In press 2024, *Psychological Review*

Theories of Consciousness from the Perspective of an Embedded Processes View

Nelson Cowan, Nick I. Ahmed, Chenye Bao, Mackenzie N. Cissne, Ronald D. Flores, Roman M. Gutierrez, Braden Hayse, Madison L. Musich, Hamid Nourbakhshi, Nanan Nuraini, Emily E. Schroeder, Neyla Sfeir, Emilie Sparrow, and Luísa Superbia-Guimarães

University of Missouri, Columbia, Missouri

Author Notes

This review was carried out in conjunction with a graduate seminar on research on consciousness, and all co-authors contributed to the conceptualization and writing. Author names after the first author were simply placed in alphabetical order. The work was supported by NIH Grant R01 HD-21338 to Cowan. There are no data or study materials. The study was not preregistered.

Address correspondence to Nelson Cowan, Department of Psychological Sciences, University of Missouri, McAlester Hall, Columbia, MO 65211 USA. E-mail: CowanN@missouri.edu. Tel. 573-882-4232.

Abstract

Considerable recent research in neurosciences has dealt with the topic of consciousness, even though there is still disagreement about how to identify and classify conscious states. Recent behavioral work on the topic also exists. We survey recent behavioral and neuroscientific literature with the aims of commenting on strengths and weaknesses of the literature and mapping new directions and recommendations for experimental psychologists. We reconcile this literature with a view of human information processing (Cowan, 1988; Cowan et al., 2024) in which a capacity-limited focus of attention is embedded within the activated portion of long-term memory, with dual bottom-up and top-down control of the focus of attention. None of the many extant theories fully captures what we propose as the organization of conscious thought at cognitive and neural levels. It seems clear that information from various cognitive functions, based on signals from various brain areas, is integrated into a conscious whole. In our new proposal, the integration involves funneling information to a hub or focus of attention neurally centered in the parietal lobes and functionally connected to areas representing the currently-attended information. This funneling process (bringing information from diverse sensory and frontal sources to contact a small parietal area where attended information is coordinated and combined) may be the converse of global broadcasting, from other proposals (Baars & Franklin, 2003; Baars et al., 2021; Dehaene & Changeaux, 2011). The proposed system incorporates many principles from previous research and theorization and strives toward a resolution of the relation between consciousness and attention.

Key words: consciousness, attention, embedded processes model, experimental psychology, neuroscience

Theories of Consciousness from the Perspective of an Embedded Processes View

Research on consciousness can serve not only a theoretical and philosophical aim of understanding the human mind (Block, 1995; Chalmers, 1995) but also a practical aim of improving peoples' perspective-taking based on understanding other peoples' experiences (Cowan et al., 2019). Consciousness is a topic of great fascination for many experimentalists but one that comes with warnings. We suspect that many experimental psychologists are motivated to do their research based partly on their own conscious experiences and an interest in consciousness but are never quite sure how they can incorporate the concept of consciousness into an experimental research approach. There is a hard problem of consciousness that philosophers decry (Chalmers, 1995), on one hand, and a set of tractable methods that psychologists espouse, on the other hand (e.g., Shiffrin & Schneider, 1977; Sperling, 1960), but there is a gap between them. How should they be combined for a good way forward in examining consciousness scientifically, with the aim of understanding its nature?

The Current Theory

To facilitate research on consciousness, we examine the behavioral and neuroscientific literature and propose a theoretical view about the organization of consciousness in the brain and mind that extends work done previously to understand perception, attention, and memory, an *embedded-processes view* (Cowan, 1988, 1995, 1999, 2019; Cowan et al., 2024). In brief, the model holds that the memory system can include temporarily activated elements, including both retrieved and newly-learned information (perhaps not yet completely consolidated) and that, within this activated portion, a subset limited to a few separate ideas or chunks can be held in the focus of attention. The information included in the focus is governed partly by aspects out of the participant's control, including incoming stimulation that is discrepant with the current neural model of the environment based on all processing that has been done on it (not all semantic information is included), and partly by voluntary control. There are brain regions thought to be closely associated with each function: (1) the representation of environmental information largely in posterior brain regions: these are sensory and associative cortical regions, such as mainly occipital regions for visually coded stimuli or thoughts and predominantly temporal regions for verbal or acoustically coded stimuli or thoughts, and regions for other senses; (2) the focus of attention largely in the intraparietal sulcus (IPS): it coordinates the attended sensory information coming from posterior regions and conceptual information that may derive from frontal as well as posterior regions, and it forms new associations between currently attended elements; and (3) voluntary control of attention and processing in frontal brain regions, and especially the lateral prefrontal cortex: it links to the IPS to help control its contents. There must be a distribution of common information among areas so that they can communicate (e.g., some information about sensation in every area), but with a difference in which kinds of information are in most detail in each area. In the extension of the model to consciousness, funneling of information from various perceptual and conceptual functions to the focus of attention in the IPS is said to be the basis of consciousness. This can include information from sensory areas upward, and also re-entrant processing from higher levels downward. Other, unconscious processing can take place via activated elements of long-term memory outside of conscious awareness. We show that this theory comports with a wide range of behavioral and brain evidence and uses important concepts borrowed from other theories, though funneling may be new to this theory.

Outline of the Article

Key questions we address to further the aim of establishing an adequate theory on a solid basis include (1) the meaning of the term consciousness and of two related terms, attention and working memory; (2) the relation of this review and of our embedded-processes theoretical approach to other research on consciousness; (3) our current diagnosis of the hard problem; (4) in an Appendix referred to at this point, a brief survey of empirical topics that can be studied from our view; (5) evidence for the neural underpinning of consciousness; (6) an analysis of some leading theories of consciousness; and (7) our own proposal of embedded processes with funneling and its relation to the other theories. Throughout, we also acknowledge that there is much more work to do and suggest what research topics would be most fruitful and decisive relative to aspects of the embedded-processes account.

Our Use of Key Terms: Consciousness, Attention, and Working Memory

Our understanding of the meaning and description of three terms, consciousness, attention, and working memory, is important for our argument. Therefore, before proceeding, we characterize our assumptions about these terms.

Consciousness

The issue of consciousness is so elusive and diversified that we found the following answer on Wikipedia (2023), which summarized a long history of the term. There it is explained that "Many philosophers and scientists have been unhappy about the difficulty of producing a definition that does not involve circularity or fuzziness… Sutherland [(1989)] expressed a skeptical attitude more than a definition: "Consciousness—The having of perceptions, thoughts, and feelings; awareness. The term is impossible to define except in terms that are unintelligible without a grasp of what consciousness means. Many fall into the trap of equating consciousness with self-consciousness—to be conscious it is only necessary to be aware of the external world. Consciousness is a fascinating but elusive phenomenon: it is impossible to specify what it is, what it does, or why it has evolved. Nothing worth reading has been written on it."

We do not agree with that pessimistic view attributed to Sutherland (1989), and much has changed lately. A key distinction in the field is that established by Block (1995) between *phenomenal consciousness*, often termed P-consciousness, and *access consciousness*, often called A-consciousness, and we start there. Then we address the issue of what limits should apply when these two types of consciousness are combined. We examine attempts to distinguish between phenomenal and access consciousness empirically, introduce a three-part distinction regarding consciousness, and provide some recommendations for experimentalists.

Phenomenal consciousness. Phenomenal consciousness refers to the subjective, qualitative character of conscious experience, often characterized as the what-it-is-likeness of being in a conscious mental state (Block, 1995; Nagel, 1974). It contains the raw, subjective, qualitative experiences of sensory experience, emotions, mental states, pain, pleasure, color, taste, and so on. Different organisms may have different experiences. For example, we might surmise that a bat experiences location and all the geometrical properties of its surroundings differently than a human being, inasmuch as bats rely much more heavily on echolocation to navigate. Phenomenal consciousness and its nature have been a matter of debate since ancient Greek philosophers but have received more philosophical attention in the post-Cartesian era. (Hutchinson, 2018 & Mortley, 2013). Key to the notion is that one has a privileged access only to one's own P-consciousness and must infer that of others through any available evidence (primarily, verbal reports, but also inferences made from other aspects of behavior and physiology combined). The definition of phenomenal consciousness is often taken to be synonymous with consciousness, and access consciousness is then overlooked. Therefore, each study must be considered while keeping in mind the implied (if not stated) definition of consciousness.

Access consciousness. The definition of access consciousness changed over the years. Block (1995) suggested that only access consciousness was reportable. However, it is not clear what counts as reportable; do nonverbal actions in response to information count? Block (2011) later proposed that contents of access consciousness are identical to the contents of working memory. Carruthers (2017) argued that according to Block's first definition, contents are in access consciousness when they are available to the control systems (reasoning, speech, action etc.); whereas his second definition suggests that information is in access consciousness only if it is set to be an input to the decision-making systems.

In keeping with the later definition, Block (2005, p. 1364) stated that "Phenomenally conscious content is what differs between experiences as of red and green, whereas access conscious content is content information about which is 'broadcast' in the global workspace. Some have accepted the distinction but held that phenomenal consciousness and access consciousness coincide in the real world…Others have accepted something in the vicinity of the conceptual distinction but argued that only access consciousness can be studied experimentally…Others have denied the conceptual distinction itself." Block went on to argue that the distinction helps make sense of recent neurological findings. According to this distinction, an organism with phenomenal consciousness but without access consciousness might engage in information processing and be aware of the information processing (have a subjective experience of it) and yet not enter that subjective experience into any kind of narrative or overall timeline of experiences.

It is not clear to us if an organism could be without phenomenal consciousness, but with access consciousness; it seems like the latter is built on the former. Phenomenal, as well as access, consciousness theoretically could include not only perceptions, but also thoughts (Nourbakhshi, in press; Sfeir & Aleksander, 2023). The distinction might be designed in part to distinguish between lower animals with presumably phenomenal consciousness but little or no access consciousness (such as slugs and reptiles) and more cognitively advanced animals with both types (such as crows, dolphins, and primates including, of course, humans). In our theory, the focus of attention must mediate access consciousness, whereas the theory is still noncommittal on whether some rudimentary version of phenomenal consciousness could exist without a focus of attention comparable to what adult humans and advanced organisms have.

Attention

We use the term attention to mean carrying out one kind of processing at the expense of another kind of processing, i.e., referring to selective attention. To characterize attention to a certain kind of processing, it is useful to distinguish between the *direction* of attention, or what exactly is attended, and two other basic qualities that describe how well it can operate: its *intensity*, or how much can be attended at once and how securely, and its *consistency*, or how well and for how long it can stay on goal-related information (Unsworth & Miller, 2021).

In our theory, selective attention always involves placing some selected information in the capacity-limited focus of attention, where it becomes conscious. There are at least two challenges to that description. First, when a target word is presented and masked so quickly at an attended location that it cannot be reliably detected, it still is processed outside of awareness and causes semantic priming (Balota, 1983; Marcel, 1983). The key for us is that although the spatial location of the target word is attended, the word itself does not reach the focus of attention and presumably is processed unconsciously. Another challenge is attribute amnesia (e.g., Chen et al., 2018), in which an attribute of an item can be used fleetingly on every trial (e.g., *is this briefly-*

presented color patch accurately described by the previous color word?) but is found not to be memorable when a surprise question is instead asked (e.g., *what was the color of the patch?*). It is possible that people learn to make the expected judgment automatically, without the information entering the focus of attention (cf. Shiffrin & Schneider, 1977). Alternatively, information may be entered into the focus of attention so briefly that it is not memorized.

Working Memory

The term working memory is used here generically to refer to the small amount of information that can be held in an accessible form temporarily and can be used to carry out various cognitive tasks including, for example, problem-solving and language use. Usually, an investigator's description or definition of working memory (if one is offered at all) is tied to assumptions and to the phenomena of most interest. Cowan (2017) identified at least nine different stated or implicit definitions of working memory in the research literature (e.g., the information used to carry out plans, a multicomponent system, a system that includes both storage and processing, and the use of attention to retain goals along with data) but all of the definitions might more or less be subsumed under the generic definition we have offered.

