One Experiment to Start Them All: The Missing Foundation of Consciousness *Science*

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Abstract

Leading scientific journals (such as *Science* and *Nature*) have recently started publishing articles about the explanation of consciousness. These publications give credence to an assumed (and profoundly mistaken) view that there *can* be a conventional ‘science’ of conscious experience in a standard-physics setting. (Here ‘standard physics’ means any setting in which emergent properties can’t exert any kind of downward-causality, *i.e.* can’t dynamically-couple with fundamental entities in ways not already accounted for by existing dynamical laws.)

The field of standard-physics consciousness science is divided between those who believe conscious experience can be studied scientifically, and dissenting views (including Dennett’s well-publicized commentaries), which claim there are no trustworthy experiments concerning experience. Here I clarify this split, attributing contingent validity to both sides, and identifying an experiment that can determine who’s ultimately right. By comparing a standard-physics simulation with actual brain-measurements, we can in principle determine if the specific non-standard physics required for reliable report-of-experience applies in our Universe. This is the ‘one experiment to start them all’, because it must yield a positive (non-standard physics) signal, if *any* experiments allegedly about experience are to be part of a rigorous, conventional, science of consciousness.

1 Introduction: No Scientifically-Reliable Experiments Under Standard Physics?

1.1 Trustworthy Science and the 'Disconnected Thermometer' Problem

If there's to be a *science* of conscious experience [or phenomenal consciousness (Block, 2005)], there must be trustworthy scientific *experiments about* experience (Chalmers, 2004; Gamez, 2014; Seth et al., 2008). It's hard to detail every property that trustworthy experiments must have, but it's straightforward to see one feature that would make experiments *untrustworthy*: if any meter (measuring-apparatus) weren't connected to the system or phenomenon it's supposed to be collecting data about, obviously we couldn't rely on that meter's data. It would be like trying to use a thermometer to measure your body-temperature, while leaving the thermometer in the cupboard!

1.2 Meters in Consciousness Science

Modern consciousness science (Baars, 1988; Crick and Koch, 1990, 2003; Hameroff et al., 1996) uses two kinds of meter (Figs. 1 and 2). One is a 'brain-meter' – typically, an EEG or MEG apparatus, or an MRI machine. The other is a meter for what's happening in conscious experience. By simultaneously collecting data on brain-state and contents-of-experience, investigators hope to correlate neural activity with experience, thus identifying 'the neural correlates of consciousness' ['NCC'; (Boly et al., 2017; Koch et al., 2016; Metzinger, 2000; Odegaard et al., 2017)].

But what is the meter-for-experience? Simply, it's some form of first-person report (Varela and Shear, 1999) by a participant in an NCC experiment. 'Report' can take many forms, for example, an in-experiment button-press or an in-experiment or post-experiment verbal or written account. [Even so-called 'no report' paradigms (Tsuchiya et al., 2015) involve *some* sort of report – minimally, experimentalists' presumption of what-report-would-be! Otherwise there'd be nothing to correlate brain-data *with*!]

1.3 'Standard Physics'

Apparently, many people [*e.g.* (Block et al., 2014; Koch et al., 2016; Odegaard et al., 2017)] trust the seemingly-innocuous structure of this two-meter NCC experimental approach. But it's currently *fatally* flawed, *if* set within an overarching standard-physics theoretical framework (which *is* the default setting for every mainstream scientific journal). I use the term 'standard physics' to refer to fundamental physical theories sharing the *structural* features of our current best descriptions – the Standard Model of particle physics, plus general relativity. Specifically, standard physics forbids top-down influences [*e.g.* some forms of 'strong emergence' (Chalmers, 2008)], in which conventionally-emergent high-level properties could have novel dynamical couplings with fundamental entities. (Defining standard physics in structural terms allows for changes in *details* – *e.g.* particle-types – in future fundamental advances.) Note that 'standard physics' *as defined and used here* does *not* forbid or even address so-called 'systems-level causality' (*e.g.* the oft-cited 'ant colony' example). But systems-level causality is irrelevant to present discussions, because *it doesn't solve the disconnected-thermometer problem* (subsection 3.6).

1.4 Scientific Reliability of First-person Report under Standard Physics

How does standard physics compromise the scientific reliability of two-meter NCC experiments? The main idea in current consciousness science is that experience is some form of emergent brain-property. [Commentators use different language to describe basically the same *dynamical* idea – *e.g.* property-duality (Chalmers, 1996), identity (Place, 1956; Smart, 1959) or complexity (Mateos et al., 2017; Seth

Figure 1. Standard physics can explain a report-of-experience experiment using only $\{e^-, r\}$ symbols. **A.** A standard experiment in physics: A system S has a macro-property P and fundamental degrees-of-freedom φ_b . The function F may be characterizable by using an M -meter to collect P -values and m_a -meters to collect φ_b -values. **B.** An idealized experiment about conscious experience: Ideally, we would use a meter to collect data on components-of-experience $\langle s_i \rangle \langle \rho_j \rangle$. (Experience is schematically depicted using the colored tree-photo. See Figure 2 for $\langle s_i \rangle \langle \rho_j \rangle$ -symbols.) Simultaneous collection of brain-data $\{A(r)\}$ would enable a correlative analysis, aimed at characterizing f . **C.** An actual neural-correlates-of-consciousness ('NCC') experiments. Because no 'experience-meter' exists, we have to use report, R , from which $\langle s_i \rangle \langle \rho_j \rangle$ -values are inferred. Note, however, that experience 'associates with' (black dashed double-headed arrow) brain-activity, that leads to (green arrow) later brain-activity, which in turn leads to report. Experience itself plays no direct role in report (except perhaps under an identity-with-brain-activity interpretation, Section 3). **D.** Standard physics (subsection 1.3) can explain the entire dataset of an NCC-experiment using only orthodox $\{e^-, r\}$ -symbols, and without employing $\langle s_i \rangle \langle \rho_j \rangle$ -symbols at all. (Note that the colored picture, schematically depicting experience, has been deleted from the image, without compromising standard physics' explanatory capacity.) This means that, if standard physics is true, NCC-experiments *aren't about experience, in any scientifically-reliable way*. (See Section 3 for rejection of the 'identity theory' response to this claim.)

Figure 2. Existing $\{e^-, r\}$ -like symbolism in physics, and new symbolism for conscious experience.

A. The matter-tree (schematically-represented by the purple line-drawing) and the experienced-tree (color-photo) aren't the same (under either indirect realism, or representationalism; Fig. 5). Existing symbols in physical theory, such as ' e^- ' (electron) and ' r ' (spatial-location), properly label (blue double-headed arrows) aspects of the *matter*-realm, *only* (above the dotted line). The question-mark indicates absence of equivalent symbols for conscious experience (below the dotted line). **B.** Symbols $\{s_i(r_j)\}$ are introduced to label macroscopic, brain-encoding-relevant, features of the matter-realm. (' $\subset$ ' indicates these symbols belong to the overall class of " $\{e^-, r\}$ -like" symbols.) A novel symbol $\langle s_i \rangle(p_j)$ then labels the component of conscious experience that corresponds directly to the $s_i(r_j)$ stimulus (macro-aspect of the matter-realm). For example, the two visually-experienced tree-edges (colored contents of red squares, lower-half) correspond to respective matter-edges (purple lines in red squares, upper half). Note the introduction of a *new spatial-coordinate symbol* p . **C.** Another set of " $\{e^-, r\}$ -like" symbols, $\{A(r)\}$, label generic brain-activity (red spikes) and configuration, at a set of brain-loci $r \in r_B$ (schematically depicted by the red-ellipse, left-hand side). A detailed theory-of-conscious-experience must include a function f relating matter-realm symbols (contents of the black-ellipse, right-hand side), describing stimuli and brain-state, to new conscious-experiential symbols $\{\langle s_i \rangle(p_j)\}$.

et al., 2011). Even recently-popular ‘pan-psychic’ proposals (Chalmers, 2015) are subject to this paper’s criticisms, because they take ‘pure’ consciousness to be physically ubiquitous but use emergence-equivalent bases to explain detailed, content-rich, human experience.] If experience is emergent-like, and standard physics holds, experience can’t directly influence brain-dynamics at all (because standard physics forbids top-down couplings – by definition!). If experience doesn’t influence brain-dynamics (Elitzur, 1989; Huxley, 1893), it can’t influence brain-dynamics governing *report*. Therefore, report can’t be ‘about’ experience, meaningfully.

Recall subsection 1.1’s temperature example: under standard physics, report isn’t actually *connected* to experience, just as thermometer-in-the-cupboard isn’t connected to the body. Then, report isn’t really *about* experience, scientifically – just as in-the-cupboard thermometer-readings aren’t about body-temperature.

Put differently, standard physics can currently explain everything in experiments allegedly-about-experience – including all speech-acts, button-presses, and other subject-behaviors – *without referring to experience at all!* The issue is far more than ‘privacy’ of experience: it is *complete inaccessibility*, as a result of standard-physics’ causal-irrelevance-of-experience! [Note that this ‘complete inaccessibility’ differs from philosophers’ ‘ineffability’ (subsection 7.4): it’s not about whether we can have ‘good’ words for experience, its about whether the words we use for experience are causally or dynamically-*related to* experience. Again, the analogy is the disconnected thermometer – not that it’s difficult to explain to another person what ‘warmth’ means.]

1.5 No Science of Conscious Experience under Standard Physics

Subsection 1.4 apparently encapsulates one of Dennett’s fundamental criticisms of modern consciousness science (Cohen and Dennett, 2011), although Dennett hasn’t presented it as standard-physics contingent [because he seems to take standard physics as unchangeable (Dennett, 1991)]. Subsection 1.4 logically implies that there can’t be *any* kind of science about conscious experience, under standard physics. (Even experiments claiming to study *report of* conscious experience, but not *experience itself*, must be flawed – because there can’t be meaningful report-of-experience, under standard physics! If ‘no meaningful report’ is counter-intuitive – or even seemingly counter-*factual* – please see Sections 2 to 7!) Some commentators (including Dennett!) then try to define consciousness as a natural phenomenon definitively *excluding* conscious experience, but this usage seems unhelpful. In this paper, ‘consciousness’ means a collection of brain-related phenomena minimally including, but perhaps not limited to, conscious experience. (Open-boundary definitions allow for *e.g.* sense-of-self or subjectivity to be included in *investigations* of consciousness, without prejudging whether sense-of-self will turn out to be simply a specific kind of experience, or something ontologically greater, *e.g.* genuine free will.)

With this usage of ‘consciousness’, then, the no-reliable-meter-under-standard-physics argument implies there can be no science of *consciousness* under standard physics, further implying that mainstream (standard physics!) claims of significant advances in the ‘science of consciousness’ are simply mistaken (Dennett, 1991; Elitzur, 1989, 1995).

1.6 Preview

Sections 2 through 7 examine typical objections to the no-science-under-standard-physics argument – and reject them! Noting that the ‘laws’ of physics aren’t in fact unchangeable, I then characterize the minimal amendment to standard physics that would allow trustworthy experiments about conscious experience (Section 8). Of course, amending basic physical law isn’t a trivial matter! Therefore, I

outline an *experimental paradigm* that can test whether *hypothetical* amendments actually describe our Universe (Sections 9 to 11). This experiment is the single highest priority for any truly scientific investigation of consciousness, because it determines whether investigations can be called 'science'! It's also vital for science-as-a-whole, because the fundamental processes of conventional science employ conscious experience, in a basic, inextricable, ways: without a science of experience, the foundations of science-in-general are shaky, at best (Section 12).

2 The 'Subjectively-Obvious' Objection to the No-Reliable-Experiments Argument

2.1 Everyday Interpretations of the Role of Experience in Report

One objection to 'NCC-report can't be about experience' is that report is '*obviously*' about experience, all the time (Taylor, 1963) – and therefore also in NCC experiments! But this misses the nuances that *science* must deal with, precisely and rigorously! The no-reliable-experiments-under-standard-physics argument doesn't say report can't be about experience. It says that it can't be, *if standard physics is true*. Of course, investigators are free to accept as truthful a subjective appearance that 'experience drives report' (so to speak). But logically they must then accept that standard physics isn't a complete description of reality! (Many *individuals* find this *personally* unproblematic. But as Section 11 explains, without *objective* data rejecting standard physics, it leads to a physics/consciousness-science split, and therefore to problems for the *collective* study of consciousness – and of reality!)

2.2 A Possible Conditioned Bias in Discussions

In-depth examination of subsection 2.1's 'subjectively-obvious' objection is important because it may well color every other discussion in this paper. Likely, we all rehearse the implicit belief that 'my decisions and actions are based directly on my experience', many times a day. This repetition may then comprise a kind of psychological conditioning (Festinger, 1957; Gigerenzer, 1991; Gilovich, 1993; Kahneman and Tversky, 1996), making it hard to enquire clearly into the relationship between behaviors (such as in-experiment report!) and experience.

Accordingly, I invite readers to pause for a moment, to examine the report-experience relationship directly. For example, at the end of the previous sentence, I assume you visually- experienced the word 'directly', as black lines/curves on a white background. If you now publicly report (say out loud!) 'I experienced the word "directly"', what role does experience play in generating that report? How do you know? (I am not asserting that experience did or didn't play a part. I'm simply inviting examination of subjective belief-systems and their origins – or alternatively of clear, subjective, truth-discernment! – as a precursor to conditioning-free discussions.)

2.3 The Standard-Physics View of First-Person Report

Standard-physics disagrees with subsection 2.1's 'subjectively-obvious' stance. (Naturally, standard physics may be wrong!). Some specific brain-activity ('B1' say) associates with some aspect of experience ('E1', say; Fig. 3A). Brain-activity B1 also leads to downstream-activity B2, which in turn leads to vocal cords producing the speech act 'I experience a straight vertical-edge'. It so happens that E1 – the aspect-of-experience associated with B1 – *is* a straight vertical-edge! So, report and experience are consistent. (Note, however, experience itself didn't play any direct part in report: brain-dynamical states B1 and B2 'generated it'.)

