors to form the raw coloured shapes of iconic
memory (*cf.* Lamme, 2004). The evidence above indicates that raw
images may even arise preattentively without this feedback.
(b) *Refined images* arise at higher, attentive levels as strong fields in
synchronized activity create working memory. Here, iconic images of
a face bind to memories by triggering top-level detectors in the
posterior cortex (*cf.* Koch *et al.*, 2016). This electrically activates
memory traces of a friend's face. Here, lower cortical fields extend
into higher cortex and limbic areas.

Computationalists might reply that while fields may explain binding, they can be cast into computational form. Here matter and fields are just the abstract computations of physics. But this pancomputationalism cannot easily get from abstract mathematical fields to *fields as continuous substances binding circuits across space*. Computationalists can use reduction, realization, or grounding here to give abstract fields this substance. But these ideas raise obscurities that imperil computationalism's intelligibility (Jones, 2016a). Moreover, the computations are superfluous in explaining binding, for it is the field's continuous substance that does all the actual work. *So RFT isn't compatible with computationalism*.

Computationalists might instead follow McFadden (2013) and attribute the neural field's unifying powers to its ability to reach with no time lag across circuits and bind information into a single consciousness akin to a dimensionless point. Yet this notable account of field unity presupposes that the field is also unified as a continuous, unified substance (as above). For if this continuity is blocked, the field can no longer unify anything.

4.3. Evidence

Additional forms of binding are addressed below. But the overall point is that the neural field (unlike computations) is a continuous, unified substance that can bind circuits across space. So RFT arguably explains binding while CNS's problematic codes fail to. RFT is supported here by evidence against other binding theories (§4), by EEG evidence that percepts correlate with neuroelectrical activity (§4), and by arguments that only strong, local fields along neural circuits have unifying powers (§2, §4).

Other aspects of RFT are also backed by evidence. For example, there is evidence that different qualia come not from multiply realizable computations, but from different sensory-detector electrochemistries in neural hardware (§5).

RFT is further supported by evidence that the effects of EM fields go beyond binding and qualia, to the actual shifting of attention and guiding of sensory activity. To start with, not only does synchrony reinforce neurons' EM fields (as explained above), but also these synchronized fields make other neurons fire synchronously (Anastassiou and Koch, 2015). This in turn reinforces the other neurons' fields and fosters their binding. Fields thus help shift the focus of attention and guide brain operations (Jones, 2017).

Specifically, slow alpha–beta frequency waves in this synchronized field activity help sculpt attention by selectively regulating ascending sensory activity with faster gamma waves. This arguably controls the contents of working memory (Bastos *et al.*, 2018). All this recent evidence vindicates field theory's long-standing claim (§2) that EM fields interact with brains and thus explain mind–brain interaction.

4.4. Locating images neurally

RFT's claim that consciousness is the underlying reality of matter-energy means that not only energy fields are conscious, but also the matter emitting them. However, this consciousness has degrees. I am unaware of the simple, negligible consciousness of any single cell in my brain. But fields unite the subliminal consciousness in many cells to form overall images I am aware of.

Where exactly does this occur? To start with, both matter and fields are forms of energy. The fields' energies depend on their photons' frequencies, while the matter's far larger energy is its rest energy (mc^2). Our qualia thus reside mostly in our neural matter, while neural fields serve to unify the qualia into overall images (see §5).[5] So, qualia are not distributed semi-globally in the field (as in many field theories), but are localized in sensory-detector electrochemistries. Images are thus neuroelectrical activity as a whole, not just EM fields.