The most theory-laden aspect of the definition we offer is what is meant by a small amount of information being held temporarily. As summarized by Cowan et al. (2024), two components of working memory are assumed to be limited in different ways. One component, not consistently in consciousness, is the activated portion of long-term memory, including newly-learned information (some of it probably not yet fully consolidated into memory). An item within this aspect of working memory may decay to inactivation over time if it is not rehearsed or refreshed, and it may suffer interference from other information. The second component, the focus of attention, is a subset of the activated memory that is supposed to be limited in terms of the number of chunks held. Within confines of a basic limit of 3-5 chunks (Cowan, 2001), a huge amount of information can be kept at the ready. For example, the focus of attention may hold "Mary, Star, Mulberry" as a short way to refer to three different song titles, which in turn can allow the retrieval and performance of three different entire songs, all from that small amount of storage, provided that it can be maintained in the focus of attention or returned to focus when needed. The contents of the focus may also be made into a newly-learned complex (e.g., a learned 3-word series), in which case it can be off-loaded to activated memory outside of attention, allowing attention to be free for other material (Rhodes & Cowan, 2018).

Relation of our Approach to Other Research on Consciousness

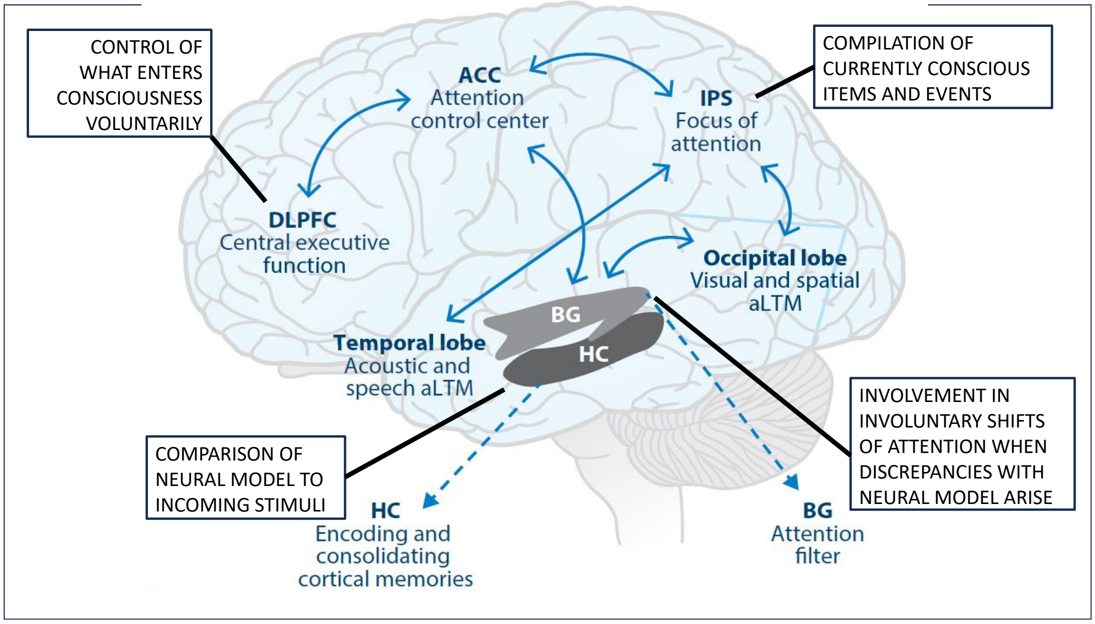
The goal of our exploration is to understand the mapping between cognitive and neural concepts, suggest a model, and suggest what work still needs to be done. Our theoretical starting point is the embedded processes model (e.g., Cowan, 1999), which rests on traditional experimental work and its relation to neuroscience, as we now explain.

Embedded Processes Model

We take as a starting point for our inquiry the embedded processes model of Cowan (1988, 1995, 1999, 2005, 2019) illustrated neurally in Figure 1. This figure arose from previous consideration of the mechanisms of attention and memory (Cowan et al., 2024) but, here, four boxes have been added to make clear the implications of this scheme for consciousness. In this model, working memory -- information that is temporarily in a state of heightened accessibility -- consists of (1) the temporarily activated elements of long-term memory (aLTM) and, embedded with that activated portion, (2) contents of the current focus of attention, which is limited at any time to several chunks (integrated items, clusters, or events) represented in posterior cortex (e.g., occipital lobes for visual information and temporal lobes for verbal information) and connected to the focus of attention represented by the intraparietal sulcus (IPS). Information can be rapidly memorized so that it can become part of activated long-term memory even within a single immediate memory trial. For example, a participant might memorize the series 3-4-1 as a step toward trying to remember a longer series of digits. Control of the current focus of attention depends on (1) bottom-up, automatic recruitment of attention, caused by sudden physical changes in the environment (e.g., a door slamming), meaningful information that is fleetingly sampled by the focus of attention (e.g., someone speaking one's name behind one's back), or a thought that grabs attention (e.g., remembering that one is late for an appointment); and (2) top-down, deliberate control of the focus of attention (e.g., concentrating on a lecture to serve the larger goal of getting a good grade in a course). The focus of attention can be jointly controlled by these bottom-up and top-down factors (e.g., if a lecturer is interesting and engaging and speaks in an animated voice). The result of several items sharing the focus of attention is that a new, integrated episode in memory is formed from the combined contents of the attentional focus.

Figure 1

Embedded Processes Model With Some Assumptions About Consciousness Stated



Note. ACC=anterior cingulate cortex, DLPFC=dorsolateral prefrontal cortex, IPS-intraparietal sulcus, BG=basal ganglia, HC=hippocampus and related structures, aLTM=activated portion of long-term memory. Adapted from Cowan et al. (2024, *Annual Review of Psychology*, Figure 3b). The four boxes indicate the involvement of various areas in consciousness and were not included in Cowan et al.

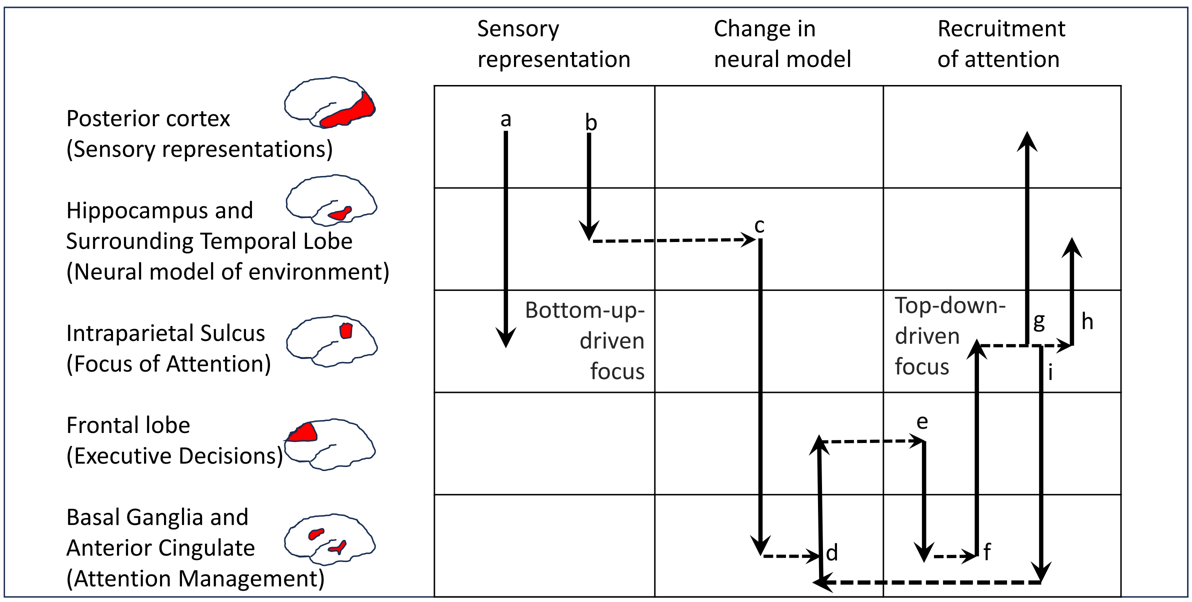
In the embedded processes model (Cowan, 1988, 1999, 2019; Cowan et al., 2024), it is presumably the focus of attention that corresponds to information in conscious awareness. That information in conscious awareness can come from sensory input, from temporarily-activated representations in long-term memory, or from some combination of the two. Abstract concepts, rules, and goals may arise with the benefit of frontal regions, leaving representations that can be included in activated long-term memory and the focus of attention. The four boxes added to Figure 1 show the roles of the various areas in consciousness. Although the IPS is considered both the seat of attention and of consciousness, top-down control of attention derives more from frontal areas and involvement of the anterior cingulate cortex, and bottom-up influences on attention come from a neural model based on hippocampal processing and involvement of the basal ganglia.

Although we respect this dichotomy between bottom-up and top-down influences, we note that the interaction of these influences is critically important. Gaspelin et al. (2023) demonstrated that top-down influences can suppress bottom-up distraction from physically distinct, salient items. Further, Awh et al. (2012) proposed that the selection and reward history of a stimulus also affect its subsequent selection, even when the stimulus is not related to the participant's current top-down goals. We would point out, though, that one task of top-down attention may be to explore the environment to pick up unforeseen and unexpected significances. In one relevant case, in selective listening, an acoustic channel to be ignored contains the participant's own name (a stimulus with a special presentation and reward history). Among young adults, it is the lower-span participants who more often notice their names (Conway et al., 2001; Naveh-Benjamin et al., 2014; Röer et al., 2021). The interpretation has been that higher-span participants more strongly restrict their attention to goal-relevant information, whereas in lower-span individuals attention wanders more, allowing the name's history to come to the fore. It is not completely clear whether this application of attention to the stimulus history should be considered top-down driven (if exploration and use of the stimulus history is considered top-down) or not (if attentive sampling of the channel to be ignored is involuntary).

Many researchers of consciousness (e.g., Tsuchiya & Koch, 2016) argue that consciousness is dissociable from top-down attention (voluntary, conceptually-driven attention as opposed to involuntary, perceptually-driven, bottom-up attention) and two points should be emphasized here. (1) Our view is compatible with the statement that top-down attention processes are separate from consciousness but, nevertheless, (2) our view suggests that the seats of attention and consciousness are one and the same; the focus of attention is where the results of attention are experienced (including some, but not complete, awareness of top-down as well as bottom-up processes). We will later discuss research supporting this embedded processes approach. Figure 2 provides a more detailed summary of how the key areas in Figure 1 could contribute to the overall direction and control of attention and consciousness in the model.

Figure 2

Illustration of the Neural Basis of Proposed Phases of Attention



Note. Solid lines (with letters) represent transfer of signals from one brain area to another, whereas dashed lines (not labeled with letters) represent temporal continuity in the flow of information within an area. In bottom-up attention, sensory information from the posterior cortex (occipital for visual, temporal for audioverbal, etc.; the activated portion of long-term memory) is (a) transmitted to the focus of attention and consciousness involving the intraparietal sulcus (IPS), and (b) is also transmitted to the hippocampus and surrounding temporal lobe areas that coordinate a neural model of the environment. If the hippocampal-related areas detect a change in the neural model, (c) a signal is sent to some parts of the attention management centers, which include the basal ganglia and anterior cingulate, and then is sent (d) to the frontal lobe, specifically including the lateral prefrontal cortex, which (e) directs some of these areas to (f) contact the IPS. This redirects the focus of attention and consciousness. This redirection now leads to the possibility of top-down control toward the salient stimulus or whatever is deemed most important. The intraparietal sulcus (g) is functionally connected to posterior cortical areas for the attended information, (h) sends relevant information for storage in hippocampal areas, and (i) communicates with the help of attention management centers that allow the frontal areas to continue to act as decision areas to direct top-down attention in a frontal-parietal loop that continues with phase (d). At all phases, **consciousness consists of the activity funneled from**

other areas of the brain through the intraparietal sulcus (i.e., brought from diverse areas into a single area), along with the constellations of activity functionally connected to the IPS (both inputs and outputs to other regions). The nature of that activity determines the level of consciousness (from Tulving, 1985: anoetic, noetic, or autonoetic; based on Norman et al., 2019: we suggest a fourth level might be metacognitive, awareness about the lower three levels, consistent with higher-order thought notions of Seth & Bayne, 2022). This scheme omits the contributions of thalamic areas to maintenance of cortical activity underlying consciousness (e.g., Redinbaugh et al., 2020).