Everything looks OK, so far, for scientifically-reliable report-of-experience. After all, report and experience are *congruent*. (Put differently, report is a *faithful* or *accurate* account of contents-of-

Figure 3. Standard-physics Problems for Precise Knowledge of the Contents of Experience. The external environment is encoded in a series of successive hierarchical brain-areas (schematically depicted here as B0 and B1; B2 is a non-encoding area governing report) B0 and B1 contain information that's *broadly* consistent but potentially differs in fine *detail*. Because there's more than one possible basis for experience (panels A and B), experience could be different in its content (perfectly-straight line, panel A; slightly zig-zag straight line, panel B), depending on which brain-area it associates with. But *whichever* brain-area experience associates with, *under standard physics* report-of-experience (text-in-“quotes”) will be *identical*, (quoted-text, panels A and B) because report is governed by an even-later brain-area B2, which takes its inputs only from B1. [Conclusions aren't affected by other assumptions (Rosseinsky, 2015).] Thus, under standard physics report is not a scientifically-reliable measure of experience, essentially because there is no direct information transfer *from* the content-of-experience *to* the content-of-report. **(A) Experience (interior of dotted-circle) ‘associates with’ (dashed double-headed arrow) brain-area B1.** B1-activity encodes the external environment in a relatively *coarse-grained* way; B1's activity encodes a perfectly-straight vertical line, resulting in experience E1. B1-information couples with B2, and B2-information couples with muscle-activity generating verbal report (transfer-of-information by dynamical-coupling schematically depicted by solid single-headed arrows.) **(B) Experience associates with brain-area B0, rather than B1.** B0-activity encodes the external environment in a relatively *fine-grained* way; B0's activity encodes a slightly zig-zag vertical line, resulting in experience E0. However, as in panel A, report is still of a *straight* (not zig-zag) line, because report is based on B1's aggregated, filtered version of B0's more-detailed data. (If B0 were connected directly to B2, in principle report could be of the E0-consistent, zig-zag, encoding. But even if B2 is connected to both B0 and B1, *under standard physics*, we still don't know *what's in experience*! Again, this would require direct information transfer *from* the content-of-experience *to* the content-of-report, to resolve the E0/E1 ambiguity. But that transfer is explicitly forbidden by the definition of ‘standard physics’ (subsection 1.3, main text).

Figure 4. Multiple levels-of-encoding in the brain lead to many possibilities-for-experience. Inset: Six neurons in early-processing area-1 (green ellipse, $\mathbf{r} \in \mathbf{r}_{B,1}$) are labelled 1.1 to 1.6. Two neurons in later-processing area-2 (blue ellipse, $\mathbf{r} \in \mathbf{r}_{B,2}$) are labelled 2.1 and 2.2. **Main figure:** Diagonal dashed line separates matter-realm (bottom-left) from experiential-realm (top-right). *Matter-realm:* Receptive fields of neurons are illustrated by black squares and dotted-rectangles. Neurons 1.1 to 1.6 become active if there is an approximately-horizontal line spanning the respective receptive-field square ($d_{1,1}$ to $d_{1,6}$). (For example, purple lines in $d_{1,4}$ to $d_{1,6}$ lead to neurons 1.4 to 1.6 becoming active, as depicted by their red-fill.) Neurons 2.x only become active if all three of their early-stage connections are active. (For example, activity in neurons 1.4 to 1.6 leads to neuron 2.2 becoming active, as depicted by its red-fill.) Hence, the effective receptive fields of area-2 neurons are the dotted rectangles labelled $d_{2,1}$ and $d_{2,2}$: area-2 neurons will fire when rectangles (rather than squares) are filled by an approximately-horizontal line. *Experiential-realm:* Ellipses depict two possible, different, components-of-experience, labelled $\langle s_1 \rangle$ and $\langle s_2 \rangle$, that could ‘associate with’ (black dashed double-headed arrows) a single configuration of brain-activity (red-filled circles, matter-realm). If neurons 1.1 to 1.6 are the neural basis of experience, we expect experience to contain the zig-zag line, $\langle s_1 \rangle$. If neurons 2.1 to 2.2 are the neural basis of experience, we expect experience to contain the flat line, $\langle s_2 \rangle$. ($\langle s_2 \rangle$ is a single, flat, horizontal line because area-2 receptive-fields are the large, dotted, $d_{2,i}$ -labelled, rectangles: area-2 neurons detect a ‘large’ horizontal line, irrespective of its detailed wiggles.) *But subsection 1.3-style standard-physics suggests we can’t know from report which of the two kinds-of-experience is actually occurring. Therefore, we can never construct a detailed theory-of-experience.*

experience.) But here is the critical problem for experiments about conscious experience [Fig. 3B; (Rosseinsky, 2015; Sperling, 1960)]. Consider some brain-activity B0 earlier in processing than B1, and containing more detailed information. (For example, in visual processing, the same feature may be represented in relatively-detailed, fine-grained, ways in early processing, and in relatively-coarse-grained ways, later.) If conscious experience associates with B0 instead of B1, contents-of-experience would be *different* (more detailed, more granular; e.g. in Figure 3B, experience-E0 contains a slightly zig-zag line, differing subtly from E1!). However, overall brain-state is the *same*, and report must be the *same* (*under standard physics*). That last parenthesis is crucial, because even professional commentators (e.g. Bridgeman, personal communication) sometimes claim ‘but we *know* the detail-level in experience’. If detailed-knowledge claims are true, again, standard physics can’t hold, because under standard physics there’s *no way for that information-about-experience to transfer into report*. (Fig. 4 presents the same result, using a schematic neuronal-level depiction.)

2.4 Standard-Physics-Report Problem Differs from Other Issues for Consciousness Science

For definiteness, the ‘disconnected-thermometer problem’ (subsection 1.1) differs from, and is independent of, other field-issues such as: potentially-dishonest report; potentially-inaccurate (but well-intentioned!) report (Bayne and Spener, 2010; Kouider et al., 2010); challenges to the NCC-project’s assumptions about the encoding/experience-relationship (Noë and Thompson, 2004); confusions between level-of-consciousness and content-of-consciousness (Bachmann and Hudetz, 2014; Hohwy, 2009); confusions between neural correlates of conscious-content, of conscious-prerequisites, and of conscious-consequences (Aru et al., 2012; Bachmann, 2015; De Graaf et al., 2012); the problem of other minds (Mill, 2006); inverted qualia (Locke, 1998); and, psychophysical parallelism (Strickland, 2014). Even if all these problems were overcome (as I believe they can!), in a standard-physics setting report still *can’t* presently be scientifically-reliable. [Of course, ‘*can’t*’ (presently!) depends on further refutations, in Sections 3 to 7, of other commonly-proffered solutions to the disconnected-thermometer problem.]

2.5 Metaphysical/Ontological Generality of No-Reliable-Experiments under Standard Physics

Emphatically, problems for standard-physics experiments about experience identified and discussed in this paper are metaphysically and ontologically general, in the sense that they do not depend on any specific conception of reality. Issues raised here concern dynamical relationships *between* degrees-of-freedom in conscious experience, and dynamics in reality-beyond-experience. (For example, Figure 5 shows two completely different conceptions of reality-beyond-experience. Problems for experiments about experience apply in both depicted situations – and all others, not depicted!)

2.6 ‘Information Transfer’ Does Not Deny or Neglect ‘Qualia-Valued’ Degrees-of-Freedom

Some commentators seem to interpret language such as ‘information about experience’ (subsection 2.4) as denying the qualia-valued nature of experience. Emphatically, this is not the case. For example, in Figure 2, $\langle s_i \rangle$ -symbols are qualia-valued; the informational-uncertainty concerns which precise s_i -stimuli (in reality-beyond-experience) are represented in qualia-valued experience. (A related way to avoid seeing problems highlighted in this paper is to cast them in terms of the alleged ‘ineffability’ of conscious experience. Emphatically [subsection 7.4], I assume that alleged-ineffability can be scientifically-circumvented by an abductive assumption, which essentially enables a standard methodology known as ‘rational reconstruction’. But rational reconstruction itself does *not* get around standard-physics problems, if the initial first-person report by person- X – used by person- Y to reconstruct experience – is not itself reliably-related to person- X ’s experience!)

Figure 5. Experiential and ‘Unseen’ Realities. **A.** *Two-realm depiction of reality.* Semi-transparent grey rectangle schematically separates ‘unseen reality’ from ‘conscious experience’. ‘Conscious experience’ includes thoughts (and imaginations), audiovisual experience of the unseen environment (depicted here schematically by a colored photo representing visual experience, plus the placeholder text ‘Sounds’), and feelings of all kinds (emotional, tactile, and proprioceptive). ‘Unseen reality’ contains all the objects studied by conventional science (*i.e.* science excluding the study of conscious experience!). Purple rectangles schematically depict *the entire physical Universe*. Two unseen-realm objects are schematically-emphasized: the physical tree (purple line-drawing) that is re-presented centrally in the experiencer’s visual experience, and the physical brain (purple line-drawing) of the experiencer (who is experiencing thoughts, sounds, feelings, and colored visual-experience of the tree). **B.** *We have no knowledge of the ‘actual constitution’ of ‘unseen reality’.* Exactly-the-same conscious-experiences are *completely-consistent* with an alternative view, in which ‘objects’ in the unseen realm exist as numbers (‘#’-symbols), which are recomputed according the laws of physics. (For example, some subset of the numbers depicted corresponds to the physical state of the experiencer’s brain. As well as the capacity to recompute unseen-realm numeric-content, Nature contains the capacity to ‘project’ specific experiential-content, according to the numeric-state of the experiencer’s brain). Note that ‘two realms’ doesn’t imply dualism, but simply reflects logical features of reality. All conventional science concerns inter-relationships *between purple entities in a single realm*; conscious-experiential science concerns inter-relationships *between realms*.

3 The Identity-Theoretic Objection to the No-Reliable-Experiments Argument

3.1 How Do Mainstream Publications Resolve 'The Impossible Trinity'?

Of course, philosophers and scientists are smart people, and they haven't entirely overlooked that standard-physics proposes a solely-brain-basis for report. Unfortunately, peer-reviewed publications about consciousness don't presently explain how experimental data can simultaneously meet three requirements: data must be about experience; data must be analysed in a standard-physics setting; and data must be scientifically-reliable. Because explanations are absent, we must *infer* how mainstream 'consciousness science' thinks it's resolving this impossible trinity. (Of course, 'analysis in a standard-physics setting' isn't an *absolute* requirement! It occurs *relative* to mainstream journals' contextual standard-physics presumption.)

3.2 Silos in Science?

It's hard to exclude the possibility that some scientists are simply *unaware* of problems inherent in standard-physics discussions of conscious experience! Silo-based specialization makes *deep* interdisciplinary training extremely rare, perhaps creating risky deficits in science: conscious experience is typically studied scientifically in neuroscience; but problems originate in physics!

Two personal observations are relevant. First, in discussions *e.g.* with presenters at conferences, physicists aren't typically focused on phenomenal consciousness, and neuroscientists aren't typically focused on standard physics. Thus, physics and neuroscience seem to be missing each other! Second, my own advanced trainings in physics and neuroscience at world-leading institutions never once mentioned standard-physics-of-consciousness *report*-problems! Hopefully, the present paper can help with training future generations of scientists.

3.3 Psychology/Philosophy/Cognitive Science: Lack Physics-Training, or Wrong Incentives?

Psychologists, philosophers, and cognitive scientists frequently mount shifting and confused defenses against the no-reliable-experiments argument. (Some of the more rational objections to associated experimental suggestions are dealt with in subsections 10.1 to 10.5.) It's hard to know whether this results from a lack of training in physics-thinking (which can't be acquired simply by taking undergraduate physics-classes), or an incentive-structure that strongly rewards *not* bringing the study of consciousness into the physical mainstream. When arguments here are finally accepted, and the experiments suggested in Section 9 are actually executed, a number of people will be out of a job, because there'll be no market *e.g.* for orthodox 'philosophy of mind'. Worryingly, *e.g.* from a game-theoretic perspective, many people with exactly the wrong incentives have been granted gatekeeper-status in the field. (Tenure does not resolve these incentive problems, because intellectual prestige is independent of monetary reward: even if financial survival is not tied to defending an irrational position, egoic survival may be.)

Beyond incentives, repeated experience with obstructionist responses (*e.g.* see subsection 10.6) brings into question whether there really *is* a collective intention in the field to begin a truly scientific approach to consciousness. One possibility is that humans are so conditioned to believe in the causal efficacy of conscious experience that they simply *cannot* behave rationally in its study, even if that conditioning is brought to their attention (subsection 2.2). (Superficial awareness is usually insufficient to deconstruct or disempower deep conditioning. Typically, further work is required.) Even if an individual superficially asserts openness towards the logical possibilities of either causal-efficacy or no causal-efficacy, unresolved *subconscious* conditioning can lead to irrational behaviors when

exploring the topic. In other everyday settings, it's commonly accepted that conflict between conscious and subconscious positions can lead to severe problems. Ironically, psychology as a discipline makes conditioning an *object-of-enquiry* in *those* settings, but does not discuss possible problems of conditioning interfering with the studies of psychologists (and other scientists), as *subjective enquirers*.

Of course, peer-review is supposed to be one antidote to distorted thinking. But if conditioning is widespread, incentives are perverse, and authority is granted positionally, or solely by virtue of track-record within a dysfunctional system, there's no reason to believe that peer-review will be effective. In fact, to the contrary, if widespread conditioning leads to collectively-confused thinking, the ensuing chaos is precisely the right arena for narrow interests to dominate. Ironically (again!), we would then have exactly the situation in the discourse of consciousness science that scientists are currently bemoaning in society at large.