Furthermore, in RFT the neural field is strongest inside, or very near, cellular membrane currents which diffuse along circuits.[6] It is thus strongest among the concentrated currents and EM energy of tightly packed cells, as in cortical columns (Jones, 2016b; *cf.* McFadden, 2006). Along sensory circuits, this local field binds the

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[5] Critics may reply that, in the local-field theory, strong external fields (from MRIs, for example) should unify experience between brains. After all, external fields can affect neural activity. Local-field theory has two replies. First, the neural fields that unify experience are those between the ions in membrane currents. Ion fields are stronger at atomic-level distances between neighbouring ions than MRI fields are between neighbouring brains (even stronger external fields from transcranial magnetic stimulation disrupt rather than unify experience in brains). Second, the energy (and thus consciousness) bound up in ions and their fields greatly exceeds that in external fields across space, which are not carried by ions. Ion currents therefore have more consciousness, and are thus better able to bridge (unify) consciousness between locations. (All this justifies calling neural fields 'localized' even though only one universal EM field exists.)

[6] Synaptic gaps do not block these membrane currents, for the currents diffuse outside membranes and along circuits. Indeed, EEGs can detect them far from their sources.

consciousness of certain cells to form images. Specifically, images and qualia often correlate with cells that are highly connected, rapidly firing, synchronized, and numerous (e.g. Goldberg, 2001; Edelman and Tononi, 2000; Jones, 2010). These factors boost local fields and EM energies among cells to help produce images. The neural locations of images is further specified in §§5–6.

5. Qualia

5.1. Neuroelectrical qualia

CNS usually attributes qualia to special circuits (labelled lines) with their own detectors and processing areas. This is often enhanced by comparisons of detector outputs to resolve ambiguity about which sensory stimuli are present. These codes may be augmented by temporal codes based on the timing of neuronal impulses (yet these convert ultimately to labelled-line codes).

Computationalism's first problem is that, in colour processing, the activities outlined above culminate in the V4 complex (e.g. Tononi, 2008), a cortical area that processes colour constancy, for example. This conflicts with the evidence above for preattentive images at lower cortical levels (§4.2).

Attributing colours to V4 also conflicts with some surprising evidence that colour qualia may partly arise in retinas. Researchers injected genes for long-wavelength cones into monkey retinas that had only short- and medium-wavelength cones. The retinas grew long-wavelength cones, enabling the monkeys to discern colours trichromatically (Mancuso *et al.*, 2009).

Critics may claim cone reactions are ambiguous, so the monkeys had to use cortical processing to discern which wavelengths were really present. But the lack of delay between the trichromatic ability arising and the new cones arising indicates that no cortical rewiring for trichromaticism occurred. Furhtermore, the paper's corresponding author, Jay Neitz, later added that disambiguation actually occurs in the retina. That is, retinal opponent cells actually disambiguate cone inputs, and are thus responsible for colour percepts: 'neurons with the combinations of cone inputs required for hue perception arise in the retina' (Schmidt, Neitz and Neitz, 2014, §1), and 'these cells are responsible for conscious color perception' (Neitz and Neitz, 2014, p. 7). Given this evidence, we perhaps should not rule out that crude colour images might arise from retinas.

Critics may feel that colours must arise from the cortex, for V4 damage causes colour blindness (Bouvier and Engel, 2006). But this may not conflict with images arising from retinas. Retinal evolution could have created preattentive images that cortical evolution later refined. Blindness would arise here because V4 damage blocks these images from reaching the subject's awareness (this subject is the mind's controlling centre, which directs attentive operations). Retinal images may or may not exist. But preattentive images evidently do exist (§4.2). So prudent views should arguably try to explain how images might arise from various levels — from retinas to V4. RFT's non-computationalist account of qualia below does so.

Computationalism's second problem is that the qualia processing operations at the start of §5.1 are so prevalent and similar in the various sense modes that it is unclear how computational circuits differ enough between sense modes to account for the stark differences in their qualia.

RFT avoids this problem too. While computations modulate detector-cell activity, qualia are attributed to the cells' electrochemistries, not their computations. This testable theory occupies the remainder of this section. It starts with the peripheral detector cells in sensory pathways.