Relation to Traditional Work in Experimental Psychology

There are means to begin to determine what information is in consciousness, such as verbal report, actions in a context such that they seem deliberate, and behavioral signs of the participant having been alerted. If one accepts these signs, then the topic of consciousness is an old one in experimental psychology. In part, it dates back to the first laboratory of psychology under Wilhelm Wundt, who emphasized the participant's state of mind while responding to stimulation (Cowan & Rachev, 2018). The topic of consciousness is strongly represented in the psychology text by William James (1890), which describes a difference between deliberate actions and automatic habits, and describes primary memory as the conscious subset of memory. Modern research further operationalized a distinction between controlled actions (typically conscious) and automatic actions (habits not necessarily conscious and not easily controlled by human will) (Shiffrin & Schneider, 1977). Such investigations included those on animals and humans being alerted to sudden or meaningful environmental changes, producing behavioral and physiological orienting responses (Sokolov, 1963), such as a rabbit turning its ears in the direction of a sudden sound.

Based on the aforementioned phenomena, we can distinguish between conscious, deliberate thoughts and behaviors versus automatic, uncontrolled mental and motor processes. As we will see, a difficulty is that one can find some situations in which the inferences about consciousness from these same modes of behavior are questionable (e.g., sleep-talking, and impulsive, automatic actions). The best one can do may be to seek convergent evidence from more than one measure pointing to the conscious state of the individual or of information conveyed by that individual.

Relation to Brain Research

The recent wave of research on consciousness centers on theories of how it is enacted in the brain. These neurally-based theories have important implications for behavioral, cognitive research. One caution from that research is that it may not be warranted to assume from manipulations affecting attention that one knows which information is in consciousness and which is not; there could be information that is in some sense attended, yet not in consciousness, or vice versa, i.e., in consciousness but not attended (e.g., Tsuchiya & Koch, 2016). This newer research looks for neural confirmation of what is and is not part of consciousness, in ways we will describe later (e.g., brain patterns associated with an awake and alert state as opposed to sleep, drowsiness, anesthesia, or coma). For example, Boly et al. (2008) used magnetic resonance imaging to show impairment of the associations between the frontal-parietal and cingulate areas with altered states of consciousness.

Neural Basis of Embedded Processes

Our goal is to consider consciousness in a measured manner that considers the great difficulties of the topic while still exploring what advances seem possible and feasible. As a beginning to understanding the relation between behavior, neuroscience, and consciousness, Figure 1 (from Cowan et al., 2024) summarizes our proposal as to how the embedded processes conception may be implemented in the brain and how it relates to consciousness.

Representation of information inside and outside of the focus of attention. Much of cognition is thought to occur outside of conscious awareness. In the model shown in Figure 1, areas within the parietal lobe keep track of information represented in various posterior brain regions that contain the information currently in consciousness. Thus, these parietal areas serve as a hub with a compendium of pointers to the information in the focus of attention. Our compendium of pointers may be the same as the priority map influenced by stimulus input, memory of the stimulus history, and top-down executive direction (Awh et al., 2012). We add to this that the pointers can be bound to one another or associated in a manner leading to a new integrated memory of the current scenario or event, which is then stored in long-term memory.

Information in what the model calls the activated portion of long-term memory but not currently in the focus of attention has been claimed to be neurally silent, i.e., represented by chemical or physical attributes of nerve cells in the absence of neural firing (Lewis-Peacock et al., 2012; Rose et al., 2016) or neurally active in a way different from information in the focus of attention (Christophel et al., 2018; Iamshchinina et al., 2021) and resolution of that issue will lend clarity to what it means neurally for information to be cognitively in the activated portion of long-term memory; is it neurally active or neurally silent?

Role of top-down attention and executive control. It has been asserted that deliberate or top-down attention is not the same thing as consciousness (Tsuchiya & Koch, 2016). That claim is not problematic for our view. Top-down attention is a process controlled by frontal areas (in coordination with the basal ganglia, e.g., Baier et al., 2010; Chang et al., 2007). They reflect executive control of behavior and help to determine what gets into the focus of attention (in our view, consciousness). They are not always successful because they are in competition with bottom-up attention from orienting responses to novel or meaningful stimuli, which depends on areas other than the frontal regions as shown in Figure 1. Thus, the information from top-down and bottom-up sources is funneled into the focus of attention, which is the capacity-limited core of working memory and conscious perception that can consider only several separate chunks of information, whether these chunks come from present stimuli (in perception) or other sources, such as long-term memory, thought, and imagination (in working memory). Because a chunk can be unpacked to contain a large amount of information (e.g., the title of a song representing its melody and lyrics) a limited capacity can represent complex thoughts.

Differences from a global workspace view. Like our view, the global workspace theory (Baars et al., 2013, 2021; Dehaene & Changeux, 2011), to be further discussed when competing theories are also considered, postulates that there is a central role of working memory in consciousness. Our theory differs from that one primarily in two ways. First, we believe that the focus of attention that is the basis of consciousness is only part of the available information that we call working memory which, by our definition, is not entirely conscious. It includes not only information in the focus of attention (both from current stimuli and from attended information in memory), but also information in activated long-term memory that is not currently part of consciousness but is temporarily easy to retrieve into the focus and into consciousness. Second, whereas Baars et al. suggest a process of "broadcasting" of information from the sensory areas to other brain areas when they enter consciousness, our conception involves more central control so that the information is seen not as broadcast from sensory areas but, rather, funneled from these areas to the IPS as a focal point of consciousness. Information that is attended becomes functionally connected between the IPS and areas representing information currently in the focus of attention. Contrast this for example with Baars et al. (2021), who said, "Deco et al. (2021) define a functional 'rich club' of active cerebral nodes and connectivities that may function as a dynamic global workspace, one that is not rigidly tied to a single anatomical region of cortex. There may be other ways to identify global workspace dynamics, but this appears to be a well-specified candidate."

The notion of funneling of information to the IPS incorporates capacity limits, making it seem more restricted than the conception of global broadcasting. Funneling is supported by the notion of structural and functional connectivity between the IPS and areas representing attended information (J.S. Anderson et al., 2010; Li et al., 2014). This process of funneling information to key areas that serve as a compendium of information in the focus of attention seems different in emphasis from the global workspace, for which Baars et al. (2021) described consciousness as "the product of highly integrated and widespread cortico-thalamic (C-T) activity."

Role of the frontal lobe. One of the primary debates in the field of consciousness has been regarding the role of the frontal areas versus the posterior areas. Although the frontal areas are often active when the participant reports a conscious experience, Tsuchiya and Koch (2016) have argued that these frontal areas are mediating control of behavior (such as reporting a conscious event). When the need to report is removed, the frontal areas become much less active. Therefore, activity in the more posterior areas would be the substrate for the representation of at least sensory information in conscious experience. This distinction makes sense in light of the general observation that damage to frontal areas of the brain often results in difficulties with the executive control of behavior, whereas damage to posterior areas more often results in disorders of consciousness, such as blindsight (inability to see what is in part of the visual field, but without losing the ability to respond to that information) and anosognosia (absence of awareness about paralysis of a limb) (for reviews see Cowan, 1995, 2019; Cowan et al., 2024). Sensory and association areas connected to the IPS are, we believe, needed for awareness of the environment, but frontal areas may only exert control of this awareness.

Necessity but insufficiency of the IPS. It stands to reason that the IPS cannot operate in isolation to produce consciousness of a given piece of information; it needs the relevant input from other regions. Consider the case of blindsight, in which damage to the visual cortex can result in preserved perceptual discrimination, presumably through subcortical areas, but without conscious awareness of the stimuli in the visual field of the damaged region. The absence of cortical input would leave the IPS with insufficient evidence to be aware of these stimuli. Perhaps a bit more difficult to explain, though, is the finding that a visual attention cue indicating which part of the blind field will receive a stimulus can speed perceptual judgments regarding the stimulus despite its invisibility to the patient (Kentridge et al., 2008). Our account of this phenomenon would once more emphasize the distinction between the control of attention and the focus of attention (cf. Majerus et al., 2018). Frontal areas mediating the control of attention might be able to sensitize subcortical regions that provide the residual perceptual information while, at the same time, the cortical circuit from the occipital regions to the IPS that would provide conscious information about the stimulus is not operating. Consequently, successful control of attention would occur in this case with the focus of attention perhaps anticipating, but then not receiving, sensory input.

Teleological Function of Consciousness

While theories of consciousness differ widely, most theorists suppose that consciousness is likely to serve a purpose in enhancing important cognition functions (e.g., Mansell, 2022), though there is disagreement even about that; consciousness could be epiphenomenal rather than useful (Rosenthal, 2008). We would suggest that a key function of consciousness is that it is something that an organism is reluctant to lose. Young children often struggle to stay awake so as to avoid missing anything, organisms struggle not to die, and humans struggle to perpetuate the posthumous survival of their experiences and point of view. Even if all cognitive integration could occur without consciousness, it would still presumably be a benefit of consciousness to provide a strong motivation for survival, probably also contributing a motive to promote survival of the social group and species.

One can ask whether performance is impaired when conscious thought is missing. We believe it is. In the case of aphantasia, the absence of visual imagery, Dupont et al. (2024) reported impairments of mental simulations and action language. In the less-studied case of anendophasia, not having an inner voice (Nedergaard & Lupyan, 2024), there were consequences when the phonological representations of words were important, and many kinds of conversational topics were impeded. These disabilities were relatively mild, allowing sufficient daily living but we would predict that if an individual had both of these types of deficient mental imagery, both visual and verbal, then cognitive functioning would be profoundly impaired. (In evaluating such a case, caution would have to be taken to ensure that the deficit was not constructed merely from an unusual cognitive misunderstanding of the difference in vividness between percepts and mental images: see Dijkstra et al., 2023.)

Next, we will consider the types of research that contribute to our understanding of consciousness, some recent theories from the neural viewpoint, and how we assess their contributions. Then we will return to our funneling thesis, with factors that have been brought up to be considered and compared to the embedded processes approach.

Combination of the Types of Consciousness in Embedded Processes

One way to explore the distinction in humans is to examine items and events that we seem to be conscious of but that do not enter a capacity-limited part of working memory (for example, unattended speech information in the selective listening procedures of Broadbent, 1958; characters in a large array that are not cued for partial report in Sperling's 1960 procedure;

the background scene in inattentional-blindness procedures summarized by Simons, 2020). If the entire suprathreshold sensory environment is entered into awareness in some form, it still seems likely that many objects and events within the scene are not *individuated* in consciousness and the focus of attention. Thus, awareness of a forest and some of its statistical properties across trees (see Chong et al., 2008) could fit in the focus of attention and does not imply awareness of the properties of any particular individual tree, though the existence of many such trees and some of their properties can be deduced from the awareness of the forest. The unindividuated scene might qualify as phenomenal consciousness, but the scene's gross summary properties along with only a few of its individual elements can qualify at any moment for access consciousness.

Experimental Attempts to Separate Phenomenal and Access Consciousness are Incomplete

There have been recent attempts to separate phenomenal and access consciousness experimentally in humans but we are not sure that the aim has yet been achieved. Bronfman et al. (2014) carried out an experiment to show phenomenal consciousness of more than participants could enter into their access consciousness. By showing participants arrays of letters with some rows diverse in print colors and other rows not diverse, they proposed that the large-pattern aspect of the whole display (the pattern of color diversity) was encoded into phenomenal consciousness, while the specific letter identities (few letters in a cued row) were encoded into access consciousness. Instead, we believe that the task is simpler than was proposed; the question that was asked about the color pattern could be answered simply by comparing the color pattern of the cued row to one adjacent row. Perhaps the distinction between layout (in phenomenal consciousness) versus specific, individuated items (in access consciousness) is a good distinction nevertheless, but we suggest that both can occur together in a common focus of attention.