3.4 Identity-Theory: One Attempt to Meet the Impossible Trinity

One attempt to get around standard-physics problems for experience-experiments (subsections 2.3 and 3.1) focuses on phrases like 'it wasn't experience itself that played any role in report' (in the last sentence of subsection 2.3's first paragraph). Say we interpret experience as being *identical with* certain aspects of brain-activity (Place, 2012; Smart, 1959). Then, it's argued [*e.g.* (Kim, 2005)], we can restate '*brain-activity* governs muscle activity which implements report' as '*experience* governs muscle activity ...'. This argument justifies replacing 'brain-activity' by 'experience' by appealing to identity: if X is identical to Y, it can be valid to replace linguistic occurrences of 'X' with 'Y'.

3.5 Identity-Theory Doesn't Solve Science-of-Experience Problems!

I don't object to identity-theoretic replacement (used carefully!). *But it doesn't solve the basic problem.* Without additional assumptions (Section 7), we *still* never know detailed contents of conscious experience, under standard physics! Subsection 2.3's problem *still* applies under identity-theory: experience might be associated with either B0 or B1, and we don't know which is happening (Rosseinsky, 2015)!

How can identity theory apparently defuse a key step in Section 2's problem-statement, but leave the problem itself intact? This *apparent* paradox results from subsection 2.3's word-choice. Section 2 gives a general, introductory, description, not explicitly focused on identity-theory. I could rewrite Section 2 to be robust to identity-theoretic arguments. (*E.g.* 'experience doesn't influence report' would become 'experiential-aspects of brain-dynamics confer no additional dynamical-couplings, under standard physics'.) However, focusing on identity-theories would compromise Section 2's generality-of-statement, vis-a-vis all possible brain/experience-relationships. (*E.g.* the phrase 'experiential-aspects of brain-dynamics' presumes or implies an *identity*-relationship in which experience *is* an *aspect of* brain-activity. Other relationships are conceptually-viable!)

3.6 'Systems-level Causality' as a Version of Identity-Theory

One defense against the no-reliable-experiments argument (a defense beloved of philosophers and cognitive scientists [subsection 3.3]) is to attribute something called 'systems-level causality' to experience, thus allegedly coupling experience with brain-dynamics, after all, and circumventing *e.g.* the kinds of problems discussed in subsection 2.3. (To be clear, specific problem discussed in subsection 2.3 is only the beginning of much deeper, and completely-pervasive, report-of-experience problems under standard physics, as discussed in subsection 7.3. Contrary to one pervasive mis-interpretation, standard-physics problems are not simply about 'approximate report': they are that *no*

report can be treated as being about experience, in a scientifically-reliable way. Again, I refer philosophers, psychologists and cognitive scientists to the two-meter discussion in subsection 1.2. If one of the meters is *disconnected* from the phenomenon, the problem is not *approximation*. It is *scientifically-meaningless* 'data'.)

The basic idea of systems-level causality is sometimes illustrated using the example of a hurricane. Say a tree was blown down by a hurricane. Right in that language, we attribute causality to a higher-level entity (*i.e.* to a hurricane, rather than to the moving air-molecules that collectively constitute the hurricane). Obviously, using 'hurricane' as a label for certain unseen-realm dynamical-states (Fig. 5), it's completely fine to use language – and attribute causality – in this way. According to the systems-level causality argument *for experience* (which I'll show is *not* fine), experience is to certain brain-dynamical states as a hurricane is to certain air-molecule states. 'Therefore' (allegedly), just as we can say hurricanes cause tree-fallings, we can say experience causes reports-of-experience (and other behaviors).

It should be clear that this argument is a version of the identity-theory reasoning I just dealt with (subsection 3.5). ('Hurricanes are *identical* to certain air-molecule configurations, so they have the same causal powers as those configurations.') I said in the previous subsection that I don't object to identity, *used carefully*. But the hurricane-experience analogy is not a careful use! 'Hurricane' here is a label for certain classes of dynamical-states of air molecules, *and nothing more*. 'Experience' is *not* just a label for certain classes of dynamical states of brains – it is a label for qualia-valued collections of natural degrees-of-freedom that associate with, or are realized-by, certain classes of brain-dynamics. (Saying that there is something to experience over-and-above brain-dynamics *per se* does not assert any kind of ontology or metaphysics: it's simply a recognition of the facts-of-the-matter. For example, in Figure 5, brain-dynamical states exist in the 'unseen' purple-realm, and experience is of course in the experiential-realm. Without any assignment of ontology or metaphysical frame, there are two things involved. Even if we say they are 'the same thing', that 'one thing' has two properties.)

But again, even if we were to grant the analogy (which we should not; Fig. 1D) – the 'system' *still* contains multiple encodings that could lead to multiple different experiences (Figs. 4 and 5). And without coupling of experience to report, there's no way of knowing what's actually in experience. So, there's no conventional, reliable, science of consciousness.

4 The 'We'd Know If Report Differed from Experience' Objection

Subsection 2.3 highlights problems when *experience* actually associates with B0 (and so is *relatively-detailed*; Fig. 3B), but *report* is made of B1, *relatively-coarse*, representation (Crick and Koch, 1995; Sperling, 1960). Then, experience and report diverge, report isn't reliably about experience, and there's no science. If we can't rule this divergence out, again, there's no science.

4.1 Chalmers' Solution for 'Phenomenal Judgment' (and a Science of First-Person Report)

Subsection 2.1 discussed the stance 'it's subjectively obvious that experience drives report' (thus potentially eliminating experience/report differences). A related position is '*we'd know if* experience differed from report' (Chalmers, 1996). Like subsection 2.1, it's a *subjectively-based* refutation of no-reliable-experiments. But it differs in the *locus-of-application* of subjectivity. Unlike subsection 2.1, it allows standard-physics (at least, in the first instance – but see subsection 4.2.1), with experience and report both deriving from brain-dynamics, but then relies on comparing actual-experience and experience-of-[report-of-experience].

For example, I actually experience red. I verbally report 'I experience red', and I have an auditory experience of my speech act. (I hear myself speaking!) I then compare actual red-experience, and experience-of-saying-'I experience red', and find them congruent. That congruence is allegedly an insurance policy for experiments about conscious experience (Chalmers, 2004). B0-based experience with B1-based report (subsection 2.3's problem) would cause *incongruence*, which we'd be aware of. Because, it's further claimed, we *don't* experience such incongruence, the B0-association/B1-report problem doesn't actually occur, so report of experience *is* scientifically reliable! [Put differently, absence of incongruence guarantees phenomenal and access consciousness are identical (Phillips, 2018), which would make report reliable concerning contents-of-experience, and not just about brain-encoded information!]

This comparison-in-experience of experience with report-of-experience is essentially Chalmers' solution to the no-consciousness-science-under-standard-physics problem (Chalmers, 1996, 2004). Continuing subsection 3.1's detective work about why experiments-concerning-experience are published in standard-physics settings, plausibly some scientists draw comfort from Chalmers' status, and his assertions that two-meter NCC approaches are methodologically-innocuous. However, as subsection 4.2 explains, no concrete comfort can be drawn, at least for a *conventionally-recognisable* science of consciousness!

4.2 Chalmers' Approach Doesn't Yield Conventionally-Recognisable Consciousness Science

Let's follow through subsection 4.1's comparison-in-experience idea, *in a standard physics setting* (Rudd, 2000).

4.2.1 Comparison-in-Experience Must Be an 'Immaterial' Process

First, no matter-process can compare two items *in experience*, under standard physics. That would require experience to act on matter, so that information about respective contents-of-experience could 'get into' a matter-based computation: standard physics forbids that experience-to-matter action. So, comparison of experience with experience-of-report-of-experience must be a disembodied process that exists, but doesn't have any matter-correlate! (Philosophers might say 'mind isn't supervenient on brain'.) No-matter-correlate for an extant process isn't specifically excluded by subsection 1.6's *standard* physics, but it certainly doesn't fit with *current* mainstream physics. Thus, consciousness scientists who rely on subsection 4.1's comparison-in-experience for reliability-of-report are mistaken, if they think investigations then cohere with modern physical theory.

4.2.2 No Brain-Coupling of Comparison-in-Experience Leads to Potentially-Private Data

Second, assume immaterial comparison-in-experience exists (thus extending current physics!). What sort of consciousness science would we then have? Even if *I* know that my report and experience are aligned, *you* can't rely on my public declaration of that alignment (or non-declaration of a mis-alignment!), *under standard physics*. Why? Because the aligned/mis-aligned comparison-process result can't be passed to the brain's matter-processes, to generate a trustworthy (information-coupled!) public declaration about absence/presence of experience/report-alignment. This could result in widespread *public* reassurances of no report/experience-inconsistency, while we all *privately* know that isn't the case. A worst-case scenario is where professional scientists reassure each other and laypeople publicly (but privately know everything's awry), and third-party onlookers take these reassurances at face value, completely unaware of the potential for private-inconsistency accompanied by public-reassurance!

4.2.3 Out-of-Hand Dismissal of 4.2.2's Concerns is Equivalent to Asserting 'New Physics'!

If subsection 4.2.2's scenarios seem like outlandish fantasies, please take a moment to examine *why* that's so. Maybe it's because it's subjectively-obvious that reports and experience cohere, and it's subjectively obvious that you could report any instance when they didn't? I'm not saying those (experientially-grounded) positions are wrong. But if those two assertions *are* your basis for dismissing subsection 4.2.2's concerns, I'm just pointing out that they respectively disagree with modern physics (subsection 4.2.1) and with standard physics (subsection 4.2.2). Again, that does not refute the assertions! I'm simply pointing out (again!) the mutual exclusivity of a conventional science of consciousness, and standard physics!

5 The 'Interventional Experiments Restore Reliability' Objection

Figure 3's problem is that experience might be associated with B0, with report based on B1 (where B0 and B1 contain *consistent* encodings, differing in their *detail*-level). So why not just disrupt B0 and B1 in turn (holding the rest of brain-activity constant), to see which is the *real* basis of experience? (Casali et al., 2013; Nieminen et al., 2016; Rutiku et al., 2016; Vernet et al., 2015). (Of course, targeted-disruption 'holding the rest of brain-activity constant' isn't *currently* technologically-feasible. Here I am discussing a potential subset of *future* technological developments.)

However, even idealized future technology cannot resolve the B0/B1 problem, if standard physics holds (Cohen and Dennett, 2011)! It's certainly reasonable to hypothesize that B0/B1 disruptions might alter contents-of-experience. (Naturally, other hypotheses are also available!) If experience is associated with B0 alone, disrupting B0 will alter experience, but disrupting B1 won't (and conversely). Critically, though, in all cases *report* will be *unaltered*, because it's generated by neural dynamics downstream from B0 and B1, and these dynamics *must be held constant* in interventions, in order to isolate the B0/B1 relationship to experience! Thus, although disruptions may alter *actual* experience, experimental participants must always *report* the *same* experience. And participants can't report 'what really happened' afterwards, under standard physics, because forming matter-based memory-traces of 'experience itself' would require an experience-to-matter coupling.

(The last point doesn't deny that humans generate experiential-components when accessing memories. *Under standard physics*, experiential-components occur because matter-dynamics from the time of memory-formation are recreated to some degree, by recall. Experiential-associations with those recreated matter-dynamics then occur – as they did at time-of-formation. But 'experience itself' isn't somehow stored internally within matter, as would be required for a disruption paradigm's accurate after-the-event recall.)

6 Can Assumptions Fix the No-Reliable-Experiments Problem?

By making additional assumptions, the no-experiments-under-standard-physics problem *can* be avoided – but at a cost!

6.1 The Assumption that 'Report is Complete'

For example, say we assume that report-of-experience is always completely accurate (Gamez, 2014). Then, of course, the problem of B0-associated-experience and B1-based-report can't happen, *by assumption*. But this just *assumes* specific theories-of-consciousness, which are what we're supposed to be discovering [subsection 2.3; (Rosseinsky, 2015)]: a given aspect of experience may be encoded in many different ways in different brain-areas (Quiroga and Panzeri, 2013), and a significant part of

the NCC project is to find out *which* brain-activity (or which collection of brain-activities!) associates with experience (Crick and Koch, 1995; Sperling, 1960).

6.2 The 'Common-Sense' Assumption that 'Report is Scientifically-Reliable'

Similarly, we could say 'it's *common-sense* to trust in a subjective sense of reliably-accurate report-of-experience' (Taylor, 1963). However, this just assumes that standard-physics is wrong: it's an entirely viable route, but without strong evidence, again it causes a split with physics, and therefore with the vast majority of science (subsection 2.1). (Adopting this assumption converts subsection 2.1's background *belief* in the 'obvious' role of experience in report into an explicit *axiom*. Both belief-based and axiomatic approaches can be valid. However, they must do one of three things: enact subsection 2.3's logical contradiction between physics and the study of consciousness; irrationally deny that that contradiction exists; or, resolve the contradiction by directly asserting amendments to standard physics – without evidence!)

6.3 Non-Contradictory Assumptions: Sometimes Valid, Sometimes Necessary

Of course, scientific progress often requires assumptions. But these assumptions should be explicitly documented, and carefully examined for overall impact on the central project's integrity. We *do* apparently need certain explicit assumptions to progress in consciousness science, presently. For example, the problem of 'other minds' appears to require abductive assumptions akin to 'my experience derives from my make-up; other humans typically have similar-enough make-ups; therefore, it's usually safe to infer that they too have experience.' However, allowing pivotal roles for enabling-assumptions doesn't mean each and every assumption is methodologically valid. If the central project includes discerning which brain- areas associate with conscious experience, and assumptions effectively decide that point (or severely curtail its exploration), the validity of the field is significantly compromised (Rosseinsky, 2015).

[For complete precision, the abductive assumption above, beginning 'my experience ...', is *already* inconsistent with standard physics! (See subsections 7.3 and 12.4.) This illustrates the care necessary in developing axiomatic approaches: solving one problem in an apparently-innocuous way may inadvertently prejudice approaches to others.]