Each of these cells detects external sensory stimuli via myriad ion channels or G-protein-coupled receptors (GPCRs) in its cellular membrane. Each ion channel is a tangle of proteins containing sensors that detect stimuli and open the channel's gate. Ions then race through (up to 10^6 per second) along binding sites that admit certain ions. The voltage-gated potassium channel (Kv) and transient receptor potential channel (TRP) are especially copious in their varieties. The serpentine GPCRs are also proteins that detect external stimuli. They amplify their own electrochemical signals with complex cascades of reactions. They lack ion channels, yet often activate nearby channels. Myriad channels and GPCRs exist. Each kind is a unique protein complex. Yet their signals can be ambiguous about what stimuli are present at this peripheral level. For example, the three retinal cones overlap in their responses to light wavelengths. Their signals are thus compared to adjust the cones' own activities and higher-level activities too.

RFT draws on the growing evidence below that each type of GPCR or channel detects a unique sensory stimulus which corresponds to a unique sensory quality. These correlations back RFT's claim that qualia are neural substances, not computations. They also back RFT's claim that percepts come from strong, local fields binding qualia

together, not from binding codes. For these unique proteins reside in very strong, localized ion currents and fields. The fields interact with polarized sites in the big proteins (at sensors, gates, channels, electro-chemical cascades, etc.). These fields can thus bind the proteins' qualia to form overall perceptions.

Because consciousness is the underlying reality of matter-energy in RFT, it is thus concentrated in the huge proteins above. By contrast, the ion currents and fields are spread thinly across the membrane. The ions and fields are therefore ideal for uniting consciousness across the membrane, while the unique proteins are ideal for determining the qualia of the membrane's consciousness. For example, red qualia reside in certain proteins (coded by the OPN1LW gene), and fields between the proteins, and between adjacent cells, unify these qualia into the bright red spot we experience while looking at a stoplight.

As already noted, each protein's consciousness is the underlying reality of its rest energy. This energy equals mc^2 — where 'm' is the protein's mass and 'c' is light's velocity. In RFT, *our different qualia are the different rest energies of these electrically active proteins* in our sensory cell membranes. The mass involved in their rest energies is measured in Dalton units below.[7]

Qualia–protein correlations have been investigated mainly at peripheral levels. But there is evidence that these peripheral proteins also exist centrally and can even contribute to higher processing (see below). This fits the evidence above that qualia may arise both peripherally and centrally. These correlations could avoid neuro-science's qualia issue concerning why colour, pain, etc. are experienced so differently, yet processed so similarly. For different qualia would actually come from different sensory-cell proteins (the same might apply to well-known computationalist and cognitivist issues with emotions — RFT can attribute these qualia to limbic hormonal receptors, as in Jones, 2016b).

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[7] Several qualifications apply here. (a) The unique GPCRs and channels that correlate with qualia may ultimately include not only these electrically active membrane proteins, but also adjacent proteins that electrically bind to them. This would in turn alter the list below of the protein masses that correlate with qualia. (b) Qualia are forged in indi-vidual cells where the field is powerful — not between or among cells, where the field is weaker. (c) Qualia would correlate with the total mass of electrically active proteins across detector-cell membranes, or with the densities of the protein masses across the membranes.

All this explains how proteins and fields interact to produce the various qualia we experience. So if all qualia ultimately correlate with such proteins, this would be strong evidence for RFT's account above of how proteins, fields, and qualia are related (further evidence for this account appeared above in §4).

Interestingly, these correlations indicate that when very similar sensory qualities (e.g. bitter tastes) correlate with different proteins, the proteins are very close in their rest energy and mass. This aligns with RFT. Similarly, the mass of the yellow-green detector (40,584 Daltons) is very close to the yellow-orange detector (40,572) but not so close to the blue-violet detector (39,135). More loosely, *detectors from different sense modes often cluster in distinctive bands*.[8] Colours cluster at 39,000–40,000, some sounds cluster at 56,000–58,000, warm–hot temperatures cluster at 85,000–95,000, cool–cold tempera-tures cluster around 127,000, and some tastes cluster at 186,000–220,000. While exceptions do exist, these might be due to present uncertainty about when the unique membrane proteins bind elec-trically with adjacent proteins such as gustaducin and transducin (qualia may thus correlate with different protein masses than now presumed).