In another attempt to separate phenomenal and access consciousness, Amir et al. (2023)

claimed to separate phenomenal and access consciousness empirically by presenting concurrent environmental sound channels (animal noises, laughter, bells, tones, etc.) and asking participants if they heard certain sounds. In the critical trials, only a pink noise was left and participants were asked if they heard anything. Some said “no,” but then when the pink noise was turned off, they still detected the change. This pattern was taken as indicating phenomenal consciousness for the tone in the absence of access consciousness because phenomenal consciousness had to be present for the change to be noticed, yet access consciousness should have led to a “yes” answer regarding the pink noise. Unfortunately, we worry that there is an issue in that the “no” answer might have meant that the participants attributed the pink noise to speaker noise rather than a specific stimulus, instead of the pink noise being inaccessible.

Further Levels of Consciousness to be Considered

One can discern several levels of consciousness beyond phenomenal and access consciousness. Tulving (1985) developed a distinction of three levels of consciousness related to different types of memory. The most rudimentary would be anoetic (not-knowing) consciousness, linked to procedural memory or the ability to remember how to do something without any notion of being able to declare what that knowledge is. Next on the hierarchy is noetic consciousness, linked to semantic memory or knowledge of the world. The highest level is autonoetic consciousness, linked to episodic memory or knowledge not only of the world generally, but also what happened to the individual in particular episodes in the past (and thinking about what can happen in the future). It seems likely to some of us that anoetic consciousness corresponds to a basic level of phenomenal consciousness (to be found presumably even in animals that are aware of their environment but may have no knowledge, i.e. no access, to a declarative memory of their experiences) and that noetic and autonoetic consciousness are subdivisions of access consciousness (with declarative knowledge and in the autonoetic case, a declarative self-history). Mansell (2022, Table 1) pointed out the near-equivalence of Tulving's (1985) distinctions and other three-part taxonomies of consciousness, the phenomenal, access, and self-awareness levels of Block (1995) and the primary, secondary, and tertiary levels of Vandekerckhove & Panksepp (2009).

Norman et al. (2019) reviewed evidence on various types of metacognition and metamemory, meaning awareness of one's own thinking and memory processes. This seems possibly a step beyond autonoetic awareness of one's external experiences because it can include awareness and thinking about one's episodic memory and autonoetic awareness, as well as thinking about lower levels of awareness. The metacognition area seems to have been studied separately from thought about consciousness so that the relation, for example, of autonoetic awareness to metacognitive thought has not much been explored. It may be problematic to think of four hierarchical levels of awareness because there appears to be a unique brain response to errors in decisions made on the basis of sub-threshold (not consciously perceived) stimuli (Charles et al., 2013), with above-chance metacognitive accuracy on trials with unseen stimuli.

Recommendations about Types of Consciousness

Ignore the nay-sayers. We disagree with the notion that nothing worth reading has been written and the implication that one should probably not even try. We offer a basic suggestion for experimentalists. A reported study of some aspect of consciousness should include an indication of what behavior or constellations of behaviors, would count as an indication of consciousness or information in consciousness, within the particular experimental paradigm.

Further research questions on phenomenal and access consciousness. An important unanswered question is how a perceptually rich environment can co-exist with a few highly processed chunks in working memory. How much does awareness of statistical properties of the environment (Chong & Treisman, 2003), perhaps in phenomenal consciousness, compete with the few separate chunks, presumably in access consciousness? It requires attention (Jackson-Nielsen et al., 2017) but more research is needed, for example, in which participants are asked to remember several objects in an array (perhaps the colors of all triangles) or those same objects plus a statistical datum (e.g., the average width of all objects, not only triangles). Will the statistical datum cost an object in working memory? The answer to such questions will help in the description of the capacity of consciousness and its limits.

Further research questions on consciousness and memory. By linking consciousness phases to types of memory, it becomes a little clearer how one might search for evidence of these types of consciousness. Absence of memory could indicate either no awareness during encoding or awareness followed by forgetting. Some types of memory might sometimes occur without concurrent conscious awareness (e.g., activated elements in long-term memory outside of the focus of attention; procedural memory). Implicit memory (e.g., having a negative emotional reaction to someone who previously acted violently but without recalling the event) may imply phenomenal consciousness. Explicit memory (e.g., remembering the event) clearly seems to imply access consciousness by usual convention. To our knowledge, though, there is no empirical demonstration of the relation between phenomenal consciousness and implicit or procedural memory, so more work on it is needed. Jacoby (1991) showed that stimuli viewed under divided attention are later familiar (i.e., with a feeling one has seen the word in the experiment) but not recollected (i.e., without an explicit memory of the context in which it was seen in the experiment). That familiarity seems to imply former phenomenal consciousness of the item and should contribute to implicit memory. For example, seeing the word *dog* with one's attention divided should later encourage one to fill in the word fragment *d_g* as *dog* rather than *dig*, even without conscious recollection of having seen either word in the experiment (just a sense of familiarity of *dog*). However, we believe that no one has tested whether there is also implicit memory for a word that was masked so closely that no stimulus before the mask was detected, yet the word caused priming (e.g., the masked word *dog* facilitating recognition of the related word *cat* shortly afterward). The masked word that causes priming is presumably not even in phenomenal consciousness. It is not recognized in an explicit memory test (Balota, 1983), but an implicit test of memory for the masked word was not used and probably still needs to be tested so we can determine whether there can be implicit memory even without prior phenomenal consciousness of the item that leads to learning.

Although memory is aligned with levels of consciousness, there could be these same levels of consciousness without concomitant memory per se. For example, one might engage in mental imagery that is not connected with either a specific past event or an imagined future event, and one can be autonoetically aware that the imagery is not from past or imagined actual future events.

Considering all levels of consciousness. The higher up on the hierarchy of types of consciousness one goes, the more likely it is that one is dealing with types of consciousness at which humans and a few other species excel. By considering the levels of anoetic, noetic, autonoetic, and metacognitive, we should get a clearer picture of the functional and evolutionary roles of these levels. Also, questions about individual and group differences in attention and memory, including lifespan development (Cowan et al., 2024) have important counterparts in the possible investigation of individual and group differences in the qualities of consciousness.

Limited expectations for definitions of consciousness. Ultimately, despite recent advances, it seems to us that there may be no clear way to define consciousness. The description that there "is something it is like" to be a conscious being may only reword the conundrum or hard problem rather than solving it. So, for example, is there something that it is like to be a rock? Well, it is a lot like being any other hard object. This question can be sharpened only by asking whether it feels like something to the rock, which just introduces a clearly consciousness-dependent term ("feel"). In the end, it may be necessary to appeal to the reader's own consciousness to understand what it is and make consciousness a postulate rather than define it. Dividing consciousness into types is a good start but may not in itself lead to a cogent definition of consciousness. For example, a computer might be found to keep track of procedural, semantic, and episodic information about itself, but all without having actual consciousness (but the absence of consciousness is debated, e.g., Blum & Blum, 2022). We suggest that research authors use the word consciousness when it seems helpful in increasing understanding of research nevertheless, but only after offering a reasonable operational definition of the term for the particular article.

A Diagnosis of the Hard Problem

Chalmers (1995) discussed the hard problem, that is, how physical systems give rise to subjective experiences of feeling conscious. He did not intend to say that most problems in psychology are easy, but they are tractable, and the same cannot easily be said for the problem of understanding conscious experience. Nobody other than the research participant herself can access this character of her consciousness. Replication, verification, and scientific inquiry make sense only when we and our interlocutors have in principle the same access to the object of inquiry. The topic of consciousness violates this principle of equal access to the evidence by all parties involved in the scientific process. Here we recommend exploring what we can learn about consciousness if the experimenter makes certain assumptions about how to access it indirectly (e.g., by believing the participant's description of her consciousness or indication of it through keypresses in response to task instructions).

Two Hard Problems Actually?

We actually see two aspects of the hard problem, which we call *empirical* and *mechanical* hardness. First, regarding empirical hardness: it is hard for an empirical, behavioral scientist to know how to deal with the fact that all evidence about the consciousness of others is private, and at best indirect. You can ask other people to talk about their subjective experiences (or respond manually), but to use that evidence you have to assume a few things and these assumptions are not generally pro forma. You have to assume that the participants are not lying. A person might easily be motivated to lie about a subjective experience that cannot be verified (e.g., "were you paying attention just now?"). You also have to assume that participants are not mistaken about what they think they are aware of or remember being aware of. It has been well-established that people often make up stories to justify what they think, and this can include fabricated memory of personal experiences. For example, a patient with dense anterograde amnesia due to hippocampal damage from encephalitis, with no capability of new declarative memory formation, was asked by his wife why he pressed the elevator button to a certain floor – given no conscious memory of what floor his room was on – and he replied, "you told me to," which was not the case (Wearing, 2005; also see the documentary on amnesia, *The Man With The Seven Second Memory*, https://www.youtube.com/watch?v=k_P7Y0-wgos). As another example, a person with parietal lobe syndrome with anosognosia, unable to move a limb but unaware of that fact, will make up excuses for why they won't move the limb, rather than become aware of the point that they cannot move the limb (Ramachandran, 1995). Self-delusion is also big among people with no impairment, as in the case of cognitive dissonance (e.g., reporting belief of an idea more strongly if one was only paid a very little bit to espouse that belief, compared to when one was paid a lot). In a cognitive dissonance experiment, the participant later shifting their actual belief toward the espoused view presumably allows them to avoid the feeling of "selling their soul" cheaply (Festinger & Carlsmith, 1959; Harmon-Jones & Harmon-Jones, 2019). In general, the investigator in a study on consciousness will have to be rather cautious about what participant responses to believe and how to interpret them.

Second, what we term mechanical hardness of consciousness is that its mechanisms are mysterious. It is difficult to think of a way that moving atoms into a particular configuration could give rise to consciousness in higher organisms but not, say, in rocks. One solution to that problem is panpsychism, the belief that all matter is intrinsically endowed with a general consciousness. That view, for example, was espoused by the inventor of the field of psychophysics, Gustav Fechner, the notion being that the physical and psychic are two sides of the same coin (Seager & Allen-Hermanson, 2009). If we instead believe that consciousness is limited to certain circumstances including (but not necessarily limited to) human mental activity, then the question is how there can be a specific organization of atoms that can produce consciousness. Many solutions have been tried, but Caseli et al. (2013) at least found an algorithm for an index of the information-bearing quality of brain activity that is higher when participants are in the state that we believe to be more highly conscious (e.g., not in a coma; not under anesthesia as in Lee et al., 2013b). The higher information content occurred in response to a magnetic pulse applied to the brain when that pulse produced local responses in different brain regions that were relatively integrated in terms of their timing but relatively differentiated in terms of their specific patterns.

Recommendations for Dealing with the Hard Problem(s)

The experimenter faces empirical and mechanical types of the hard problem. Neither of these is prohibitive for research, however, so long as the hard problems are often acknowledged in writing. We may not solve the hard problems, but useful research can be done on consciousness after the hard problems are specified. Empirical hardness can be circumvented by development of a list of behaviors and patterns of brain activity that seem to accompany aware, alert thought. We can learn how many items on the list have to agree with the observed evidence before a participant is considered clearly conscious, clearly unconscious, or in a range of uncertainty. Mechanical hardness can be approached (and often has been approached) by finding typical brain activity correlates of conscious activity and by finding ways to eliminate parts of the brain activity that nevertheless leave consciousness intact (e.g., quieting the frontal lobes: Tsuchiya & Koch, 2016).

Evidence on the Neural Underpinning of Consciousness

The broad and diverse topics relevant to consciousness that can be examined according to our view, including verbal reports, behavioral evidence, physiological brain evidence, and neuropsychology, provide an important backdrop for the present discussion and are reviewed in the Appendix. We will argue that the contents of consciousness can be taken as the same as the currently attended information (though not the same as top-down attention, as we will explain). We will then qualify these statements with a consideration of the need for a hierarchical, distributed representation across functions.

The Focus of Attention Separate from the Top-Down Control of Attention

We would emphasize the involvement of the IPS whenever deliberate attention is involved, reflecting the information in the focus of attention but not consistently including processes that help direct this focus from the bottom up (factors of stimulus salience) or from the top down (factors of attention control). Recent evidence supports this view. Majerus et al. (2012) found that the IPS and dorsal attention network centered on it generally were active for task-related attention, whereas the ventral attention network centered on the temporoparietal junction was active for stimulus-related distraction. In terms of the embedded-processes model, our suggestion would be that the attraction of attention from discrepancies between stimuli and the neural model of the environment occur outside of the IPS, but that the IPS presents a picture of the resulting focus of attention and conscious outlook, which is usually weighted more toward task-relevant information than toward distractions.