7 The 'No Experiments *Now* but New Insights May Arrive in The *Future*' Stance

7.1 A Novel, Imaginary, 'No-Report' Basis for Consciousness Science

Sections 2 to 6 exhaust major objections and proposed solutions to the no-experiments-under-standard-physics result. Of course, we could say that *currently* experiments appear to be impossible under standard physics, but some *future* insight may show why it was all always OK (Blackmore, 2005). For example, some line of reasoning above might be flawed. Or, we could find some entirely new objective or subjective resolution to the B0/B1 problem (Section 2). To give one (extreme!) example, say a new fundamental physical theory discovers novel particle-states (Beck and Eccles, 2003) that are 'somehow' known to be required for experience. And say these particles are only found in B0. Then we'd have discovered the neural correlates of consciousness, without using report at all! (Naturally, we could query the 'somehow': *how* do we 'know' that these particles are 'required for experience', without using report?! However, it seems difficult to exclude *e.g.* some presently-unimaginable conceptual reasoning that *could* lead to certainty about the novel-particle/experience relationship.)

7.2 No Currently-Known, Standard-Physics, Path to a Conventional Consciousness Science

However, this article doesn't aim to prove that standard physics in every future setting is incompatible with consciousness science. It's simply to point out that *currently* there's no known (assumption-free!) way to establish reliable data-collection in a standard-physics context.

Again, if this seems unreasonable, because of apparent reportability of present-moment experience, please examine the logic. *If* experience *is* reliably reportable, standard physics is false. It's that simple! But: *physics* won't accept your subjective assertion of reliable-report, as sufficient evidence to change its fundamental 'laws'! It demands objective data. And remarkably, as Section 9 explains, this should be available, if report *is* reliable!

7.3 Standard-Physics-Report Problems Not Limited to Verbal-Report/NCC Settings

For brevity, Sections 3 to 11 focus on subsection 2.3's problems for detailed knowledge of experiential-contents (including interventional paradigms; Section 5). But standard-physics-problems: aren't limited to these settings; don't only relate to report-of-visual-experience; and, aren't restricted to verbal report [as opposed to *e.g.* forced-choice (De Gelder et al., 1999; Persaud et al., 2007) or so-called 'no-report' (Frässle et al., 2014; Pitts et al., 2014) settings].

Subsections 7.3.1 to 7.3.3 discuss *settings* for the investigation of experience whose structures differ radically from subsection 2.3's set-up. Briefly, concerning *visual*-experience and *verbal*-report: subsection-2.3-style problems for report-of-*visual*-experience transfer immediately to every sensory modality that's hierarchically-encoded (Quiroga and Panzeri, 2013); and, problems with *verbal* report must 'contaminate' every allegedly more-objective method [*e.g.* forced-choice and 'no report'] (Overgaard, 2010), because those methods must ultimately be calibrated via explicit, verbal, inter-subjective, exchanges, between experimental participants and investigators.

7.3.1 Level of Consciousness

What about studies focusing on *level*-of-consciousness (or 'state'), rather than detailed-*contents*? [Representative studies examine *e.g.* sleep (Massimini et al., 2005; Nieminen et al., 2016), anaesthesia (Colombo et al., 2019; Lee et al., 2018; Sarasso et al., 2015), coma/vegetative-states (Boly et al., 2011; Owen et al., 2006), and drug-effects (Carhart-Harris et al., 2014; Muthukumaraswamy et al., 2013), or combine many of the preceding study-styles, and others (Casarotto et al., 2016; Guevara Erra et al., 2016; Mateos et al., 2017).]

Unfortunately, level-approaches all suffer from a generalisation of subsection 2.3's problems, so they can't sustain a reliable foundation for consciousness science, either. At the extreme, a *level*-report discriminates between *not-conscious* and *conscious*. But *level*-reports are governed by neurons, just as subsection 2.3's *content*-reports are. To make a scientifically-reliable discernment between 'conscious' and 'non-conscious' (as a basis for reliable-report), neurons need dynamical-inputs from these conscious/not-conscious experiential-states (or from an 'absence-of-experience' state!). But, again, experiential-states *can't* couple with neurons, under standard physics.

7.3.2 Conscious Contents: Rivalry, Masking etc.

Doesn't most currently-active work concerning correlates-of-*contents* actually involve paradigms I haven't discussed yet, such as multi-stable perception (Meng and Tong, 2004) [including binocular rivalry (Frässle et al., 2014; Leopold and Logothetis, 1996; Tong et al., 1998)], various kinds of masking (Melloni et al., 2007; Morris et al., 1998; Pitts et al., 2014; Rutiku et al., 2016) [including continuous flash suppression (Tsuchiya and Koch, 2005)], or inattentional blindness (Mack and Rock, 1998; Pitts et al., 2012; Rees et al., 1999; Todd et al., 2005) [including the attentional blink (Raymond

et al., 1992; Sergent et al., 2005)]? Such paradigms occupy a sort of middle ground between subsection 2.3's detailed-content and subsection 7.3.1's overall-level (e.g. waking/sleeping).

And isn't this middle-ground *immune* to standard-physics problems? Surely, we can't be mistaken about e.g. faces vs. houses (Tong et al., 1998), as we might about a straight vs. slightly zig-zag line (Fig. 3)? But the standard-physics problem *isn't* 'being mistaken' – it's rigorously and logically integrating a dynamical-coupling/causality analysis of report-of-experience into a standard-physics setting. One standard-physics problem for all 'middle-ground' work arises when I, as an *investigator*, start to talk or write about e.g. 'conscious experience of house/face': talking/writing are processes-in-matter, and under standard-physics I can only mistakenly imagine that matter-based talking/writing are meaningfully-connected to house/face-experiences. [As subsection 7.3 noted (Overgaard, 2010), under standard physics, middle-ground paradigms that allegedly have *participants* meaningfully-distinguish between objective and subjective choices, introduce further contradictions.] Thus, all middle-ground paradigms are *also* standard-physics-invalid.

7.3.3 Unambiguously-Encoded Contents

Finally, what if a component-of-experience were encoded in just *one* brain-location? Certainly, subsection 2.3's B0/B1-E0/E1 problems wouldn't then apply. But just as in subsection 7.3.2, the very reference to 'experience' in the opening sentence above is meaningless, under standard physics!

You may think I've pulled off some sort of confidence trick, here! Subsection 2.3 seemed to base the whole standard-physics argument on problems concerning *multiply-encoded features* of the environment (Fig. 3). Then, suddenly, *without* multiple-encoding here, a similar standard-physics problem allegedly exists!

Here's what has actually happened. In subsection 2.3, I first used multiple-encoding of detailed-content as the clearest, most-unobjectionable, demonstration of problems due to no-information-transfer-from-experience-to-brain. Then, in subsection 7.3.1, I went to the other end of the content/level-spectrum, and explained that the same lack of information-transfer compromises report of wake/sleep distinctions. Finally, in subsection 7.3.2 and here, I brought that same lack-of-transfer problem back, respectively to middle-ground and unambiguously-encoded percepts.

The problem for unambiguously-encoded percepts in developing theories-of-consciousness is that, somewhere, we have to implicitly (or explicitly!) *report this-percept-is-in-experience* (and *that*, other, brain-encoded, aspect *isn't* – the same requirement applies to subsection 7.3.2's masking and inattentional blindness paradigms). For such contrast-reports to be scientifically-reliable, they must originate in information-about-experience. Thus, in-experience/not-in-experience for an unambiguous-encoding (or in a masking/inattentional-blindness paradigm!) is entirely analogous to the B0/B1-problem, because in both cases reported-contrasts are unreliable unless coupled with information about actual experiential-contents. *And that's impossible, under standard physics.*

7.4 Problems Differ from Philosophy's Alleged 'Ineffability' Issue

Some philosophers claim that experience can never be explained by science, because the qualitative nature of experience can't be reduced to the quantitative measures that e.g. physical sciences are concerned with (Goff, 2017). Essentially, this is the 'experience is ineffable' argument.

But this argument mistakes the nature of scientific explanation. As Figure 2 shows, we can introduce qualia-valued symbols and study their relationship to quantitatively-measured brain-states. (This

approach doesn't explain why 'redness' exists, or why it associates with certain brain-dynamical states. Equally, physics doesn't explain why photons exist, or why they interact in the way they do with quarks and electrons.)

Some commentators confuse present arguments about no-experiments-under-standard-physics with the ineffability argument, and therefore see present arguments as introducing nothing new. Emphatically, this paper denies that philosophical ineffability is an insurmountable obstacle to consciousness science, in principle (*e.g.* per Figure 2's approach.) Instead, it observes that any methodology that *could* in principle circumvent ineffability, *can't* work in practice as a scientific approach, because qualia-valued symbols can't be assigned values *in a reliable way* (the disconnected-thermometer problem). The scientific problem is not intractability of qualia. It is their lack of causal influence (or coupling with brain-dynamics).

7.5 Problems Occur Before, And Are Not Resolved By, 'Rational Reconstruction'

Some commentators have objected that treatment here does not treat 'rational reconstruction', and therefore fails to address the central basis of consciousness science. This objection is just a failure to understand the basic chain of logic involved *in* rational reconstruction. ('Rational reconstruction' is the view that in-experiment reports can be used by third-parties to reconstruct what they – or others – would have experienced, based *e.g.* on an abductive assumption that similar-enough biological-systems will have close-enough experiential-properties).

For rational reconstruction to work, report must in the first instance be reliably related to experience. Under standard physics, it can't be. Therefore, rational reconstruction is invalid under standard physics (and *is* treated by present arguments!).

7.6 Implications of No Current, Conventional, Standard-Physics, Consciousness Science

If there's no assumption-free way to collect reliable experiential-data under standard physics, there's no assumption-free consciousness science. One logical conclusion is that publication of scientific explanations of consciousness (in standard-physics settings) should stop – and prior, allegedly-assumption-free, claims should be retracted, as unreliable. [This applies even to studies that examine access consciousness, if they claim 'access' means report-of-*experience*, as opposed to report-of-data, or encoded-information, such as modern computers can make.]

One alternative to cessation/retraction would be explicit addition of riders stating that 'data reported here can only be meaningfully about experience if standard physics doesn't hold'. This brings us to this paper's second theme. What minimal amendments to standard physics *would* allow a trustworthy consciousness science? And what experiments can tell us whether standard or amended physics holds, *in the Universe we inhabit?*

8 What Sort of Fundamental Physics Would Allow for Reliable Experiments?

Without loss of subsection 7.3's generality, let's return to subsection 2.3's focal point (Fig. 3). The brain encodes the external environment in a hierarchy, typically containing many consistent but detail-differing encodings of a given environmental aspect (Quiroga and Panzeri, 2013). Thus, experience could in principle take many different forms [via association with different hierarchical brain-areas; (Rosseinsky, 2015)]. This leads to the standard-physics problem of never knowing if report is about actual contents of experience (the B0/B1 problem, subsection 2.3 and Fig. 3), and thus to never being able to collect reliable scientific-data about actual contents of experience.

All subsection 7.3's issues stand or fall with this basic problem. So, removing it would restore our capacity to do all kinds of consciousness science!

8.1 A Pedagogical Demonstration: The Substance-Dual, Interactionist, Setting

For a pedagogical moment, consider substance-dual interactionist models of conscious experience (Popper and Eccles, 1977; Rudd, 2000). (I'll adopt and then drop this class-of-approach. It's the easiest way to introduce dynamical requirements for a real consciousness science.) Here matter-dynamics in the brain couple with degrees-of-freedom in 'mind-stuff', *and* certain mind-configurations couple 'back' to specific brain-dynamics (interactionism!). Specifically, imagine that experience-of-the-external-environment couples directly with report-governing brain-areas, so that reports like 'I *experience* a vertical red-edge' only happen when there actually *is* such an *experience*. For example, we could imagine there's neural inhibition on the word 'experience', which must be removed by active mind-stuff coupling. Then, reports-about-experience would be reliably *about* experience, and, as a separate function or brain-activity, we could still have report-about-brain-encoding (e.g. a report about a vertical red-edge, *without* conscious experience). Thus 'subjective' and 'objective' report would become two, independent, capacities, both informationally-reliable.

8.2 General Case: Information-Transfer from Contents-of-Experience to Brain-Dynamics

Clearly, subsection 8.1's *style* of experience-to-brain coupling *could* generate reliable reports-of-experience, if it tightly-couples report to contents-of-experience. Generally, what's required is a form of information-transfer from experience to brain-dynamics, which grounds *experiential* reports in experience itself! With this understanding available, we can now drop substance-dual interactionism! All that's needed is *information-transfer*, irrespective of how experience itself arises (e.g. ontologically). Experience could be identity-theoretic, emergent, property-dual, quantum *etc.* – in every case, regardless of how experience 'comes to be', we just need information-transfer from that experience, into report. Of course, this raises (but doesn't answer!) the question of *how* transfer takes place. However, the pressing question for a genuine consciousness science isn't the 'how' of information-transfer. It's *whether it exists*. *Information-transfer directly and explicitly contradicts subsection 1.3's definition of standard physics*. So, *if* it exists, it profoundly revises existing conceptions of fundamental physical order. And such revisions must be *experimental* questions (at least, according to physics!).

8.3 Demands for an Information-Transfer 'How'

Often, information-transfer hypotheses evoke demands for plausible 'how' mechanisms, before experimental tests can be discussed. This response-style has a certain validity, protecting limited experimental resources from frivolous and trivial requests that can be reasonably ruled out, via close correspondence with analogous, already-tested, contexts. But Section 10 dismisses the idea that experience-to-brain coupling *has* been already-tested. Moreover, as Section 12 establishes, the scale of implications from no-experiments-under-standard-physics surely justifies qualified relaxation of 'how'-hurdles for experiments. (In any case, as subsection 12.1 briefly discusses, it's straightforward to identify a range of 'how' suggestions!)