While the evidence for qualia–protein correlations is extensive, it must now be itemized to support RFT. My list in §5.2 summarizes experimental investigations of the correlations, which is in its infancy but growing fast. This list was compiled from well-known protein directories. Other sources are cited as needed. The directories include:

> http://www.guidetopharmacology.org/GRAC/FamilyDisplayFor
> ward?familyId=81
> https://www.genenames.org/
> https://www.genecards.org/
> http://channelpedia.epfl.ch/ionchannels
> https://www.ebi.ac.uk/gxa/home

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8   These bands of rest energy in RFT resemble computationalism's sensory spaces. Yet the bands do not encode qualia. Instead qualia are the energies' underlying natures. These qualia–energy correlations are no more explicable than the charge–particle correlations in physics. Still, these are not serious explanatory gaps, for we just lack cosmologies today to explain them.

5.2. Evidence

Sounds: Sound frequencies may be detected by voltage-gated potassium channels in cochlear hair cells (Ramanathan *et al.*, 1999; Adamson *et al.*, 2002; Beisel *et al.*, 2007). The most cited examples are the channels that come from genes KCNA1 and KCNC1 and have masses of 56,466 and 57,942. They have distinctive electrophysiological signatures and correlate with higher frequency sounds. These correlations (and those below) are evolutionarily conserved.

These channels have also been found in the brainstem's cochlear nuclei and MNTB, which help locate sound sources. Removal of both channels from avian cochlea reduces their numbers in cochlear nuclei (Lu *et al.*, 2004). Removal of the KCNC1 channel from mice MNTB prevents detection of high-frequency sound (Macica *et al.*, 2003). The detectors thus appear at different levels in the auditory pathway, and work together there in sound detection.

Tastes: Arguably, sour stimuli correlate with the TRP channel PKD2L1 (91,982), while salty correlates with the EnaC channel detector complex SCNN1A (75,704) + SCNN1G (74,270) + SCNN1D (70,215) = (220,189). (For simplicity, proteins will be referred to via their genes' names.) More dependably, sweet correlates with the unique GPCR complex T1R2 (95,183) + T1R3 (93,386) = (188,569), while savoury correlates with GPCR complex T1R1 (93,074) + T1R3 (93,386) = (186,460) — as noted in Zhao *et al.* (2003). Bitter correlates with the large GPCR family TAS2R (https://www.genecards.org/) which clusters around 35,000 (overall correlations are too numerous to detail here).

Lemon and Katz (2007) dispute protein–taste correlations, for T1R3 detects both savoury and sweet, and both are detected by several proteins. Yet, as it turns out, this is just due to both being detected by the different complexes of several components above. So correlations do hold.

Note that while many of the TAS2Rs (aka T2Rs) exist, they have very similar masses that correlate with different bitter compounds (e.g. coffee, quinine, kale, grapefruit, turmeric). Several T2Rs can coexist in one taste-detector cell. They also exist in immunological, digestive, and other systems (for which the compounds detected by T2Rs are instrumental). But only in sensory pathways do T2Rs contribute to the subjective mind's unified sensory experience.

The correlations above exist peripherally. Yet T2Rs have also been found in the brainstem, cerebellum, nucleus accumbens, and cortex

(Singh *et al.*, 2011). These brain sites deal with early sensory processing, sensory aversion, memory, and recognition. So these GPCRs operate at various levels in the taste pathway. Peripheral T2Rs help activate cells higher in the pathway, and the latter in turn help activate their own T2Rs.