The focus of attention and the seat of awareness seem to be represented in the same cortices activated when items are perceptually presented. The number of items currently attended can be decoded in the IPS (Lewis-Peacock et al., 2012; Majerus et al., 2016; Rose et al., 2016). Research from numerous sources suggests that part of the IPS serves as a hub of attention connected with areas of the posterior cortex representing currently activated information, no matter whether it is information from perception or working memory. The evidence includes connectivity analyses using magnetic resonance imaging of the brain (MRI: J.S. Anderson et al., 2010; Li et al., 2014), changes in IPS activity with the administration of subanesthetic levels of isoflurane or propofol (Fontan et al., 2021; Heinke & Schwarzbauer, 2001), transcranial magnetic stimulation and resulting behaviors (Kanai et al., 2008; Zaretskaya et al., 2010), analysis of brain lesions (Vandenberghe et al., 2010), parietal lobe epilepsy (Salanova, 2012). We suggest that this hub of attention (which can be activated either through top-down or bottom-up sources) also provides an index for the items in consciousness. For example, Kanai et al. (2008) found perceptual fading with magnetic stimulation of the IPS. Zaretskaya et al. (2010) found that magnetic stimulation of this area specifically was instrumental in lengthening the duration for which one stimulus remained stable before switching to a conflicting percept. Exemplifying the use of convergent physiological data as discussed in the Appendix, Zaretskaya et al. (2010) presented stimuli that resulted in binocular rivalry, images to the two eyes that could not be fused into a single image. The subjective report is typically that one image is seen to the exclusion of the other, but the image that is seen typically alternates in a matter of seconds. Magnetic resonance imaging (MRI) indicated neural activity changes that coincided with a switch from one percept to another, corresponding to the information represented in consciousness, and magnetic stimulation to the IPS (a hypothesized hub of attention) altered the rate at which the percept switched, providing considerable validity to the verbal reports of what was perceived.

More support for the scheme of the IPS as a hub of attention and awareness (albeit with frontal involvement as a controller of attention) comes from research with functional magnetic resonance imaging. Lewis-Peacock et al. (2012) used multivoxel pattern analysis to demonstrate active patterns for information just presented (of two types at once, e.g., a face and a set of lines) and for information needed currently in the task; the pattern for information that was not currently needed but might be needed later in the trial subsided, but it was reactivated when a cue indicated that it was again needed. The theoretical account was that activation of the representations occurred only for items currently in the focus of attention (and we would say awareness), and not for the dormant representation.

According to Cowan (1988, 1995, 2019; Cowan et al., 2024), dormant representations comprise the activated portion of long-term memory, including rapidly-learned information. Physiologically, the activation could be neural, chemical, and/or synaptic, but without all of the neural growth that will take longer to stamp in new information permanently. It might therefore instead be termed unattended short-term or working memory, missing some activation that characterizes working memory information that is in the focus of attention. The attended information, in contrast, includes IPS activation.

Several lines of research reinforce the concept that the focus of attention mediated in the IPS interacts with the activated portion of memory outside of the focus. Rose et al. (2016) showed that unattended information that was still possibly needed for the task could be brought back into the focus of attention using magnetic stimulation. Cowan et al. (2011) presented spoken letters along with an array of colored squares to be remembered in a short-term recognition task and found that although many brain areas responded to one modality or the other, only the IPS in the left hemisphere responded to both modalities, as one would expect of a hub of attention. Li et al. (2014) reanalyzed that data set and found that the IPS was functionally connected to whatever posterior regions represented the information in working memory, which depended on which modality or modalities were to be remembered on a trial. Majerus et al. (2016) showed that whereas the content of working memory was represented in various posterior regions (different for verbal versus visual information), the IPS reflected the number of items in working memory; thus, they were able to train the computer classifier to recognize how many visual items were in working memory and the same classifier automatically worked for verbal information, and vice versa; the IPS links to the content elsewhere, presumably keeping track of it. Hutchinson (2019) reviewed neural correlates of inattentional blindness and found IPS activity to be a major correlate.

Inattentional blindness is a very important case that still will require additional research to enhance our understanding. The capacity limit of the focus of attention mediated by the IPS (Cowan et al., 2024) is too small to include everything about the vast visual and acoustic fields of information available in the environment with each item registered in working memory individually, so that inattentional blindness is often the result; but consciousness still somehow manages to include an overall scenario that includes statistical properties of the whole environment and makes it appear complete and rich (Chong et al., 2008; Simons, 2000).There is not yet enough research to determine if the overall scene statistics count for a certain number of individuated chunks that could be added to the focus of attention if the overall scene's general and statistical properties were somehow ignored.

Gossaries et al. (2018) showed that the role of the IPS is not simply to hold pointers (links) to the information, but also to keep them from interfering with one another. Remembering three directions of movement in order to select the correct one to answer a probe was more work for the IPS than remembering one direction of movement along with two colors. This finding was also replicated with different stimulus features, bars at different orientations, by Cai et al. (2020). The IPS may bind elements currently in focus into a new event (Cowan, 1988, 2019; Halford et al., 2007; Oberauer, 2019), providing further detail about the nature of the funneling process we have suggested. Of course, other areas also show activity related to awareness, but the IPS seems to be the most constant among various procedures.

An old but yet under-utilized method for understanding the basic role of different brain areas in consciousness is verbal reports and other observations in cases of brain lesions. For example, Salanova (2012) reviewed clinical manifestations of the rarely-studied case of parietal lobe epilepsy. The behavioral observations were summarized (p. 392) as follows: "contralateral somatosensory sensory perturbations described as numbness or tingling, though some patients also described pain and a thermal sensation. A less frequent aura includes disturbances of body image described as a sensation of movement of one extremity or a feeling that an extremity has spatial displacement. Other patients described twisting or turning sensations, inability to move one extremity, or a feeling of weakness in the hand contralateral to the epileptogenic zone. A few patients report aphasic auras, vertiginous sensations, conscious confusion, and cephalic sensations and complex visual or auditory hallucinations suggesting seizure propagation to involve the temporolimbic areas." These observations are consistent with the notion of parietal areas as heavily involved in consciousness of at least some types.

Considerable work on brain oscillations in the gamma band (30-80 Hz) ties them to attention, consciousness, and working memory (for a review see Jensen et al., 2007). A seminal idea of Lisman and Idiart (1995) was that several cycles of a gamma wave can fit into one slower oscillation that carries the signal. Each gamma cycle represents the various features of a particular object in working memory, which allows for the integration of features of each object in memory without the objects becoming confused; the number of cycles that fit in the slower wave accounts for the attentional capacity limit. Tying gamma activity to consciousness more directly, Doesburg et al. (2009) found theta modulation of gamma oscillations tied to the conscious percept in binocular rivalry, which Zaretskaya et al. (2010) link to the IPS. Although it seems likely that oscillatory patterns in many brain areas are important for consciousness, Palva et al. (2010, p. 7580) noted that "subjects' individual behavioral VWM [visual working memory] capacity was predicted by synchrony in a network in which the intraparietal sulcus was the most central hub," showing the importance of the focus of attention for consciousness.

The Need for a Hierarchical, Distributed Representation

Although we have argued for frontal regions as the controller of attention and parietal regions as the focus of attention, in both cases a given level of operation logically needs its own information about the lower level in order to operate; in that way, stored information must be distributed across levels of the processing hierarchy. Consider the analogy of a carpet company that has a boss, a middle manager, and a carpet salesperson. The boss may decide, "we want to try to sell more of the newer kinds of carpeting, which more people are buying lately." The boss (prefrontal cortex) needs to have rudimentary knowledge of types of carpet in order to direct the middle manager (IPS) as to what kind of thing to put on display. Then the middle manager can point to, or call up, the most relevant available salesperson (e.g., for visual items, part of the visual cortex with currently-active information) to bring out the most relevant items that have arrived in store or are in stock. However, the middle manager must know enough to be able to direct the query to the most relevant salespeople. For a working memory task, the attention control center must have rudimentary knowledge about what to tell the IPS on a given trial (e.g., in keeping with instructions that might occur on a specific trial, ignore what's on the computer screen and attend to the sounds) and the IPS must have enough knowledge to select the correct stimuli (e.g., where sounds are kept in the brain and which ones are task-relevant as defined by the frontally-located central executive). Indeed, Odegaard et al. (2017) have made a case for a distributed representation of information in prefrontal cortex, and one of the reviewers of the manuscript noted a similar issue for the IPS. What would differ between levels (sensory and association cortex, IPS / focus of attention, and prefrontal / executive) regarding knowledge would be the level of detail about each kind of information: at the sensory level, sensory detail; at the focus-of-attention level, knowledge to coordinate this sensory input with top-down instructions; and at the central executive level, knowledge of how to form helpful top-down instructions incorporating some idea of different kinds of sensory and abstract information.

Attention and Consciousness

We maintain that consciousness without attention cannot happen, almost by definition. It is presumably impossible to be conscious of everything presented to the senses and its meaning at once, so some sensations or ideas enter consciousness only at the expense of others. Like consciousness, selectivity is also intrinsic to the nature of attention so we believe that, if something is in consciousness, it is also being attended to the exclusion of many other things. More work is needed to assess how the totality of consciousness is limited; a forest with countless tiny details is in some important sense perceived, but what is the total limit of the amount of information that can be perceived in the forest, combining the individual object level with the higher-level statistical structure of the environment?

It might be possible to be aware of something that is attended, but without the contribution of top-down attention. This possibility is exemplified by popout effects, when attention is drawn to an item because of its distinctive configuration compared to the background (e.g., Treisman, 1988), or when the participant has learned that the item is meaningful or task-relevant (e.g., Shiffrin & Schneider, 1977). See also the evidence on binocular rivalry in the absence of report or frontal lobe involvement as described by Tsuchiya and Koch (2016), reviewed in the Appendix and below. We need to know more, however, about the types of consciousness that follow when bottom-up cues attract attention. How much information is encoded into access consciousness (not just phenomenal consciousness) on the basis of bottom-up cues alone, and how much information is encoded only because of top-down activity that follows the initial recruitment of attention?

The conclusion that information can be attended and processed without conscious awareness of it, in masked priming (Balota, 1983; Marcel, 1983) needs further work because it is not certain whether it is specifically attention that is involved, as opposed to automatic processing. If participants had to attend to flanking items on the left and right of the spot at which the masked prime is presented, rather than attending to the spot itself, would priming be abolished? Related studies by Naccache et al. (2002) and Sumner et al. (2006) are relevant. Naccacche et al. embedded two digits, a prime and a target, among masks at a quick pace of presentation in a series that ended with the target. The task was to press one key if the target was smaller than five and another if the target was larger than five. To get a prime-target compatibility effect on response times, the participants did not need to know how soon in the series the invisible prime would occur, suggesting that the effect of priming was not dependent on attention to the prime. (Less importantly for our purposes, the effect only occurred if the participants knew at what point the subsequent target would occur, suggesting that the application of the information from the prime was not automatic.) Sumner et al. closely masked a prime that comprised carats pointing rightward or leftward, which was compatible or incompatible with a subsequent target with carats to which a directional response was to be made. Before the prime, there was an exogenous attention cue leading the participant to the location at which the prime occurred or a different location. Attention to the location of the prime enhanced the priming effect, though it occurred to some extent even when the prime was unattended. Interestingly, the direction of the priming effect was opposite when the prime was visible or invisible. Taken together, these studies suggest that there is automatic processing of an unconscious prime even without attention, but that attention to the location of the prime may enhance the effect. Why these effects are opposite for visible versus invisible (masked) primes is an interesting question; clearly, there is some uncertainty in this domain and more work is needed on the role of attention in processing items that cannot be detected. However, obtaining a masked priming effect for an invisible prime (Balota, 1983; Marcel, 1983) does not appear to be sufficient evidence that the spatial area at which the prime arrived was closely attended at the time that the prime was processed. In those classic studies, it might only have been looking in the direction of the prime that mattered, which can occur without attention to that direction or location in space.