9 The 'One Experiment': Testing for the Physics that Allows Reliable Experiments

9.1 The 'One Experiment': Outline

Testing for Section 8's information-transfer is straightforward, in principle (although extremely demanding, in technical practice). Simply, if there's non-standard physics at work in report-of-experience (Elitzur, 1989, 1995), it should appear in comparison of actual brain-data with a detailed standard-physics simulation. If increasing detail and precision demonstrate the brain uses only standard-physics, then a *conventional* science of consciousness would seem to be in fatal trouble. (Subsection 11.4 discusses possible constructions for the study of experience in this 'standard-physics-brain' scenario.)

Let's start with an idealized version of the experiment, using an imagination of perfect future technology.

9.2 An Idealized Version

First, assume we can measure all biophysically-relevant features of the human body, to sufficient precision. ('Biophysically-relevant features' might, for example, be cell-level data, plus electromagnetic-field activity. 'Sufficient' precision is set by the experimental objective: we need to be able to collect data that's comprehensive and precise *enough*, to provide initial conditions for robust brain-activity simulations. Subsection 10.2 discusses dependence of required precision on general dynamical features of actual brain-activity: the more sensitive later-time brain-dynamics are to small present-moment variations, the more precise data collection must be.)

Next, assume we have a detailed brain-simulation (Markram, 2006), which takes detailed biophysical data at a given instant as input, and uses standard physics to compute temporal evolution of brain-states. (This simulation must also model sensory organs, so it can mimic experiments in which human participants respond to stimuli.)

Finally, the basic overall approach is to measure a human subject's state at the start of an experiment, and use that data (plus simulated stimuli) to compute a standard-physics prediction of the subject's brain-state throughout an experimental session. In the actual session, detailed biophysical measurements continue, various stimuli are presented, and the subject makes *reports of conscious experience* of those stimuli. For a single conscious-experiential task, this paradigm would generate two streams of detailed brain-data: actual measurements and a standard-physics simulation. If *non-standard* physics exists in the brain (notably, Section 8's information-transfer), it will then be detectable by comparing *non-standard-physics actual* data with *standard-physics simulated* data. (Note that, even if hypothetical couplings from experience to brain-dynamics are infinitesimally small at their first 'point of contact', they must be amplified to the neuronal/neural-network level, if they are to resolve no-experiment problems. For example, subsection 8.1 described an imagined mechanism in which absence of information-transfer inhibits positive use of the word 'experience'. If analogous mechanisms exist, their impact must ultimately be visible in neural dynamics governing language, which are *non-infinitesimal*, and eminently measurable.)

9.3 The 'One Experiment' Is *Not* A Thought-Experiment: Sufficient Data May Already Exist!

To those perhaps unfamiliar with the present experimental field in neuroscience, or with the details of simulation techniques, the idealized experiment of the previous subsection may seem impossible to execute, or at best, to be some sort of distant imagination. Emphatically, the primary objective of this paper is not just to describe a 'thought experiment', but to marshal resources towards the actual execution of the overall paradigm suggested by subsection 9.2's idealized version.

Specifically, *we may already have observed* experience-to-brain causality/coupling, in brain-measurements widely-reported in the literature. However, as the next subsection will explain, brain-data is always currently interpreted as deriving from standard-physics dynamics, thus missing points made in this paper. The first practical step in implementing in-practice versions of subsection 9.2's idealization would be to adapt existing brain-simulations [e.g. (Farisco et al., 2018; Markram, 2006)] to see if they could effectively arbitrate between standard/non-standard-physics hypotheses. Again, emphatically, the 'One Experiment' points to a project or paradigm that could (and should!) begin *today*.

9.4 Comparing the 'One Experiment' to Existing Experimental Paradigms

How does subsection 9.2's idealised experiment differ from standard NCC approaches?

Typical, current approaches to the neural correlates of *contents*-of-consciousness (subsections 2.3, 7.3.2 and 7.3.3) involve comparison not of *actual* data with *simulations*, but of *actual* brain-data in one experimental 'condition' with *actual* data in another [e.g. brain-data when 'conscious of red-shape' with brain-data when 'conscious of empty space']. But if both actual brain-states reflect non-standard information-transfer, they *may* tend to net out, in actual-actual comparisons. Even if they *don't* net, all observed differences are currently interpreted as the result of standard-physics brain-dynamics (in *mainstream* approaches).

Level-of-consciousness paradigms (subsection 7.3.1) will be free of the netting-out problem (if hypothetical non-standard physics associated with experiential-report doesn't occur e.g. in deep sleep!). Again, however, observed differences are always interpreted in terms of standard-physics, currently. And for both content- and level-approaches, it's not just possible to separate observations into standard and non-standard physics, without the detailed simulation that's central to Section 9's approach. [Interestingly, one recent experiment *has* adopted a simulation-benchmark approach (Lee et al., 2018), although not to evaluate standard vs. non-standard physics.]

10 Objections to 'The One Experiment', and Responses

This Section addresses five common, reasonable, objections to Section 9's experimental suggestion (and then a few much less-reasonable ones!).

10.1 'We Already Know ... That Experimental Results Will Show Standard Physics'!

First, consider the claim that there's no point in doing Section 9's experiment, because *we already know* it won't detect any non-standard-physics. This objection has two sub-types, based respectively in physics and in neuroscience.

The physics sub-objection is that novel information-transfer would violate e.g. conservation of energy-momentum, and therefore it 'can't' exist (Wilson, 1999). But this just doesn't hold up. [For example, it would 'disprove' the possibility e.g. of dark-matter gravitational signatures (Trimble, 1987)!] Simply, we may need to extend the accounting-system for energy to include experience-related dynamics. Or, we may discover that some conservation laws don't hold in brains, in ways they do elsewhere (Burns, 1999). (Denying that so-called 'laws' are open to empirical examination appears to desert open-minded science, for dogmatic belief. Being *open* to changes in fundamental physics isn't caving in to anything-goes weak-mindedness, *if we insist on incontrovertible empirical evidence* – e.g. from Section 9's experiment! – before *adopting* any such changes.)

The neuroscience sub-objection is that existing brain-dynamical observations have already ‘proven’ that all human brain-activity obeys standard physics: essentially, the suggested experiment has already been completed! But this isn’t defensible. Measurements in living systems are typically nowhere near as precise as those in non-biological physics [e.g. (Attwell and Laughlin, 2001; Niven, 2016; Shulman et al., 2004)]. And analysis of brain-activity in conscious, human, subjects, precise enough to test for standard vs. non-standard physics, simply hasn’t been undertaken yet.

10.2 ‘The Brain is Too Dynamically-Sensitive to Simulate Accurately’

Next, consider arguments that brain-dynamics are dynamically hyper-sensitive, implying no amount of precision in measuring initial conditions would ever suffice for creating faithful, long-time-interval, simulations (Chen and Yu, 2003). However, such objections are empirically unproven [and arguably starting to be falsified by actual demonstrations, e.g. (Lee et al., 2018)]. In fact, meso-scale observations even suggest a kind of structural dynamical stability, rather than hyper-sensitivity (Freeman and Quiroga, 2012). Hyper-sensitivity also seems biologically-implausible. Although it may well be that certain brain-functions leverage e.g. deterministic chaos (Lorenz, 1963), widespread, pervasive, hypersensitivity would render overall brain-function subject to diversion by small internal and/or external fluctuations, which seems sub-optimal (e.g. evolutionarily).

10.3 Calibration of Numerical Parameters in the Simulation

A third type of objection – or implementational hurdle – concerns calibration of detailed simulation-models. Typically, such models contain numerical parameters which are adjusted so simulated and actual-system behaviors match. An unusual challenge associated with Section 9’s approach is that such comparison-based parameter tweaking may blend *non*-standard physical behaviors (if they exist) from actual brain-dynamics into the calibrated simulation – which is supposed to only contain *standard*-physics. Failure to address this problem might obscure experimental signals. Equally, developing a detailed brain-simulation without any calibration may be infeasible.

10.4 A Detailed Simulation May Associate with Its Own Conscious Experience!

A fourth type of objection – or implementational scenario [suggested e.g. by functionalist theories-of-consciousness (Chalmers, 1996)] – points out that a detailed-enough brain-simulation could itself become conscious! The *apparent* problem with such scenarios is that we would end up comparing conscious brains with conscious simulations. Then, seemingly, both actual and simulated data would contain ‘signatures of consciousness’. In this view, we might get *no* contrastive signals (even if consciousness is in principle ‘visible in the brain’) because consciousness-in-the-brain and consciousness-in-the-simulation would net out!

Actually, this is a non-problem (or perhaps better, completely manageable!). The issue [which is typically ignored in discussions of digital ‘consciousness’ (Carter et al., 2018; Dehaene et al., 2017)!] is *dynamical-coupling* of experiential-contents with report-dynamics. If the simulation becomes conscious (i.e. possesses experience), but that experience *doesn’t* couple with simulation-computations, simulation-output will still follow standard physics, and can provide a perfectly-good benchmark for evaluating standard vs. non-standard physics, in actual brain-dynamics. If the simulation becomes conscious and its experience *does* couple with its own computations, then *that coupling will itself be directly observable* e.g. by comparing manual execution of the simulation-program (which will lack experiential-coupling) and actual execution (which will diverge from programmed behavior, precisely when experience couples!). Thus, although ‘conscious simulations’ can’t be excluded, the

only problematic cases for Section 9's paradigm are simulations also coupling with their own experience – which can be directly detected!

10.5 A Positive Experimental Signal 'Just Doesn't Seem Very Likely'

Subsections 10.1 to 10.4 present relatively well-formed objections, which are well-met by rational responses. Another class of vague, ungrounded, objections to Section 9 claim that 'a positive signal *doesn't seem very likely*', or '*there's no reason to believe* novel information-transfers exist'. Subjective assessments of probability-of-result are impossible to meet rationally. (Somewhat ironically, given subsection 12.2's observations, such assessments constitute one of many places where science's overall process is subject to criticisms of being a subjective, rather than objective, enterprise!).

However, good experimental-resourcing decisions aren't made just on *probability*-of-positive-result – they also incorporate *significance* of potential outcomes (positive and negative). Specifically, as subsection 12.2 explains, the absence of a positive result has profound consequences not just for consciousness science, but for science as a whole. And we can only *get* a positive result – and avoid those consequences – by doing the experiment! (As subsection 11.1 notes, benefits from positive experimental signals greatly exceed merely avoiding consequences from the *absence* of such signals! But to those subjectively-attributing essentially zero probability to positive signals, only the *disbenefits* of an *absent* signal can have any present-moment decision-salience.)

10.6 Trivial, Obtuse Objections

As mentioned, subsections 10.1 to 10.4 present relatively well-formed objections, deserving rational responses. Here I address a couple of shallow, poorly thought-out, objections made by professional commentators. They are only included because of the quite extraordinary fact that people in the field actually give them weight! (But – for some comprehension of why these kinds of obtuse responses occur – see subsections 3.2 and 3.3 for schisms in and around the field, which seemingly lead to chaotic obfuscation, and keep the field trapped in a dangerously-confused state.)

10.6.1 Non-standard Physics Related to Experiential Report 'Not That Important'

One trivial objection that's been given is that a positive signal (establishing non-standard physics) would not really be that significant! An alleged-analogy is Wigner's argument that the involvement of consciousness in the 'collapse of the wavefunction' (quantum state-vector reduction) doesn't contradict some interpretations of quantum fundamentals, and so could be seen as falling within the overarching explanatory framework of current physics. Analogously, it's then been argued, discovery of non-standard physics in the brain wouldn't contradict certain interpretations of current physicalism – and therefore wouldn't be that important.

The very analogy employed here demonstrates the nonsensical nature of this argument: a putative discovery that consciousness collapsed wavefunctions would be frankly astonishing, to the mainstream of physical science! Moreover, I make no claim that non-standard report-related physics contradicts physicalism *per se*. (To the contrary, in Section 13, I describe exactly how a version of physicalism could be maintained in the face of non-standard experimental results.) But to anyone even tangentially-connected to current mainstream views in physics and neuroscience, observations of non-standard dynamical innovations in brain-dynamics, potentially associated with experiential report, would arguably be the most significant empirical observation in the last hundred years. Both Wignerian collapse and experience-to-brain coupling violate *standard* physics *as defined in subsection 1.3*.

Clearly, it is possible – and would be immensely significant! – for an observation to violate standard physics but lie within the overarching frameworks of physics and physicalism.

10.6.2 Non-standard Physics Related to Experiential Report ‘Merely Micro-Correlations’

A related and equally curious objection is that any ‘One Experiment’ positive signal would ‘merely be a micro-correlation’, and not establish any kind of causality. Of course, this is true, in one sense. *But if no such micro-correlations are observed, there can't be any science of consciousness.* Nowhere does this paper assert that non-standard observations per Section 9 are *sufficient* for a science of consciousness. (In fact, explicitly, Section 11 points out they *wouldn't* be.) But arguments in Sections 2 to 7 establish that they are *necessary*. If critics disagree with necessity arguments, they should say so (although no refutations have been forthcoming).

Furthermore, obviously (to anyone with more than a passing familiarity with developing a scientific research agenda), a ‘mere micro-correlation’ must be the starting point for any serious, subsequent, attempt to investigate causality/coupling. (For example, critics would likely argue against causality experiments, on the grounds that no correlations have yet been observed!) And one can hardly argue *for* a reliable consciousness science (the position under criticism in this paper), while simultaneously claiming that causality can never be established!

11 Positive Signals and Further Tests, Null Signals and Non-Conventional Science

This Section discusses the results Section 9's experiment could yield, and their respectively-appropriate interpretations, and next steps. Two kinds of result are discussed: a positive signal (confirming *non-standard* physics), and a null signal (actual brain-activity consistent with standard-physics). (A third natural possibility is *ambiguous* data. In this case, plausible next-steps would include developing approaches with greater resolution-sensitivity. If that's not technically-feasible, consciousness science could only exist in a contingent, uncertain, form, pending further developments.)