Temperatures: Temperatures correlate with TRP channels (Wang and Siemens, 2015). These include TRPM8 for cold (127,685), TRPV3 for warm (90,636), and TRPV1 for hot (94,956). The chloride channel ANO1 (114,078) may also occupy the hot range. Interestingly, the ANO1 and TRPV1 hot detectors have rather similar masses, despite being quite different TRP channels. Note that the TRPV1 also detects hot peppers, burns, and other inflammations — all involving burning sensations.

The TRPM8 exists peripherally and in the spinothalamocortical pathway which relays pain and temperature responses from the periphery to the cortex. It is also found in the hypothalamus, which regulates body temperature, and the amygdala, a limbic, emotional area (Su *et al.*, 2004).

Pains: Nausea may correlate with the 5-HT3 (55,280) ion-channel receptor. Painful pressure (which may have degrees) correlates with potassium channels KCNC4 (69,767) and KCND3 (73,451). Painful cold correlates with TRP channel TRPA1 (127,501), while burning pain correlates with TRPV2 (85,981). Burning also correlates with TACR1 (a GPCR), but there is no conflict, for such burning, inflammatory pain varies in quality in different tissues.

While these correlations exist peripherally, the 5-HT3 nausea detector also exists in brainstem areas involved in vomiting (the vagal system, postrema, and nucleus tractus solitarius). It also exists somewhat in pain perception areas like the spinal dorsal horn, and limbic emotional areas like the hippocampus, amygdala, and prefrontal cortex (Koyama, Kondo and Shimadal, 2017).

The KCNC4 painful-pressure detector has been found in the thoracic spinal cord, brainstem nuclei, cortex, hippocampus, globus pallidus, and amygdala. The related KCND3 detector exists in the substantia nigra, hippocampus, retrosplenial cortex, raphe, and amygdala (Rudy *et al.*, 1999; Brooke *et al.*, 2004; Birnbaum *et al.*, 2004; Su *et al.*, 2004). All these areas help process pain, and help link pain to memory, aversion, emotion, and behaviour.

The TACR1 inflammatory-pain detector exists in brain areas dealing with pain and touch perception, and related areas dealing with

autonomic control, motor control, stress response, sensory aversion, pain inhibition, and emotion. These areas include the putamen (Lai *et al.*, 2008), locus coeruleus, and ventral striatum (Douglas and Leeman, 2011), the thalamus, amygdala, hypothalamus, periaqueductal gray, substantia nigra, and area postrema (Yip and Chahl, 2001). This GPCR occurs across the brain in regular and truncated forms (Lai *et al.*, 2008), arguably for different functions (including non-sensory) when bound to different proteins.

Odours: Hundreds of olfactory GPCRs correlate with myriad stimulants and their related odours. The details are unclear, yet one odour often correlates with several GPCRs, and one GPCR often correlates with several odours. Still, tight correlations between GPCRs and odours are quite possible. To start with, odours like lime or lemon, and peanut or pecan, can often be complexes of simpler odours, some of which belong to several complexes. These simple odours could tightly correlate with their own GPCRs. Tight correlations can also hold at higher levels. Here, GPCRs can detect novel odours that reinforce differences between overall lime and lemon odours. So lime and lemon could be mixtures of odours that correlate tightly with specific GPCRs in a hierarchy of family relations. Future research can clarify this. These points also apply to other sensory modes.

Colours: Cone cells contain OPN1 proteins that are GPCRs of the opsin class. Light-absorbing molecules attached to these different opsins detect different light wavelengths, due to the molecules' different spatial conformations. This starts cascades of reactions, mediated partly by transducin molecules, which hyperpolarize the cells. Depolarization quickly follows. Humans detect short, medium, and long wavelengths with OPN1SW (39,135), OPN1MW (40,584), and OPN1LW (40,572). Higher cells disambiguate their signals, beginning with inhibitory and excitatory feedbacks into cones from higher retinal cells. These sharpen contrasts and colours (Jackman *et al.*, 2011), and tighten correlations between wavelengths, OPN1s, and colours.