In work with neural oscillations, more research is needed to establish the precise relation between attention and consciousness directly. In one such effort, Wyart and Tallon-Baudry (2008) presented near-threshold stimuli either at the location the participant was attended or at a different location and were able to find trials in which the participant was attending (whether or not they saw anything) and trials in which the participant saw something (whether or not they were attending). These two processes yielded different frequencies of electromagnetic activity, with awareness generating a signal centered at about 60 Hz and the direction of attention yielding activity at about 80 Hz. These signals were all located posteriorly in the brain. Although top-down attention to a location is therefore not the same as awareness of an item, awareness of an item still can be the same as attention to that item.

In sum, the research on attention and working memory has important implications for a theory of consciousness. We would predict frontal activity in the case of directed attention, versus more IPS activity for awareness, as shown in Figures 1 and 2. This topic seems like one that is very important for the assessment of the overall scheme we have suggested for consciousness and attention. Consciousness might occur for several items in the focus of attention, but frontal activity (top-down attention) may be capable of bringing additional items into focus or prolonging the duration during which an item remains in focus. More research is needed on the process of attending in search of something with and without success in that search, to distinguish the neural involvement in attention versus conscious awareness. Items that have been attended until they are well-learned and therefore no longer recruit much attention can be brought back into attention when the item suddenly becomes high priority, according to electrophysiological work (Reinhart & Woodman, 2014).

Strengths and Limits of Various Theories of Consciousness

We suspect everyone agrees that theorization about consciousness has been extremely difficult. In a practical sense, it might be possible to make inroads into an understanding of how consciousness works in humans, without understanding the fundamental nature of consciousness overall. Such an approach would appear to be in accord with the approach of Gustav Fechner, the founder in the 1800s of the field of psychophysics, the science relating the physical world to the psychological effect of that world. Fechner (1851/1901) wrote of his belief that the entire earth was conscious, as a great being with cycles just like a living organism. For him in fact, the universe was a tree of life and everything in it together was alive and conscious. Nevertheless, Fechner chose to do research on what was probably the most tractable part of the relation between the physical and the psychological, namely an investigation of humans' thresholds to detect weak stimuli (Beiser, 2020). Similarly, we might restrict ourselves at first to trying to understand how it is that consciousness takes place in humans and animals, without worrying whether there are other ways in which consciousness could be manifest, as in artificial intelligence or beehives considered as a single super-organism.

In contrast to this restricted scope that we advocate, current theories of consciousness address it across platforms. Indeed, a key question that distinguishes theories is what beings can experience consciousness. Which animals can experience it? Can artificial intelligence experience it, or perhaps a whole colony of ants, with each ant considered akin to a neuron in the system? This question is often posed (e.g., Doerig et al., 2021), but it may not be the most practical, proximal question to ask right now (but is being asked, e.g., LeDoux et al., 2023). A still-unanswered, more proximal question is how consciousness is mediated in humans particularly. If we can answer that, it may eventually lead to a more general rule about what it takes to give rise to consciousness. As an analogy, suppose we wanted to know the general rule for an entity to move in one direction without an outside influence. Perhaps it would be easier to start instead with the more proximal question of what it takes for an upright human in particular to move forward. The answer would have something to do with raising a foot, allowing gravity to pull down the leg; and, in the process, the leg is attached to the rest of the body, pulling it forward as the leg falls. The forward motion is preserved enough to allow the other leg to come up and swing forward, and so on. After having a theory of humans moving forward, one could also ask how other beings move forward (e.g., four-legged animals, snakes, mechanical vehicles). There would be a different specific theory for each one but, taken together, the similarities among the theories could then clarify the larger theory of what it takes generally for a self-propelled entity to move forward (something about a solid body that does not break up into pieces, more force in one direction than in another, and the force being large enough to overcome friction). Similarly, even if we had a better understanding of human consciousness, more information would be needed to answer the general question of what the requirements are for a conscious entity. There might be consciousness in beings very different from ourselves, and it might be supported quite differently than in humans. New instruments might be needed to assess, for example, whether there is consciousness of some kind in artificial intelligence, or an actual conscious "hive mind" across a colony of bees or ants. This is the empirical aspect of the hard problem we mentioned previously, that would need to be overcome.

We divide theories of consciousness into several types. The most prevalent type in psychology and neuroscience is the type in which consciousness is said to depend on aspects of information processing. Because information processing theoretically can be carried out by many different types of systems (e.g., not only human brains but also animal brains, computers, or perhaps ensembles of organisms such as bees in a hive), this prevalent kind of theory is also unsettling because it can predict non-human and non-animal consciousness.

In a second variety of consciousness theory, which has not been followed much, it is specified that consciousness is in principle specific to a nervous system, through some characteristics of nerves that we do not yet fully understand, or even is specific to humans.

In a third kind of consciousness theory, panpsychism, consciousness depends on a very general principle of matter and can apply generally to everything in the universe, just to varying degrees, or is somehow dependent upon an aspect of physics upon which the brain capitalizes.

Information Processing Theories of Consciousness

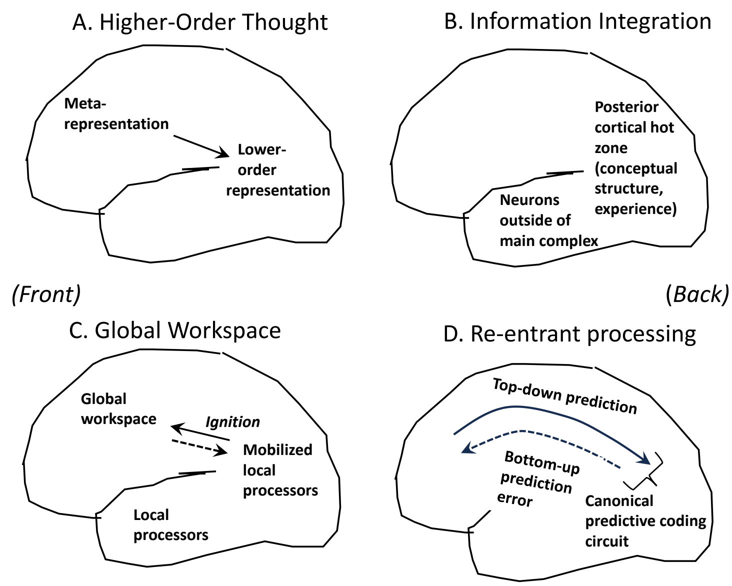
Higher-order Thought Theories

Higher-order theories of consciousness (HOTs; Brown et al., 2019) propose that conscious experiences involve a minimal inner awareness of one's mental processes, monitored by higher-order representations (brain representation depicted in Figure 3A). First-order (i.e., lower-order) states encompass basic mental states like perceptions, thoughts, and emotions, while higher-order states meta-represent these first-order states. In HOT, consciousness arises when a first-order state is the focus of a specific higher-order representation. There can be thought-like states in computational terms (Seth & Bayne, 2022). Several examples in HOTs are used to explain contents available to consciousness, as well as unique qualities of different conscious experiences (i.e., qualia) in the context of meta-representations (Odegaard et al., 2018).

Evidence cited for HOTs includes findings implicating the prefrontal cortex in conscious contents and brain lesion research linking metacognition to prefrontal areas (Lau & Rosenthal, 2011). Challenges arise from studies suggesting that anterior areas might facilitate subjective report or executive control rather than consciousness (Tsuchiya et al., 2015). HOTs imply that only species with developed frontal cortices possess consciousness. In contrasting views, rudimentary forms of consciousness have been proposed to exist in a wider array of animals (Vandekerckhove & Panksepp, 2009).

Figure 3

A Depiction of Brain Processes Associated with Several Information Processing Theories of Consciousness, after Seth and Bayne (2022)



Note. **A**: higher-order thought theory, after Seth and Bayne (p. 443, Figure 1); **B**: information integration theory, after Seth and Bayne (p. 445, Figure 3); **C**: global workspace theory, after Seth and Bayne (p. 444, Figure 2); **D**: re-entrant processing theory, after Seth and Bayne (p. 446, Figure 4).

Information Integration Theories

Information Integration Theory or IIT, explained by Tononi (2008), is based on the notion that there is a hierarchy of conscious states and there is a measure of information integration that indicates the level of consciousness (brain representation depicted in Figure 3B). Integration is not as high if all brain areas operate in synchrony and provide little information that is unique per area, or if various areas operate separately and do not coordinate with one another (Northoff & Lamme, 2020). Brain evidence (through imaging measures) is good to indicate that there is lower integration in clearly low-awareness states, such as in a coma or during anesthesia, compared to awake states (Casali et al., 2013; Demertzi et al., 2019; Mashour et al., 2021).

One might point to a difficulty in integrating across different methods. People who are in a more conscious state typically do not just lie there being conscious (unless they are, say, meditating); they use the frontal lobes to plan and carry out activities. This additional activity in which conscious and alert individuals engage is not consciousness per se, but a secondary consequence of it. However, in situations in which participants are to receive stimuli without responding, the frontal lobes are relatively quiet (Koch et al., 2016). Therefore, it may be difficult to find a way to measure information integration in a manner that truly is correlated with consciousness and not with confounded neural activity like the frontal lobe executive component that often accompanies consciousness but is not necessary for it.

Mansell's (2022) theory is one in which qualia, or conscious feelings, come from "novel information integration" (p. 7). This can occur when goals of the system conflict with one another and need resolution of the conflict. Although we agree that situations of conflict are perceived with greater attention and alertness than conflict-free situations of habit (James, 1890) or automatic processing (Shiffrin & Schneider, 1977), it is difficult for us to see this conflict and novel integration as the full basis of the experience of continuity throughout an individual's presumably conscious day. For example, it is not clear how it would account for a déjà vu experience (Brown, 2003). We do not explore this new theory in further detail as we await further relevant evidence.

Global Broadcasting Theories

The global workspace theory (GWT) of consciousness, is a type of information processing theory first proposed by Baars (1988), expanded on by various researchers, including Dehaene et al. (1998), and updated by Baars et al. (2021). The theory proposes to explain how some cognitive tasks appear effortless, while others require conscious effort. It proposes there are two computational spaces in the brain, including the processing network and the global workspace network. (Brain representation depicted in Figure 3C.) The processing network consists of specialized processors, with cortical domains and connections that perform specific functions, such as visual processing, language comprehension, or memory storage. The global workspace, on the other hand, is composed of distributed cortical neurons capable of long-range connections with neurons in other cortical areas, which allows for information from specialized processors to be broadcasted to and from the global workspace. The workspace can accommodate and integrate a wide range of information needed for higher-level cognitive processing. The global neuronal workspace theory (Dehaene & Changeux, 2011) is a neuronal version of Baars' theory that stresses the importance of the prefrontal cortex as a neural constituent of consciousness.

The notion of global broadcasting is important inasmuch as it explains why consciousness seems to be a unitary phenomenon; except for split-brain patients, there is no evidence that consciousness can have several, unrelated pools of awareness at the same time. The global workspace also has limited capacity, such that only a subset of inputs can effectively access the global workspace at any given time. This selective gating is achieved through modulatory projections from workspace neurons that either amplify or suppress the inputs from peripheral processor neurons. Therefore, the global workspace is responsible for making certain information conscious, while other information remains unconscious. It can be thought of as a spotlight or focus of attention (cf. Cowan, 1988; Cowan et al., 2024) that can highlight specific information for conscious awareness and for decision-making.

The global workspace is identified with working memory and therefore is, by one definition, the quality of access consciousness (Block, 2011). In contrast, information integration theory seems to focus on phenomenal consciousness so we can begin to see the possibility of multiple theories of consciousness operating together.