11.1 Positive Signals (Confirming Violation of Standard Physics)

A positive signal would of course be momentous, constituting the first discovery of fundamental ‘new physics’ in a purely-*biological* setting. Equally, however, the ‘mere’ discovery of non-standard brain-physics wouldn't *necessarily* suffice to completely establish the scientific-reliability of experiential-report. Obviously, there might (in principle) be previously-observed non-standard brain-physics that has nothing to do with conscious experience! Moreover, consequent to Section 12.4's discussions, there might be one sort of non-standard physics to do with report-of-contents, and another to do with experiencing-of-experiencing! We would need to disentangle these, and other possibilities. In summary, an initial positive signal is *necessary* for a reliable experimental science-of-experience, but may not be *sufficient*: further investigations might be required.

11.2 A Positive Signal Would Establish Another Empirical Contribution to NCC Methodology

Although the standard-physics problem for scientifically-reliable report (subsection 1.4) generalizes to *all* areas of consciousness science (subsection 7.3), detailed connections between the field's current experimental methods and a putative positive signal is perhaps best explained in the neural-correlates-of-conscious-*contents* (‘NCC-contents’) context.

Early NCC-contents approaches [e.g. (Beauregard et al., 2001; Coghill et al., 2003; Leopold and Logothetis, 1996; Melloni et al., 2007; Tong et al., 1998)] simply contrasted (Baars, 1988) brain-measurements across conditions with and without experience-of-target. Later commentaries [e.g. (Aru

et al., 2012; De Graaf et al., 2012)] pointed out that simple-contrast potentially confounds the specific correlates being sought (NCC-target, say) with prerequisite (NCC-pr) and consequent (NCC-co) processing. Further analysis (Bachmann, 2015) identified additional sub-variants and detailed inter-relationships, with a taxonomy of nine sub-components! Simply, subsection 11.1's positive signal would constitute a *tenth* contribution to NCC observations, 'NCC-npr' say, where 'npr' stands for non-standard (or 'new') physics associated with reliable report. (NCC-npr is really to do with report, not directly with phenomenal experience. So, at best it's part of the NC-of-one-kind-of-*access*-consciousness. And it's not really a *correlate* – it's a marker of information-transfer via dynamical-coupling, or loosely, part of the *causal chain* of reliable-phenomenal-report!).

Section 9's simulations may need require substantial advances in the project of disentangling the multiple *standard*-physics NCC-contributions (Bachmann, 2015; Pitts et al., 2014), if they're to reveal *non-standard* signals. This observation could be viewed as either further indication of severe technical challenges for Section 9's approach (adding *e.g.* to those already mentioned in subsections 9.2, and 10.2 to 10.4), or a synergistic overlap with a currently-pressing, existing need (somewhat in the spirit of subsection 12.3's appeal, to leveraging investments already committed to elsewhere).

11.3 Null Signals (Confirming Standard Physics)

A null signal would confirm that standard-physics alone governs *e.g.* the flow of information from sensory organs, through brain processing, to muscle-activity that generates all forms of report. This would put consciousness science in a difficult place. 'Science' usually means an integrated and coherent knowledge-system, as well as a central role for (scientifically-reliable!) experimental data. So, consciousness science should be integrated and coherent with standard physics (under a null signal), and carry out scientifically-reliable experiments about experience (which don't exist, in a conventional way, under the standard physics required by a null signal!). In summary, null signals would render conventionally-recognisable consciousness science *impossible*.

11.4 The Prospects for Consciousness Science under a Null Signal

Of course, as mentioned repeatedly, people are often subjectively certain that reports-of-experience originate in experience itself (Section 2), and that reports-of-experience are reliably accurate (Section 4). It's the latter, reliable-accuracy, that's really the minimal requirement for trustworthy consciousness science. Under a null signal's confirmation of only-standard-physics in the brain, the sole existing theoretical basis for required report-reliability would be Chalmers' immaterial comparison-in-experience (Section 4). But making this approach foundational in consciousness science has drastic consequences for the relationship between the study of consciousness and the rest of science.

11.4.1 Consciousness Science Would Be in Conflict with Current Physics

First (subsection 4.2.1), it introduces a deep divide with current physics, which doesn't recognize the validity of a real, immaterial process. (Of course, spacetime dynamics are real, and not 'made of matter'. But they're not 'immaterial', because here that really means 'having no correlate in any of the entities or constructs of current physics'.)

11.4.2 Consciousness Science Couldn't Rely on Public Declarations

Second (subsection 4.2.2), it introduces a divide between consciousness and other phenomena, in terms of the private/public nature of discourse: an immaterial comparison-process can't couple with brain-dynamics (under a standard-physics null-signal), so its results can never be made public. Because it's then possible that every participant in consciousness science has private information they *can't* declare,

third-parties can never trust public discourse: they need to participate in every experiment *themselves*, to acquire potentially-private data, and need to evaluate for themselves every theoretical argument appealing to commonly-agreed features of experience (because those 'common agreements' might be contradicted by private data). The study of consciousness would then be quite unlike the rest of science, to put it mildly!

12 Experience-to-Brain Coupling, Consciousness Science, and Science-as-a-Whole

12.1 Who's Right, Concerning Experiments-About-Experience?

A number of philosophers (Cohen and Dennett, 2011; Wilkes, 1988), physicists (Hawking, 2000) and biologists (Graziano and Kastner, 2011; Huxley, 1893) either doubt there can be a rigorous or recognisable consciousness science, or express serious concerns and argue for care (Paller and Suzuki, 2014; Phillips, 2018). (Throughout, 'consciousness' is used in subsection 1.4's 'experience-plus' sense. With this usage, denying a science of *experience* – e.g. as Dennett does – means denying a science of *consciousness*.) But a different group of investigators [e.g. (Block et al., 2014; Overgaard, 2017; Seth, 2018; Storm et al., 2017)] pursue just such a science. How can we reconcile this fragmentation?

In a sense, both sides are right! We just need to make their viewpoints contingent on whether our Universe obeys standard physics, or alternatively amended-versions allowing for specific experience-to-brain coupling (Section 8). (Although the 'how' of coupling isn't the focus of this paper, many mechanisms are available. For example: strong emergence or other classical-dynamical novelties, non-standard quantum mechanisms, or even new fundamental particle-kinds with new basic-couplings.)

12.1.1 Who's Right ... Under Standard Physics!

If the Universe obeys standard physics, Wilkes, Dennett, Hawking, and the other naysayers are right. Moreover, even 'access consciousness' approaches must be studies of information processing without any reference *at all* to experience (subsections 7.3 and 12.4). The best we could do currently is to found the study of consciousness on Chalmersian comparison-in-experience (subsection 4.1). But this doesn't give a conventionally *scientific* approach (subsection 11.4).

12.1.2 Who's Right ... Under (Specific!) Non-Standard Physics!

If the Universe obeys specific non-standard physics (Section 8), all the standard approaches of modern consciousness science (including NCC approaches, and associated analyses and theories) are scientifically-valid. And it's valid to discuss 'experience'. (Under standard physics, subsection 7.3's observations imply problems with even using the words 'conscious experience' in a scientific-setting, as subsection 12.4 discusses further.)

12.2 Standard Physics and the Conduct of Science-as-a-Whole

Clearly, whether experience-to-brain coupling exists is crucial for *consciousness* science. But it's also crucial for *science-as-a-whole*.

12.2.1 Indirect Realism Emphasizes the Role of Experience in Science's Basic Processes

When science starts to study conscious experience, it becomes clear that naïve or direct realism (Gibson, 1967) isn't viable (Lehar, 2000). (That is, a table I visually experience isn't the-material-table-in-itself, directly: it's a re-presentation, based on brain-encoded information.) In turn, discarding direct realism and adopting an indirect alternative concretizes the distinction between experienced-

table and matter-table, raising the question of *what science is about*. All of science (outside the study of consciousness!) is about *matter-tables*, *matter-bodies*, *matter-atoms*, and the spacetime in which those matter-entities are embedded. But all first-instance language appears to refer to *experienced-tables*, *experienced-bodies* and *phenomenal-space*. For science to function, it must define things like electrons, locations, and time coordinates. However, it can only approach acts-of-definition via *experienced* rather than *matter-made* entities. (For example, try defining ‘an electron’ without any reference to experience. It’s possible – but the electron so imaginarily-defined is then only hypothetically-relevant to our lived-experience, and so *to our inhabited Universe!*)

12.2.2 If Study of Experience is ‘Unscientific’, So Are the Foundations of Science!

Subsection 12.2.1 inverts criticism of consciousness science by physicists and others who deem experience to be too inherently ‘subjective’ (*i.e.* unreliable!) to qualify for scientific study (Hawking, 2000). It points out that *everything* in allegedly-*objective* science has been defined via *subjective* experience. If experience can’t be scientific, neither can any definitions in the rest of science! Similar arguments emphasize that: data collected in scientific experiments is at least accompanied by *experience*, if not directly derived from it; theoretical innovation and hypothesis-formation occur *in experience*; and, peer-review of data and theory is attributed by scientists themselves to their own *subjective* assessments *in experience*.

Although it’s possible to argue experience plays no active role in any of these steps, that pushes the onus of reliable, rational, scientific progress back onto mechanical action of biological brains. For example, scientists can’t rely on ‘clearly seeing’ that a proof holds, much in the way that a logically-consistent standard-physicist must say she *can’t* rely on ‘clearly reporting experience accurately’ (subsection 2.1). Instead, validations of proofs, and other scientific activities, are only reliable if detailed workings of the human brain are reliable. Thus, trustworthiness of science ultimately relies on a complete, future, account of how human brain-matter does science: we *can’t* currently rely on *any* subjective, experience-based, assessment – although we apparently *do*, currently!

12.3 No Experience-to-Brain Coupling Opens Science to Relevance-and-Reliability Queries

Put directly, without experience-to-brain coupling, it’s hard to know what science is about (subsection 12.2.1). And scientific activity becomes questionable, pending complete understanding of the (non-experiential) human brain (subsection 12.2.2). A few years these points might have been pedantic nit-picking. Now, with science under attack from a number of directions, and with trust in science vital for resolution of many societal problems, they are perhaps more salient.

Subsection 10.5 mentioned reluctance to advance Section 9’s suggestions, based on subjective probabilistic assessments such as ‘we’re unlikely to see a positive signal’ – and how such subjectivity can be hard to counter. The relevance of experience-to-brain coupling to science’s intellectual basis, and thus to its societal standing, is one antidote to such subjectively-sourced reluctance, because good decision-making reflects *magnitude* of potential rewards, as well as *probability* (subsection 10.5). [A further decision-consideration is the expected *cost*. Certainly, Section 9’s brain-simulations and measurement-technologies might be expensive. However, significant investments in both are already underway (Alivisatos et al., 2013; Frégnac, 2017; Markram, 2006; Poldrack et al., 2017). Thus, testing experience-to-brain coupling may be a *relatively*-marginal expense, if existing investments can be effectively leveraged.]

12.4 Consciousness Science, Revisited: How Is It We Can Even Talk About ‘Experience’?!

Science-as-a-whole depends on certain definitions. I can only define 'electrons' by first distinguishing between a matter-table – which is where the electrons are! – and an experiential-table. Making that distinction requires talking about matter-in-general and experience-in-general. But a recent paper (Chalmers, 2018) re-raises [e.g. (Bailey, 2006)] the issue of how we are able to even talk about experience, *as a general phenomenon*. Relatedly, subsection 7.3 already pointed to content-related problems in discussing 'experience' *in a standard-physics context*.

Parallels between Chalmers' 'meta-problem' and subsection 7.3 suggest a way forward, by drawing an analogy between meaningful-and-reliable report on *specific-instances-of-experience* (which we've discussed at length!), and meaningful-and-reliable report on *experience-as-a-whole* (still a mystery, at this point!).

12.4.1 Scientific Status of Coupling-Based Solutions to 'Talking About Experience'

Of course, from a *scientific* perspective, meta-problem resolutions by coupling experience-of-experience to brain-dynamics are just *hypotheses*, and it's not immediately clear how to test them *experimentally*. (However, as subsection 11.1 notes, signals for experience-of-content-coupling might be mixed with signals for experience-of-experience-coupling!) Theoretically and conceptually, proposing that brain-coupled experience-of-experience exists as a natural feature can link three major approaches to consciousness: matter-centric explanations (Kim, 2005; Mateos et al., 2017), the Gödel/quantum line (Penrose, 1989), and certain schools of non-dual spirituality (Aquinas, 1981; Brentano, 1977; Spira, 2017).

12.4.1.1 Experiencing as a Form of 'Knowing': Experiencing-of-Experiencing ...

Starting with spirituality, some non-dual approaches identify experience-of-experience as a pure form of consciousness – and propose it's this experiencing which 'knows' that experience exists. (In experience-of-experience, the 'object' of experiencing is experience 'as such', rather than a specific edge, table, or thought, as 'content'.)

12.4.1.2 Mathematical 'Knowing' as Non-Algorithmic Computation, Insight, or 'Seeing'

Next, consider the Gödel/quantum line. In one interpretation of the Penrose/Lucas approach (Lucas, 1961; Penrose, 1989), some quality of conscious experience – sometimes called 'insight' – establishes the truth of mathematical theorems that can't be proved mechanically (Heijenoort, 1990). If there's indeed a type of experiencing that can establish truth, and this truth-discernment can be applied to experience itself, we have a basis for knowing that we have experience. (Specifically, 'the *truth* of experience existing' is identical to '*knowing* we have experience' – thus linking to subsection 12.4.1.1's non-dual knowing-of-experience!)

12.4.2 An Experience-to-Brain-Coupling Solution to 'Talking About Experience (In General)'

Briefly, one neglected meta-problem solution is to couple brain-dynamics with (hypothetical!) experiential-awareness of the existence-of-experience-*itself*! (Compare Section 8's hypothetical coupling of brain-dynamics with awareness of the existence-of-specific-experiential-*contents*.) Thus, just as reliable report-of-experiential-features-in-experiments *can* exist if information-transfer concerning specific experiential-features occurs (subsection 8.2), so reliable report-of-experience-as-a-category *could* exist *hypothetically*, if Nature contains capacities *both* to reliably experience the existence-of-experience, *and* to transfer *that* information into the brain.