   OPN1 proteins have also been found in brains, including occipital, parietal, and prefrontal areas (Su *et al.*, 2004; https://www.genecards.org/). OPN1s may thus operate at different levels, like the T2R bitter detectors above. That is, cones with OPN1s feed forward through cortical opponent-processing to activate higher cells, such as V4 glob cells — and the latter may have their own OPN1s which are also

activated. Short-wavelength light would therefore most strongly activate OPN1SWs in retinas and V4 blobs, both having (in RFT) blue qualia.

So, in sensory-code jargon, this labelled-line account uses across-neuron codes, and even temporal codes, behind the scenes to disambiguate its own activity. The latter codes alter qualia by feeding backward or forward to modulate labelled-line activity (*cf.* Cariani, 1999).

5.3. Testable conclusions

If further experimental research finds correlations between detector proteins, sensory stimuli, and qualia in all cases, RFT would be successfully tested. For other theories would have difficulties explaining why qualia correlate with detector proteins set in intense, localized neuroelectricity. Standard theories attribute qualia to computations by overall circuits rather than specific electrochemical substances. They attribute the binding of qualia to computational codes, not to the continuous substance of a neuroelectromagnetic field. They thus raise serious issues (§§3–6).

By contrast, RFT predicts and explains these correlations between qualia and detector proteins in intense neuroelectricity. In its realist theory, qualia are the underlying reality of these proteins, while in its binding theory, intense local fields reach into the proteins to bind their minimal qualia into overall percepts. *Fully verifying the correlations would thus support RFT's overall (realist and binding) theory over other theories. So this is a future empirical test of RFT.*

To summarize, standard theories fail to explain how such different qualia arise from such similar processing circuits, and how these qualia bind to form overall percepts. By contrast, RFT suggests how different qualia arise from different proteins in processing circuits, and how fields in the circuits bind these qualia to form overall percepts. If RFT fully passes the test above, it will be the only theory to explain how different qualia arise and how they bind to form percepts.

Critics might advance several counter-arguments to these conclusions.

(1) Arguably, RFT's account above of qualia–protein correlations is only partly testable, for its realism is metaphysical. In reply, RFT's account of the correlations is that the qualia are the proteins, and only RFT's realism fully explains this identity. Reducing qualia to observable proteins does not explain what realism does: why qualia are

unobservable in proteins (see §7). So verifying the correlations verifies the realist account of the correlations.

(2) Arguably, neuroplasticity threatens RFT. For example, if the visual cortex is recruited for somatosensory processing by blind subjects, and these cortical detectors are stimulated, then subjects report somatic qualia (Ptito *et al.*, 2008). This threatens RFT's claim that visual detector proteins always correlate with visual qualia. In reply, RFT is not threatened if neurogenesis and plasticity yield not only new detector synapses, but also new detector GPCRs or channels. Many somatosensory GPCRs and channels already exist in occipital and parietal lobes (Su *et al.*, 2004), so neurogenesis of more of them would hardly be surprising.

(3) Arguably, multiple realization threatens RFT. To start with, RFT treats qualia as electrochemical substances, not multiply realizable relations. This echoes Bickle's (2003) view that multiple realization may seem plausible for neural systems, but traditional identity is more plausible at molecular levels (for example, memory consolidation uses universally conserved molecular mechanisms). But both views differ from Aizawa and Gillett's (2009) view that molecular mechanisms are multiply realized throughout visual circuits. The relevant example here is that the protein which detects medium-wavelength (green) light is realized in two forms — a normal form and a hybrid form with parts from the long-wavelength detector. The overall point is that computationalists might use this example to refute RFT. They might argue that green correlates not with one unique protein, as RFT claims, but with the two proteins that green is multiply realized in. In reply, RFT is not refuted, for it can simply argue that if the normal and hybrid proteins have different molecular masses then they yield different green hues. If the two proteins have the same mass, then they yield the same green hue. This same hue is not multiply realized — it is always the same rest energy from the same mass.[9] (Moreover, computationalists have not actually explained how different qualia arise and how they bind to form percepts. So how could they really know green is realized in different proteins? And how could they