Learning Quality Theories

Birch et al., 2020 posit an Unlimited Associative Learning theory of consciousness. Unlimited associative learning is supposedly a type of learning unique to conscious life, serving as an evolutionary transition marker from unconscious to conscious beings. Associative learning is distinguished from other forms of learning based on five seemingly linked (naturally clustered) features of advanced learning: (1) the conditioned stimulus can be a compound of features; (2) it can be novel; (3) it can involve second-order conditioning, such that a stimulus can gain value by being paired with another conditioned stimulus, as for example in learning the value of money; (4) it can involve trace conditioning, i.e., conditioning that depends on remembering a recent stimulus that is no longer present when the valued stimulus arrives; and (5) the organism can flexibly adapt to the changing value of a stimulus. These are features that, when considering an organism's sufficient decision-making capabilities, could help that organism adapt to conditions that can quickly change.

These learning capabilities could help the organism adapt and survive when the environment changes too quickly for there to be a useful genetic adaptation. The authors believe that consciousness is present in most vertebrates, some arthropods, and coleoid cephalopods. It seems to us also that it is the kind of learning that is facilitated by working memory and deliberate decision-making, so the higher-level thought theory, global workspace theory, and unlimited associative learning theory possibly could work together.

Re-entrant Processing Theories

This sort of theory (Edelman & Gally, 2013) emphasizes the importance of feedback from higher-level processing regions to basic sensory regions within conscious processes. It is also known as recurrent, reverberant, reafferent, or feedback processing. For vision, there is a dorsal stream that sends information from sensory regions to the prefrontal cortex (the "where" pathway) and a ventral stream that does so for "what" the information is, but these are said not to elicit consciousness until information is sent back from the frontal areas to the more posterior regions (brain representation depicted in Figure 3D.) Re-entrant, but not feedforward pathways appear to be suppressed during general anesthesia (Imas et al., 2005; Lee et al., 2013a).

Critics argue for a more integrated view, acknowledging the interactive contributions of both feed-forward and feedback processes to conscious experiences (Melloni et al., 2007). This ongoing discourse underscores the complexity of neural dynamics underlying perception and consciousness. However, the theory seems at odds with research showing that the frontal areas are mainly involved in decision- and response-related processes that are usually concomitant with consciousness, rather than consciousness itself (Koch et al., 2016).

Theories of Consciousness Requiring a Neural Substrate

In all of the theories presented so far, it is theoretically possible for an inorganic system like a computer to attain consciousness if the necessary aspects of information processing are established. In contrast to this assumption, many people strongly believe that it is in principle impossible for a machine to become conscious. Although this belief does not amount to a full-blown theory, it implicitly embeds the assumption that an as-yet-unknown aspect of neural functioning accounts for consciousness. It would presumably be possible to mimic the key aspect of neural functioning, but possibly not inorganically according to this sort of theory.

A possible example of this sort of theory (hard to understand and explain, but worth trying) is the “Orch OR” theory by Hameroff and Penrose (1996, 2014; Hameroff, 2021). The theory depends on a finding in modern particle physics that is difficult for everyone to fathom, quantum entanglement. It is a finding that particles seem to communicate instantaneously when they start out together and are sent far apart before they are examined. To get an intuitive feeling for the mystery quickly, imagine that two entangled particles had opposite values on a quality called “spin.” If measured at the same angle, their spins are always opposite. If measured at different angles, their spins could be expected still to correlate. However, the observed correlation is even larger than what could be expected according to this scenario, as if the observation of one particle somehow communicated to the other before its measurement. Some “loopholes” (what psychologists call confounds) could explain the result but there are strong claims that the loopholes have been blocked. To account for these results, physicists talk of the particles as being in a “superimposed” state (e.g., both positive and negative spin at the same time, even though it sounds logically impossible) in which its definite state does not occur until it is measured (a conscious act), and the measurement of two entangled particles seem to communicate: the “waveform collapses” to yield either positive or negative spin, but not both, in an opposite manner for two entangled particles even if they are far apart. The uncertainty in nature, in which a particle seems to be in a superimposed state before they are measured, opens up thoughts about the kinds of uncertainty attributed to consciousness and free will. Hameroff and Penrose proposed that microtubules in the brain have particle pairs that give rise to consciousness as uncertain states become realities. Hameroff (2021, p. 76) concluded that

"Spanning disciplines and scale, with high explanatory power, Orch OR is the most complete theory of consciousness. But if quantum interference in microtubules […] cannot be demonstrated, or if demonstrated, proves insensitive to anesthesia, Orch OR will be falsified. Orch OR is the most complete, and most easily falsifiable theory of consciousness."

If it is eventually found that computers can do everything that humans can do, including having an integrated information transfer, using a global workspace, having higher-order thought, and so on, then we can ask (1) whether there is evidence for or against the computer's consciousness, and (2) whether there is anything in humans resembling the microtubule situation that Hameroff and Penrose (1996) and Hameroff (2021) described. Answers to these questions would then help to describe the necessary basis of consciousness. Of course, answers to these questions are probably not in our currently foreseeable future.

Panpsychic Theories of Consciousness

As we examined in discussing the founder of the field of psychophysics, Gustav Fechner, (Beiser, 202), some hold the theory that the universe itself is conscious, that everything in it has some consciousness, or that consciousness is a quality that can migrate from one soul to another, a kind of belief that seems consistent with Buddhist beliefs. It seems fair to suggest that we have no idea how to begin to test these ideas at this point, though it cannot be ruled out that there will be a method to do so in the future. IIT also is a form of panpsychic theory (Tononi & Koch, 2015), which can be explored at least for higher animals.

Further Details on Theories

For a more extensive exposure to theories of consciousness largely from a neural view, beyond what we have summarized, one can consult several reviews (Doerig et al., 2021; He, 2023; Koch et al., 2016; Northoff & Lamme, 2020; Seth & Bayne, 2022). Demonstrating the timeliness and heat of the topic is a recent controversy. Several groups with different theories of consciousness were able to find funding to plan and carry out an adversarial collaboration (Cogitate Consortium, 2023) in which some predictions of several different theories of consciousness were tested with several major brain imaging techniques. The authors concluded that of two major theories examined, neither the Information Integration Theory nor the Global Neuronal Workspace Theory accounted for all of the results; both theories would have to be modified. Fleming et al. (2023) posted a letter about the collaboration signed by many scientists from 151 listed institutions, entitled "the integrated information theory of consciousness as pseudoscience," complaining largely about the press reaction to the collaboration, which they said was too favorable to information integration theory, and complaining about some information integration theorists declaring victory. A declaration of victory is difficult for us to see in the cited *Science* article (Finkel, 2023) or *Nature* article (Leharo, 2023), though it may apply slightly more to articles in the Economist (2023) or the New York Times (Zimmer, 2023). Lau (2023) explained in more detail why he considered the information integration theory to be pseudoscience and disliked the process by which the adversarial collaboration was carried out. On September 18, 2023, on X (formerly Twitter), David Chalmers (@davidchalmers42) wrote, "IIT [information integration theory] has many problems but 'pseudoscience' is like dropping a nuclear bomb over a regional dispute. It's disproportionate, unsupported by good reasoning, and does vast collateral damage to the field far beyond IIT…." We believe that most of the theories under current consideration are in a similar position of being difficult to establish and seeming frightening to some inasmuch as the proposed key attributes of a conscious system are not specific to brain systems, but could apply to some other system, such as artificial intelligence in computer systems. The embedded processes approach we have suggested, with a funneling mechanism of consciousness, is probably in the same position.

Recommendations on Theories for Experimentalists

Northoff & Lamme (2020) suggested a convergence of theories, and we tend to concur. Imagine some society of intelligent robots asking, "Does human life depend on food, water, oxygen, or chocolate?" The answer is that several of these components are needed and another enhances life without being essential to it. It may be that a combination of information integration with a global workspace, higher-level thought, and complex learning all are needed for the alert, human consciousness that is the standard referent when we discuss consciousness. It is possible to learn from individuals who may be deficient in one or more of these qualities, showing some levels of consciousness but not others, such as individuals with frontal lobotomy or anosognosia. We take this into consideration when discussing our embedded processes view.

A New Theoretical Synthesis: Embedded Processes with Funneling

Summary of the Theoretical View in Contrast with Other Views

In our theoretical suggestion, there is a role for all of the theoretical approaches we have detailed, as they all emphasize aspects of the normal, productive use of consciousness. However, their contributions differ and they do not mention the funneling hypothesis specifically. The hypothesis is that the arrival of information from sensory areas to the IPS (left and right combined) signifies that this information is in conscious awareness and the focus of attention. There is re-entrant processing from the IPS to these posterior cortical areas as well, instructing them to stay active while they are attended. Top-down attention is exerted from frontal areas to the IPS, and this controls the direction of attention. The relation of the embedded processes view and funneling hypothesis to other theories is as indicated in the following paragraphs.

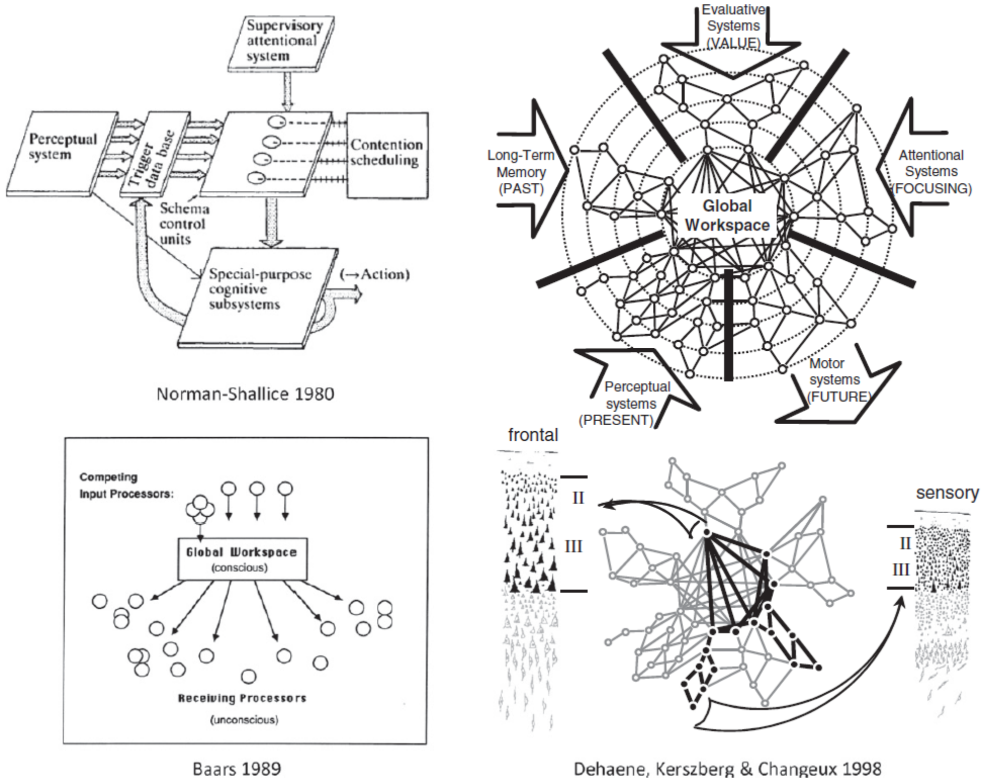
According to the higher-order thought (HOT) hypothesis (e.g., Brown et al., 2019), it is a representation of reality that comprises the conscious manifestation of the organism. We agree that higher-order thought is an important component of consciousness; until information is represented, there is probably no way to react to it in a way that is useful. However, for us, certain informal comparisons casts doubt on that hypothesis as the metric of consciousness. Is an infant in a very alert state, wide-eyed and staring at an older human to absorb information about the new world, less conscious than an adult who is in a foggy state, having just woken up, groggily thinking about something complex? Questions like this would have to be examined empirically somehow, to determine whether more higher-order thought must mean more consciousness or whether the physiologic patterns suggest that the representation of information and the state of consciousness are to some extent independent.

According to the information integration hypothesis (e.g., Tononi, 2008), an organization with complex interacting, coordinated hubs of neural activity is the hallmark of a conscious state. We do not deny this but suggest that not all parts of this integrated activity are equivalent. Loss of a frontal hub may result in impaired voluntary control but not impaired consciousness and the converse is somewhat true with parietal damage (e.g., producing anosognosia or hemispatial neglect).