12.4.2.1 Matter-Based Experience Hypothetically Induces Experience-of-Experience

Finally, consider the ‘experiencing as a matter-property’ hypothesis that’s fundamental to modern, mainstream, consciousness science. Materialist/physicalist approaches could hypothesize that matter-contingent experiencing is always, inherently, *also* accompanied by experiencing-of-experiencing. (The only difference between subsection 12.4.1.1’s non-dual approach and this matter-based construction is whether experiencing/experiencing-of-experiencing is treated as fundamental or matter-contingent, respectively.) Hypothetical brain-coupling of experiencing-of-experiencing would then offer the basis for meaningfully ‘talking about experience’ – via essentially the same mechanism as in subsections 12.4.1.1 and 12.4.1.2!

12.4.3 A Unifying Scientific Frame for Radically-Diverse Narratives About Consciousness

Thus, instead of typical emphases on ontological and explanatory differences between approaches discussed in subsections 12.4.1.1 to 12.4.2, we could see them instead as *potentially* sharing a common mechanism for resolving the meta-problem (*i.e.* brain-coupling of experience-of-experience).

Scientifically, both the no-experiments-under-standard-physics problem (subsections 1.4, 2.3 and 7.3) and the meta-problem (subsection 12.4) are best viewed via experimentally-testable dynamical-couplings with the brain (respectively, with experience or experience-of-experience), rather than through arguments about metaphysics (monism, dualism and the like), explanatory style (quantum/classical, emergent, identity-theoretic, and so on) or even detailed theory [integrated information (Tononi et al., 2016), complexity (Mateos et al., 2017; Seth et al., 2011), global neuronal workspace (Baars, 2001; Dehaene and Changeux, 2011), higher-order thought (Lau and Rosenthal, 2011), Orch-OR (Hameroff and Penrose, 2014), predictive coding (Hohwy, 2013) *etc.*].

13 Summary

Unless a *specific* kind of non-standard physics holds (Section 8) (or some new insight arrives!), the non-scientifically-reliable-data-about-experience problem (subsections 1.4, 2.3, 7.3, and 12.4) renders *all* metaphysical, explanatory, and theoretical approaches *unscientific* (including those listed at the end of subsection 12.4.3). Thus, the ‘One Experiment’ (Section 9) is the missing foundation for a potential, future, consciousness science, because it can provide evidence for specifically-relevant new physics (if it exists!).

Without additional assumptions (Section 6), or novel future insights (Section 7), under standard physics there can’t be a conventionally-public, experimentally-based, integrated, science of conscious experience (Sections 0 to 7). This refutes claims by mainstream publications that they explain either experience *directly*, or report that’s interpretable as being *about* experience. (Refutation follows from mainstream journals’ contextual-presumptions of standard physics.) Minimally, such papers should explicitly declare a hypothetical, immaterial-but-real, basis for report-accuracy (thus diverging from mainstream physics and conventionally-public science; subsection 11.4), or include a rider stating that experimental methodology is scientifically-reliable only under specific amendments to standard physics (Section 8).

If standard physics applies universally (or even just specifically, in human brain-dynamics!), the problem of conscious experience isn’t ‘hard’: it’s *impossible*, scientifically speaking, because no scientifically-consistent methodology for data-collection can exist! (To be precise, it’s impossible, *unless* we discover some future way to detect conscious experience without relying on report, *e.g.* as imagined in subsection 7.1.) Note, however, that specific non-standard physical *dynamics* for a genuine science of consciousness (Section 8) aren’t an *ontological* requirement, *e.g.* denying the possibility of

physicalist consciousness science (Kim, 2005), employing only existing fundamental physical constructs. It merely – and crucially! – denies that a recognisable science of consciousness can exist if physicalism *insists on standard-physics dynamical-couplings*, between those constructs and *e.g.* putatively-emergent features-of-experience.

One aim of this paper is to provide a literature resource about the physics required for a genuine science of consciousness. As subsection 12.1 explains, the lens of experience/brain-coupling is also a way to understand the otherwise-incomprehensible fragmentation of views about consciousness science, and the related ‘meta-problem’ (subsection 12.4). Subsection 12.2 also points out that existence (or otherwise) of scientifically-reliable report-of-experience has significance far beyond consciousness science. Without experience-to-brain coupling, it’s hard to know what science is really about – or to defend it against accusations of subjectivity, or overreach (subsection 12.3). (Of course, the fact that science-as-a-whole would be supported by discovery of such a coupling isn’t *evidence* for its existence. It’s additional *motivation* for finding out *whether* it exists.)

The overarching goal of this paper, however, is to initiate discussions about ‘the One Experiment’ (Section 9). In principle, everyone interested in consciousness science should support the execution of this experiment: without it, a conventionally-recognisable science of consciousness has no firm ground. In this sense, ‘the One’ is the progenitor of all conventionally-reliable experiments-about-experience. And because of the significance of report-of-experience to science-as-a-whole (subsections 12.2 and 12.3), plus the potential for discovering new fundamental physics in a biological setting (subsection 11.1), arguably the ‘One Experiment’ should be one of humankind’s highest scientific priorities. It’s somewhat curious, then, that no-one even seems to be even talking about it yet!

Declaration of Contingent Validity

This paper’s discussion of ‘conscious experience’ (starting in the first sentence of subsection 1.1) is only scientifically-valid if Section 8’s non-standard physics exists in our Universe.

References

- Alivisatos, A. P., Chun, M., Church, G. M., Deisseroth, K., Donoghue, J. P., Greenspan, R. J., et al. (2013). The brain activity map. *Science* 339, 1284–1285.
- Aquinas, T. (1981). *The Summa Theologica of St. Thomas Aquinas*. English Dominican Translation. New York: Christian Classics.
- Aru, J., Bachmann, T., Singer, W., and Melloni, L. (2012). Distilling the neural correlates of consciousness. *Neuroscience & Biobehavioral Reviews* 36, 737–746.
- Attwell, D., and Laughlin, S. B. (2001). An energy budget for signaling in the grey matter of the brain. *Journal of Cerebral Blood Flow & Metabolism* 21, 1133–1145.
- Baars, B. J. (1988). *A Cognitive Theory of Consciousness*. Cambridge: Cambridge University Press.
- Baars, B. J. (2001). *In the Theater of Consciousness: The Workspace of the Mind*. New York: Oxford University Press.

- Bachmann, T. (2015). On the brain-imaging markers of neural correlates of consciousness. *Frontiers in psychology* 6, 868.
- Bachmann, T., and Hudetz, A. G. (2014). It is time to combine the two main traditions in the research on the neural correlates of consciousness: C= LxD. *Frontiers in Psychology* 5, 940.
- Bailey, A. (2006). Zombies, epiphenomenalism, and physicalist theories of consciousness. *Canadian Journal of Philosophy* 36, 481–509.
- Bayne, T., and Spener, M. (2010). Introspective humility. *Philosophical Issues* 20, 1.
- Beauregard, M., Lévesque, J., and Bourgouin, P. (2001). Neural Correlates of Conscious Self-Regulation of Emotion. *Journal of Neuroscience* 21, RC165.
- Beck, F., and Eccles, J. C. (2003). Quantum processes in the brain: A scientific basis of consciousness. *Advances in Consciousness Research* 49, 141–166.
- Blackmore, S. J. (2005). *Conversations on Consciousness*. Oxford; New York: Oxford University Press.
- Block, N. (2005). Two neural correlates of consciousness. *Trends in cognitive sciences* 9, 46–52.
- Block, N., Carmel, D., Fleming, S. M., Kentridge, R. W., Koch, C., Lamme, V. A., et al. (2014). Consciousness science: real progress and lingering misconceptions. *Trends in cognitive sciences* 20, 1–2.
- Boly, M., Garrido, M. I., Gosseries, O., Bruno, M.-A., Boveroux, P., Schnakers, C., et al. (2011). Preserved feedforward but impaired top-down processes in the vegetative state. *Science* 332, 858–862.
- Boly, M., Massimini, M., Tsuchiya, N., Postle, B. R., Koch, C., and Tononi, G. (2017). Are the neural correlates of consciousness in the front or in the back of the cerebral cortex? Clinical and neuroimaging evidence. *J. Neurosci.* 37, 9603–9613. doi:10.1523/JNEUROSCI.3218-16.2017.
- Brentano, F. C. (1977). *The Psychology of Aristotle: In Particular His Doctrine of the Active Intellect : With an Appendix Concerning the Activity of Aristotle's God*. Berkeley: Univ of California Pr.
- Burns, J. E. (1999). Volition and physical laws. *Journal of Consciousness Studies* 6, 27–47.
- Carhart-Harris, R. L., Leech, R., Hellyer, P. J., Shanahan, M., Feilding, A., Tagliazucchi, E., et al. (2014). The entropic brain: a theory of conscious states informed by neuroimaging research with psychedelic drugs. *Front. Hum. Neurosci.* 8. doi:10.3389/fnhum.2014.00020.
- Carter, O., Hohwy, J., Boxtel, J. van, Lamme, V., Block, N., Koch, C., et al. (2018). Conscious machines: Defining questions. *Science* 359, 400–400. doi:10.1126/science.aar4163.
- Casali, A. G., Gosseries, O., Rosanova, M., Boly, M., Sarasso, S., Casali, K. R., et al. (2013). A theoretically based index of consciousness independent of sensory processing and behavior. *Science Translational Medicine* 5. doi:10.1126/scitranslmed.3006294.

- Casarotto, S., Comanducci, A., Rosanova, M., Sarasso, S., Fecchio, M., Napolitani, M., et al. (2016). Stratification of unresponsive patients by an independently validated index of brain complexity. *Annals of neurology* 80, 718–729.
- Chalmers, D. J. (1996). *The Conscious Mind: In Search of a Fundamental Theory*. New York: Oxford University Press, USA.
- Chalmers, D. J. (2004). “How can we construct a science of consciousness?,” in *The Cognitive Neurosciences*, ed. M. Gazzaniga (Cambridge, MA: MIT Press), 1111–1119.
- Chalmers, D. J. (2008). “The varieties of emergence,” in *The Re-Emergence of Emergence: The Emergentist Hypothesis from Science to Religion*, eds. P. Davies and P. Clayton (Oxford: Oxford University Press), 244–256.
- Chalmers, D. J. (2015). Panpsychism and panprotopsyism. *Consciousness in the physical world: Perspectives on Russellian monism* 246.
- Chalmers, D. J. (2018). The meta-problem of consciousness. *Journal of Consciousness Studies* 25, 1–41.
- Chen, G., and Yu, X. eds. (2003). *Chaos Control: Theory and Applications*. Berlin ; New York: Springer.
- Coghill, R. C., McHaffie, J. G., and Yen, Y.-F. (2003). Neural correlates of interindividual differences in the subjective experience of pain. *Proceedings of the National Academy of Sciences* 100, 8538–8542.
- Cohen, M. A., and Dennett, D. C. (2011). Consciousness cannot be separated from function. *Trends in Cognitive Sciences* 15, 358–364.
- Colombo, M. A., Napolitani, M., Boly, M., Gosseries, O., Casarotto, S., Rosanova, M., et al. (2019). The spectral exponent of the resting EEG indexes the presence of consciousness during unresponsiveness induced by propofol, xenon, and ketamine. *Neuroimage*. doi:10.1016/j.neuroimage.2019.01.024.
- Crick, F., and Koch, C. (1990). Towards a neurobiological theory of consciousness. *Seminars in the Neurosciences* 2, 263–275.
- Crick, F., and Koch, C. (1995). Are we aware of neural activity in primary visual cortex? *Nature* 375, 121–123.
- Crick, F., and Koch, C. (2003). A framework for consciousness. *Nature neuroscience* 6, 119–126.
- De Gelder, B., Vroomen, J., Pourtois, G., and Weiskrantz, L. (1999). Non-conscious recognition of affect in the absence of striate cortex. *Neuroreport* 10, 3759–3763.
- De Graaf, T. A., Hsieh, P.-J., and Sack, A. T. (2012). The ‘correlates’ in neural correlates of consciousness. *Neuroscience & Biobehavioral Reviews* 36, 191–197.
- Dehaene, S., and Changeux, J.-P. (2011). Experimental and theoretical approaches to conscious processing. *Neuron* 70, 200–227.

- Dehaene, S., Lau, H., and Kouider, S. (2017). What is consciousness, and could machines have it? *Science* 358, 486–492. doi:10.1126/science.aan8871.
- Dennett, D. C. (1991). *Consciousness Explained*. Boston, MA: Little Brown.
- Elitzur, A. C. (1989). Consciousness and the incompleteness of the physical explanation of behavior. *The Journal of Mind and Behavior* 10, 1–20.
- Elitzur, A. C. (1995). Consciousness can no more be ignored. *Journal of Consciousness Studies* 2, 353–357.
- Farisco, M., Kotaleski, J. H., and Evers, K. (2018). Large-Scale Brain Simulation and Disorders of Consciousness. Mapping Technical and Conceptual Issues. *Front. Psychol.* 9. doi:10.3389/fpsyg.2018.00585.
- Festinger, L. (1957). *A Theory of Cognitive Dissonance*. Stanford, CA: Stanford University Press.
- Frässle, S., Sommer, J., Jansen, A., Naber, M., and Einhäuser, W. (2014). Binocular rivalry: frontal activity relates to introspection and action but not to perception. *Journal of Neuroscience* 34, 1738–1747.
- Freeman, W., and Quiroga, R. Q. (2012). *Imaging Brain Function with EEG: Advanced Temporal and Spatial Analysis of Electroencephalographic Signals*. New York: Springer.
- Frégnac, Y. (2017). Big data and the industrialization of neuroscience: A safe roadmap for understanding the brain? *Science* 358, 470–477. doi:10.1126/science.aan8866.
- Gamez, D. (2014). The measurement of consciousness: a framework for the scientific study of consciousness. *Front. Psychol* 5, 714. doi:10.3389/fpsyg.2014.00714.
- Gibson, J. J. (1967). New reasons for realism. *Synthese* 17, 162–172.
- Gigerenzer, G. (1991). How to make cognitive illusions disappear: Beyond “heuristics and biases.” *European review of social psychology* 2, 83–115.
- Gilovich, T. (1993). *How We Know What Isn't So: The Fallibility of Human Reason in Everyday Life*. Reprint edition. New York, NY: Free Press.
- Goff, P. (2017). Can Science Explain Consciousness? *Philosophy Now* 121, Aug/Sep 2017.
- Graziano, M. S., and Kastner, S. (2011). Human consciousness and its relationship to social neuroscience: a novel hypothesis. *Cognitive neuroscience* 2, 98–113.
- Guevara Erra, R., Mateos, D. M., Wennberg, R., and Perez Velazquez, J. L. (2016). Statistical mechanics of consciousness: Maximization of information content of network is associated with conscious awareness. *Phys. Rev. E* 94, 052402. doi:10.1103/PhysRevE.94.052402.
- Hameroff, S. R., Kaszniak, A. W., and Scott, A. C. eds. (1996). *Toward a Science of Consciousness: The First Tucson Discussions and Debates*. 1st ed. Cambridge, Mass.: A Bradford Book.