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[9]   Arguably, in RFT, the green hue can occur in organic or inorganic electrochemical structures having the same rest energy. But this is not really multiple realization, for the hue is always identified with a single energy level. Still, RFT is compatible with activities that are subliminal (unlike the green hue) being multiply realizable — and with abstract ideas like 'Dalton was a scientist' being multiply realized (for their content is nebulous, unlike the green hue).

know the proteins really differ in ways essential to them realizing green?)

6. Shapes

6.1. Neuroelectrical images

Our detection of the shapes our qualia assume starts with retinal activity and culminates with the ventral cortical pathway detecting ever larger borders, surfaces, and objects. Computationalists often assume that integrated shapes are perceived when higher cells have sufficient information to detect which shapes are present together, as when three lines are detected as a triangle.

While top-level cells do attentively monitor objects (Le Chang and Tsao, 2017), computationalism's problem is that no cells monitor the entire visual scene — which is largely preattentive — to recognize which shapes are present altogether. Shapes appear not just in refined images from higher levels, but also in preattentive and iconic images from lower levels (§4.2).

RFT tries to explain how perceptual shapes arise without this issue. The account below summarizes Jones (2016b), which can be consulted for further details. As already argued, prudent accounts of images should address how images might arise at all levels, from retinas to the cortex. RFT doesn't require that retinas have conscious images which help form our refined images. But RFT does offer explanations for the possible existence of retinal images.

To start with, OPN1s could create the colours in these retinal images as explained in §5 (in the paragraphs on Neitz and OPN1s). Mutual inhibitions by retinal cells could enhance border contrasts (Jackman *et al.*, 2011). A strong field arises within the concentrated currents and EM energy among millions of tightly packed, interconnected retinal cells (§4.4). This field could bind these cellular arrays to form crude pictorial images of coloured shapes.

Retinas connect systematically into visual areas of the thalamus and cortex (here the inverted retinal image would be turned right side up by higher mechanisms such as vestibular correction — Ramachandran and Ramachandran, 2007). The field along this pathway from retinas to lower cortex could unite consciousness in these areas to form the preattentive images of §4.

Of course, retinas may just be subliminally conscious — after all, they lack the feedbacks from higher cortex that help lower cortex

create raw images. Nonetheless, electrical activity in retinas and their ascending fibres would be strong. So the systematic connection between cortical cells and retinas could root the pictorial form of images in retinas. This would explain how images get the elliptical shape of retinal peripheries (Jones, 2016b) — and why cortical distortions don't appear in images, while retinal detachments and retinal blind spots do.

V1's dense array of columns and electrical activity, fortified by feedback loops, would enhance details in these pictorial images (*cf.* Lamme, 2004). Myriad V1 columns connect tightly together into the retina's centre, making the centre of images detailed and smooth. Far fewer blobs connect into the retina's periphery, leaving peripheral images coarse and grainy.

But if retinas play no such role in the overall pictorial form of images, then lower cortex alone could create this form (cortical distortions would not appear in these images for reasons given in Jones, 2016b). Connections from V4's OPN1s could give the images colours.

6.2. Computational roles

Higher cortical areas greatly refine our raw images of coloured shapes. Here RFT often draws on computational mechanisms (though these are treated by RFT as electrochemical reactions in circuits instead of abstract processes). RFT can do so because, as already noted, it treats conscious areas of colour as neuroelectrical, yet it allows that computations help refine these images behind the scenes — and that damage to these mechanisms can impair these refinements. These mechanisms are very familiar, so they will be just briefly listed.