- Hammeroff, S. R., and Penrose, R. (2014). Consciousness in the universe: A review of the 'Orch OR' theory. *Physics of life reviews* 11, 39–78.
- Hawking, S. W. (2000). "The Objections of an Unashamed Reductionist," in *The Large, the Small and the Human Mind*, ed. M. Longair (Cambridge: Cambridge University Press), 169–172.
- Heijenoort, J. van (1990). *From Frege to Gödel: A Source Book in Mathematical Logic, 1879-1931*. Cambridge, Mass: Harvard University Press.
- Hohwy, J. (2009). The neural correlates of consciousness: new experimental approaches needed? *Consciousness and cognition* 18, 428–438.
- Hohwy, J. (2013). *The Predictive Mind*. Oxford University Press.
- Huxley, T. H. (1893). "On the Hypothesis that Animals are Automata, and its History," in *Collected Essays: Volume I, Method and Results* (London: Macmillan), 195–250.
- Kahneman, D., and Tversky, A. (1996). On the Reality of Cognitive Illusions. *Psychological Review* 303, 582–591.
- Kim, J. (2005). *Physicalism, or Something Near Enough*. Princeton, N.J.: Princeton University Press.
- Koch, C., Massimini, M., Boly, M., and Tononi, G. (2016). Neural correlates of consciousness: progress and problems. *Nature Reviews Neuroscience* 17, 307–321. doi:10.1038/nrn.2016.22.
- Kouider, S., De Gardelle, V., Sackur, J., and Dupoux, E. (2010). How rich is consciousness? The partial awareness hypothesis. *Trends in cognitive sciences* 14, 301–307.
- Lau, H., and Rosenthal, D. (2011). Empirical support for higher-order theories of conscious awareness. *Trends in cognitive sciences* 15, 365–373.
- Lee, H., Golkowski, D., Jordan, D., Berger, S., Ilg, R., Lee, J., et al. (2018). Relationship of critical dynamics, functional connectivity, and states of consciousness in large-scale human brain networks. *Neuroimage* 188, 228–238. doi:10.1016/j.neuroimage.2018.12.011.
- Lehar, S. (2000). The function of conscious experience: an analogical paradigm of perception and behavior. *Consciousness and Cognition* 9, 2.
- Leopold, D. A., and Logothetis, N. K. (1996). Activity changes in early visual cortex reflect monkeys' percepts during binocular rivalry. *Nature* 379, 549.
- Locke, J. (1998). *An Essay Concerning Human Understanding*. Revised edition. , ed. R. Woolhouse London: Penguin Classics.
- Lorenz, E. N. (1963). Deterministic Nonperiodic Flow. *J. Atmos. Sci.* 20, 130–141. doi:10.1175/1520-0469(1963)020<0130:DNF>2.0.CO;2.
- Mack, A., and Rock, I. (1998). *Inattentional blindness*. MIT press Cambridge, MA.
- Markram, H. (2006). The blue brain project. *Nature Reviews Neuroscience* 7, 153–160.

- Massimini, M., Ferrarelli, F., Huber, R., Esser, S. K., Singh, H., and Tononi, G. (2005). Breakdown of cortical effective connectivity during sleep. *Science* 309, 2228–2232.
- Mateos, D. M., Wennberg, R., Guevara, R., and Perez Velazquez, J. L. (2017). Consciousness as a global property of brain dynamic activity. *Phys. Rev. E* 96, 062410. doi:10.1103/PhysRevE.96.062410.
- Melloni, L., Molina, C., Pena, M., Torres, D., Singer, W., and Rodriguez, E. (2007). Synchronization of neural activity across cortical areas correlates with conscious perception. *The Journal of Neuroscience* 27, 2858–2865.
- Meng, M., and Tong, F. (2004). Can attention selectively bias bistable perception? Differences between binocular rivalry and ambiguous figures. *Journal of vision* 4, 2–2.
- Metzinger, T. (2000). *Neural correlates of consciousness: Empirical and conceptual questions*. The MIT Press.
- Mill, J. S. (2006). *An Examination of Sir William Hamilton's Philosophy and of the Principal Philosophical Questions Discussed in His Writings*. Michigan: University of Michigan Library.
- Morris, J. S., Öhman, A., and Dolan, R. J. (1998). Conscious and unconscious emotional learning in the human amygdala. *Nature* 393, 467.
- Muthukumaraswamy, S. D., Carhart-Harris, R. L., Moran, R. J., Brookes, M. J., Williams, T. M., Errtizoe, D., et al. (2013). Broadband Cortical Desynchronization Underlies the Human Psychedelic State. *J. Neurosci.* 33, 15171–15183. doi:10.1523/JNEUROSCI.2063-13.2013.
- Nieminen, J. O., Gosseries, O., Massimini, M., Saad, E., Sheldon, A. D., Boly, M., et al. (2016). Consciousness and cortical responsiveness: a within-state study during non-rapid eye movement sleep. *Sci Rep* 6, 30932. doi:10.1038/srep30932.
- Niven, J. E. (2016). Neuronal energy consumption: biophysics, efficiency and evolution. *Current opinion in neurobiology* 41, 129–135.
- Noë, A., and Thompson, E. (2004). Are there neural correlates of consciousness? *Journal of Consciousness studies* 11, 3–28.
- Odegaard, B., Knight, R. T., and Lau, H. (2017). Should a Few Null Findings Falsify Prefrontal Theories of Conscious Perception? *J. Neurosci.* 37, 9593–9602. doi:10.1523/JNEUROSCI.3217-16.2017.
- Overgaard, M. (2010). How consciousness will change our view on neuroscience. *Cognitive neuroscience* 1, 224–225.
- Overgaard, M. (2017). The Status and Future of Consciousness Research. *Front Psychol* 8. doi:10.3389/fpsyg.2017.01719.
- Owen, A. M., Coleman, M. R., Boly, M., Davis, M. H., Laureys, S., and Pickard, J. D. (2006). Detecting awareness in the vegetative state. *science* 313, 1402–1402.

- Paller, K. A., and Suzuki, S. (2014). Response to Block et al.: first-person perspectives are both necessary and troublesome for consciousness science. *Trends Cogn. Sci. (Regul. Ed.)*. doi:10.1016/j.tics.2014.09.008.
- Persaud, N., McLeod, P., and Cowey, A. (2007). Post-decision wagering objectively measures awareness. *Nature neuroscience* 10, 257.
- Phillips, I. (2018). The methodological puzzle of phenomenal consciousness. *Philosophical Transactions of the Royal Society B: Biological Sciences* 373, 20170347. doi:10.1098/rstb.2017.0347.
- Pitts, M. A., Martínez, A., and Hillyard, S. A. (2012). Visual processing of contour patterns under conditions of inattention blindness. *Journal of cognitive neuroscience* 24, 287–303.
- Pitts, M. A., Metzler, S., and Hillyard, S. A. (2014). Isolating neural correlates of conscious perception from neural correlates of reporting one's perception. *Frontiers in psychology* 5, 1078.
- Place, U. T. (1956). Is consciousness a brain process? *British Journal of Psychology* 47, 44–50.
- Place, U. T. (2012). Thirty Five Years On—Is Consciousness Still a Brain Process? *Grazer Philosophische Studien* 36, 19–31.
- Poldrack, R. A., Baker, C. I., Durnez, J., Gorgolewski, K. J., Matthews, P. M., Munafò, M. R., et al. (2017). Scanning the horizon: towards transparent and reproducible neuroimaging research. *Nature Reviews Neuroscience* 18, 115–126. doi:10.1038/nrn.2016.167.
- Popper, K. R., and Eccles, J. C. (1977). *The Self and Its Brain*. Berlin: Springer International.
- Quiroga, R. Q., and Panzeri, S. (2013). *Principles of Neural Coding*. Boca Raton, FL: CRC Press.
- Raymond, J. E., Shapiro, K. L., and Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of experimental psychology: Human perception and performance* 18, 849.
- Rees, G., Russell, C., Frith, C. D., and Driver, J. (1999). Inattention blindness versus inattentional amnesia for fixated but ignored words. *Science* 286, 2504–2507.
- Rosseinsky, N. M. (2015). The measurement of consciousness: assuming completeness of first-person report significantly restricts scope and reliability of theory-discrimination. *Front. Psychol.* 6. doi:10.3389/fpsyg.2015.00025.
- Rudd, A. (2000). Phenomenal judgment and mental causation. *Journal of Consciousness Studies* 7, 53–66.
- Rutiku, R., Tulver, K., Aru, J., and Bachmann, T. (2016). Visual masking with frontally applied pre-stimulus TMS and its subject-specific neural correlates. *Brain research* 1642, 136–145.
- Sarasso, S., Boly, M., Napolitani, M., Gosseries, O., Charland-Verville, V., Casarotto, S., et al. (2015). Consciousness and Complexity during Unresponsiveness Induced by Propofol, Xenon, and Ketamine. *Curr. Biol.* 25, 3099–3105. doi:10.1016/j.cub.2015.10.014.

- Sergent, C., Baillet, S., and Dehaene, S. (2005). Timing of the brain events underlying access to consciousness during the attentional blink. *Nature neuroscience* 8, 1391.
- Seth, A. K. (2018). Consciousness: The last 50 years (and the next). *Brain and neuroscience advances* 2, 1–6.
- Seth, A. K., Barrett, A. B., and Barnett, L. (2011). Causal density and integrated information as measures of conscious level. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 369, 3748–3767.
- Seth, A. K., Dienes, Z., Cleeremans, A., Overgaard, M., and Pessoa, L. (2008). Measuring consciousness: relating behavioural and neurophysiological approaches. *Trends in Cognitive Sciences* 12, 314–321.
- Shulman, R. G., Rothman, D. L., Behar, K. L., and Hyder, F. (2004). Energetic basis of brain activity: implications for neuroimaging. *Trends in neurosciences* 27, 489–495.
- Smart, J. J. C. (1959). Sensations and brain processes. *The Philosophical Review* 68, 141–156.
- Sperling, G. (1960). The information available in brief visual presentations. *Psychological monographs: General and applied* 74, 1.
- Spira, R. (2017). *Being Aware of Being Aware*. 1st ed. Sahaja.
- Storm, J. F., Boly, M., Casali, A. G., Massimini, M., Olcese, U., Pennartz, C. M., et al. (2017). Consciousness regained: disentangling mechanisms, brain systems, and behavioral responses. *Journal of Neuroscience* 37, 10882–10893.
- Strickland, L. (2014). *Leibniz's Monadology: A New Translation and Guide*. Edinburgh: Edinburgh University Press.
- Taylor, R. (1963). *Metaphysics*. First. Englewood Cliffs, NJ: Prentice-Hall.
- Todd, J. J., Fougner, D., and Marois, R. (2005). Visual short-term memory load suppresses temporo-parietal junction activity and induces inattention blindness. *Psychological science* 16, 965–972.
- Tong, F., Nakayama, K., Vaughan, J. T., and Kanwisher, N. (1998). Binocular rivalry and visual awareness in human extrastriate cortex. *Neuron* 21, 753–759.
- Tononi, G., Boly, M., Massimini, M., and Koch, C. (2016). Integrated information theory: from consciousness to its physical substrate. *Nature Reviews Neuroscience* 17, 450–461. doi:10.1038/nrn.2016.44.
- Trimble, V. (1987). Existence and nature of dark matter in the universe. *Annual Review of Astronomy and Astrophysics* 25, 425–472.
- Tsuchiya, N., and Koch, C. (2005). Continuous flash suppression reduces negative afterimages. *Nature neuroscience* 8, 1096.

- Tsuchiya, N., Wilke, M., Frässle, S., and Lamme, V. A. F. (2015). No-Report Paradigms: Extracting the True Neural Correlates of Consciousness. *Trends in Cognitive Sciences* 19, 757–770. doi:10.1016/j.tics.2015.10.002.
- Varela, F. J., and Shear, J. (1999). First-person methodologies: What, why, how. *Journal of Consciousness studies* 6, 1–14.
- Vernet, M., Brem, A.-K., Farzan, F., and Pascual-Leone, A. (2015). Synchronous and opposite roles of the parietal and prefrontal cortices in bistable perception: a double-coil TMS–EEG study. *cortex* 64, 78–88.
- Wilkes, K. V. (1988). “---, yishi, , duh, um, and consciousness,” in *Consciousness and Contemporary Science*, eds. A. Marcel and E. Bisiach (Oxford: Clarendon Press), 16–41.
- Wilson, D. L. (1999). Mind-brain interaction and violation of physical laws. *Journal of Consciousness Studies* 6, 8–9.