An example is depth perception. It is constructed behind the scenes using clues such as parallax and juxtaposition. It is more of a concept involving potential sensorimotor associations than a raw percept like the coloured areas mentioned above. Colour constancy also involves computations. These include opponent processing. This too occurs behind the scenes, though the resulting colours may come from OPN1s in V4. V5 mechanisms such as saccadic suppression keep eye movements from being noticed. These mechanisms help maintain the visual stability of moving objects in images during eye movements. Object recognition comes from higher shape-detector circuits electrically activating memories. These memories are stored in the cortical

sites that created the original perceptions through the sensory processes noted above (Kosslyn, 1994).

So RFT offers ways of accounting for images, whatever levels they arise from. It ultimately treats perceptual qualia, such as coloured shapes, not as abstract computations, but as the underlying reality of neuroelectrical activity. Numerous computations refine these qualia behind the scenes. Images are unobservable in sensory circuitry because they are the circuitry's underlying nature. (Note that because this neuroelectrical activity is inherently conscious, it needs no higher-level monitoring agent to become conscious.)

6.3. Evidence

This overall account of perceptual shapes is supported by the various lines of evidence in this paper for neuroelectrical binding (§4.3), electrochemical qualia (§5.2), preattentive images (§4.2), and possibly retinal images (§5.1). See Jones (2016b) for additional support. While this partly Gibsonian account goes beyond evidence at times, it is no more speculative than existing accounts — whose problems it avoids.

7. Consciousness

CNS faces issues in explaining not only how qualia, their shapes, and their binding are encoded, but also in how these abstract codes yield the conscious areas of colour in pictorial images. For example, computationalists often reduce images to the observable activities of CNS (e.g. Tononi, 2008). This ignores the explanatory gap between these radically different entities (Levine, 2006). RFT avoids this issue by treating images as the underlying reality of electrical activity in neural maps, beyond what is observable of this activity. This explains what reductionism has not — why images cannot be observed in brains.

RFT also avoids issues raised by computationalists who appeal to realization, emergence, etc. In general, RFT tries to avoid such obscure relations between computations, brains, and qualia by simply treating our qualia as the underlying reality of brain activity. There is insufficient space to address all these points here. They are fully addressed in Jones (2016a).

8. Conclusions

Computational neuroscience attributes percepts to abstract calculations realized in multiple cellular forms. Yet growing evidence indicates that while neural systems are massively computational, their qualia are seated in their unique electrochemistries, not in multiply realized computations or codes. For example, sensory circuits process detector signals too similarly to encode colours and other qualia that differ so greatly. Also, qualia codes based on globally integrated information conflict with evidence that images can exist pre-attentively. Computations do modulate detector activity behind the scenes, yet mounting evidence suggests that qualia are actually seated in the unique electrochemistries of detectors.

Also, the binding of colour and shape circuits into unified percepts is not encoded or computed by synchrony, synapses, or feedbacks between these circuits. Evidence instead shows that percepts correlate with neuroelectrical activity spotted by locally activated EEGs. Unlike computations, this field activity is a continuous, unified substance. It can extend locally along (and between) specific circuits to bind them into pictorial forms. Evidence also shows that this field interacts with sensory circuits to help attentively guide sensory activity.

Finally, computational neuroscience creates obscurity about how all its codes yield conscious pictorial images. Its obscure ideas of codes, reductions, emergence, realization, etc. can be avoided by RFT's simple realist view that pictorial images are the underlying, conscious nature of neuroelectrical activity across neural maps.[10]

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[10] RFT thus rejects dogmatic, arrogant claims that empirical science will explain everything. While RFT does not entail any religious ideas, it may partly accommodate monotheism's conscious act of creation, theistic ideas of free will, and mysticism's oceanic consciousness. Its account of how subjective minds emerge from oceanic consciousness (Jones, 2016b) may render mystical and theistic views compatible.

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