In the global workspace views (e.g., Baars et al., 2021; Dehaene & Changeaux, 2011; see Figure 4), a network reflecting working memory is the basis of consciousness. This conclusion depends on the definition of working memory, which by some definition can contain information outside of the focus of attention. Some of that information includes unconscious primes, which are not part of consciousness yet influence consciousness. More work is needed to understand how phenomena like that occur and whether a global workspace theory should expect it. Moreover, as we have explained, we do not believe in global, whole-brain mediation of conscious but instead a process funneling information to the parietal regions. From there, the synchrony between the parietal regions and occipital and temporal regions representing information defines the presence of information in the focus of attention and conscious awareness. Information from frontal regions directs the contents of the focus of attention but, we think, does not define consciousness, at least when one is talking about phenomenal consciousness. (It is of course possible that when attention is directed toward mental activities deliberately directed by executive processes or involving monitoring one's thoughts through deliberate metacognition, the frontal lobes may be more essential to those aspects of consciousness.)

Figure 4

The Progression of Models According to Dehaene and Changeaux (2011)



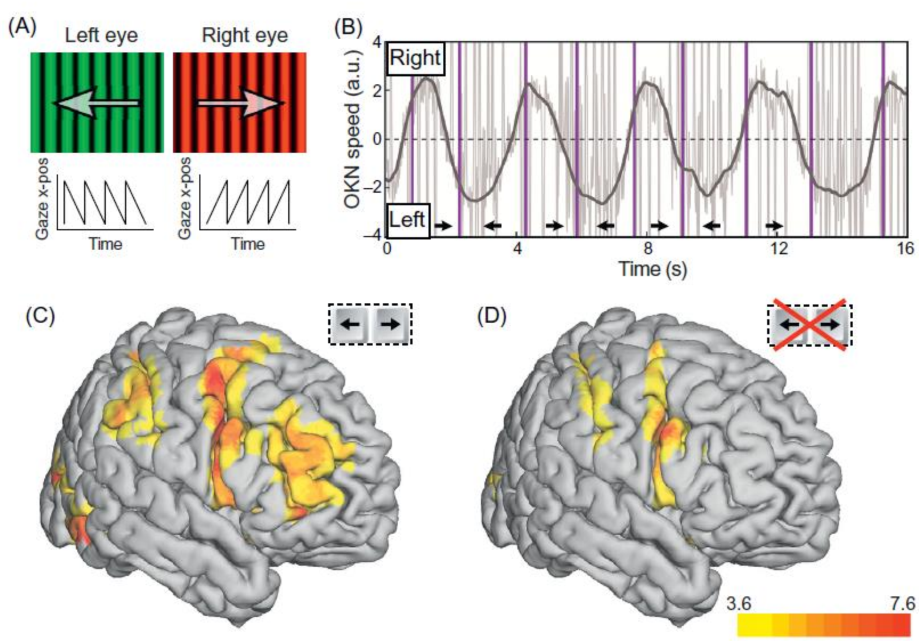
Note. The proposed model was frontally-based and global in contrast to the present approach (cf. Figures 1 and 2), which advocates a hub of attention in the parietal lobe and funneling of information to that area, which connects to a small, capacity-limited number of elements representing the information in awareness. Figure reproduced from Dehaene and Changeaux (2011, p. 209, Figure 6).

Evidence against an essential role of the frontal areas in basic sensory consciousness is provided by research showing that the frontal contribution to performance is largely in the process of reporting the percept. Using optokinetic movement, it is possible to know the percept in binocular rivalry even without a deliberate report. When the left and right eyes receive conflicting information about the direction of movement of a grid, the eyes follow the movement that is perceived, the optokinetic response. When the bistable percept changes from one direction to another in binocular rivalry, that change in percept can be seen in the eye movements. Figure

5, reproduced from Tsuchiya and Koch (2016, based on Frässle et al., 2014), shows that frontal activity in humans was considerable when it was required to report an alternating perceptual experience based on binocular rivalry (compared to reporting an experience of a physically alternating pattern presented to both eyes), but the difference between conditions mostly disappeared when no reporting was required (see also Koch et al., 2016). Electrical stimulation of many frontal regions does not disturb reports of conscious experience (Raccah et al., 2021). Notice that the parietal activity (which includes parts of the IPS) remains in both cases. Frontal areas probably play a larger role in coordinating and constructing higher-level or more abstract thoughts (e.g., Baars et al., 2021).

Figure 5

An Indication of the Brain Function Corresponding to Switches in the Perceived Direction of Movement in Binocular Rivalry With or Without Deliberate Reporting of the Percept



Note. Part A shows the stimuli, Part B shows the switching optokinetic responses, Part C shows brain activity when there is deliberate reporting, and Part D shows brain activity when there is no deliberate reporting, only optokinetic movement. Reproduced from Tsuchiya1 and Koch (2016, p. 83, Figure 5.3).

According to an unlimited associative learning theory (Birch et al., 2020), second-order learning is the hallmark of consciousness. The mechanism of unlimited associative learning may involve symbolic representations that can be combined to form new, higher-order concepts, bindings, or relational integration, all mechanisms that have been proposed to be mediated by the attention-rich component of working memory (e.g., Halford et al., 2007; Holyoak & Monti, 2021: Oberauer, 2019). Therefore, we view this kind of learning as a likely benefit of the use of the focus of attention in humans, presumably making it an accompaniment of consciousness. Yet, in cases of anterograde amnesia, one might find consciousness without much associative learning of this type. There is also the issue of the state of the organism when this learning is not taking place; we expect that there is still consciousness. It is possible that there is no unlimited associative learning without consciousness, but this should be testable by asking whether a computer program assumed not to be conscious can still achieve unlimited associative learning. So the jury remains out on the status of this kind of learning.

Re-entrant theories of learning (e.g., Edelman & Gally, 2013) emphasize the role of frontal regions in returning information from sensory input back to these same regions again in a loop. If there is necessary information from sensory regions to the IPS and a loop in which the IPS returns neural activity, this funneling of information is a sort of re-entrant processing of consciousness. Ordinarily, but not inevitably, the processing will also involve frontal regions also funneling input to the parietal regions. However, consciousness can still be present without the involvement of those regions (e.g., perhaps in cases of frontal lobotomy), but will often not exhibit normal deliberative control.

The theory based on quantum mechanics (e.g., Hameroff & Penrose, 2014) may be incompatible with the present view inasmuch as we do not understand how to determine the role of microtubules in cells that contribute to conscious versus unconscious processing, given considerable evidence for both types of processing. The panpsychist theory also cannot be considered to deal with a type of consciousness closely related to what we term the focus of attention, as it ascribes consciousness to everything in or out of that focus.

In sum, within the embedded processes view with funneling (Figures 1-2), several qualities serve as strong correlates with consciousness but not fundamental causes (higher-order thought and unlimited associative learning). Information integration, working memory, and re-entrant processing all seem critical to the conscious process, though without the necessity of frontal lobe involvement to the extent typically suggested by some of the (for contrasting views on frontal lobe involvement, see Soto & Silvanto, 2014; Tsuchiya & Koch, 2016; Velichkovsky, 2017). The loop between the IPS as a hub of attention and posterior areas representing information in focus is critical. The IPS is the global workspace yet, rather than broadcasting information, it receives information funneled to it, which in turn can be controlled by frontal processing.

The brain is organized via hubs of activity (van den Heuvel & Sporns, 2013) and the IPS is a hub with rich multimodal anatomical and functional connections to the sensory cortex, and also profuse connections to the frontal cortical areas involved in working memory and attention (J.S. Anderson et al., 2010; Cowan et al., 2024; Li et al., 2014; Power et al., 2013). Perhaps that is why it, as a hub of the focus of attention, has been shown to be involved in a wide range of higher-level activities, such as reaching (e.g., Inouchi et al., 2013) and symbol use in math (e.g., Bugden et al., 2012). The relation between embedded processes and the other views is summarized in Table 1.

Table 1

Two Basic Characteristics of Theories of Consciousness and The Relation to the Embedded Processes View

Theory Type	Seat of Consciousness	Role of Frontal Lobes	Relation of Each Theory to the Embedded Processes View
Higher-order Thought	Knowledge & thought areas	Contributing	Needed for at least noetic, autonoetic and metacognitive functions
Information Integration	Whole-brain	Necessary	Necessary but not always across all brain areas; integration necessary across hemispheres (left, right IPS) and functionally connected information
Global Workspace	Whole-brain	Contributing	Critically important; operation through funneling to the IPS; not broadcasting
Learning Quality	Complex neurosystem	Not specifically dependent	Not necessary but important for noetic and autonoetic memory
Re-Entrant Processing	Whole-brain	Necessary	Important in terms of re-entry into focus of attention in the IPS
Neurally-specific	Whole-brain	Contributing	Nothing is known that would prevent implementation in non-neural systems
Panpsychist	Everything	Uncertain	Conflicts with present theory
Embedded Processes View	Focal point in the IPS	Contributing	New funneling hypothesis is key to the framework

Recommendations for Research on the Embedded Processes View

Seeking disconfirmation of the embedded processes view. Above, we have reviewed considerable evidence favoring the role of a hub of attention involving the IPS and functional connectivity to other brain areas representing information within the attentional focus. More work is needed to determine if the activated portion of long-term memory outside of the attentional focus is mediated by neural activity (e.g., Christophel et al., 2018) or other neurochemical or anatomical means of preserving information, i.e., activity-silent representations (e.g., Rose et al., 2016). The distinction makes a difference for the concept of consciousness because the activity-silent view suggests that the conscious versus unconscious distinction is binary, whereas otherwise it could be a matter of degree. Work to support the concept of information being funneled into the IPS could be tested through animal studies with precise ablations of the IPS or its equivalent, measuring the apparent effects on awareness, to our knowledge not much explored (e.g., in studies of optokinetic movement that can reveal perception of a direction of movement: Frässle et al., 2014). If such a study does not affect consciousness, it would disconfirm the funneling hypothesis and probably the embedded processes view. In that case, next step might be to determine whether consciousness is neurally a more global trait than in the present view, as in the global broadcasting hypothesis, or whether it depends on other specific areas correlated with the pattern of IPS involvement that we have discussed, but not dependent on the IPS itself after all.

Although many theories of consciousness seem to favor a brain-wide complex for what is conscious (e.g., Dennett et al., 1991), that view actually is difficult to reconcile with the considerable neural contribution to sophisticated unconscious processing (e.g., in unconscious priming, unconscious inferences, and walking and talking during sleep) and is more difficult to pin down neurally compared to when consciousness is proposed to depend crucially on a small neural area like the IPS as in the embedded processing theory with funneling.

Neural subparts of the focus or hub of attention. The focus of attention may have an enormous mission: to combine sources from the senses, from long-term memory, and from novel abstract ideation into a unified experience. The exact involvement of the IPS can depend on the methods of examination (Iamshchinina et al., 2021), for reasons that do not yet seem fully clear. Although the experience of consciousness seems unitary to the individual, it is potentially of great importance to consider that the neural representation of the focus of attention may have functioning subparts that could yield new insights into the nature of consciousness. We have talked as if the IPS is a single area underlying a unified consciousness but of course, there are subparts.

At a gross level, left and right hemispheres both have an IPS. If the IPS is to serve as the hub of a unitary consciousness, it seems critically important to understand the role that the connection between hemispheres plays. In the classic cases in which the corpus collosum was severed as a treatment of severe epilepsy (Gazzaniga et al., 1962), the assumption has been that the left and right hemispheres take on independent conscious identities, but a recent summary suggests that not enough is known to draw that conclusion (de Haan et al., 2020). Research on interhemispheric functional connectivity in patients with a range of levels of consciousness (brain-dead, comatose, recovered from coma, locked-in) and in normal controls shows a strong correlation of the level of consciousness with the level of interhemispheric connectivity, including the connectivity between the left and right IPS (Ovadia-Caro et al., 2012).

The IPS has subparts in each hemisphere that may lend insight into how sources of information are combined in the focus of attention. The IPS and its subparts have been investigated on anatomical, neurological, and behavioral levels. Currently, the field is engaged in research beginning to specify the functions of these subparts. The IPS has several subsections uncovered through retinotopic mapping (Wang et al., 2015) in which one can find repetitions of the representation of parts of the visual field (Swisher et al., 2007). However, the IPS is not only a visual center. J.S. Anderson et al. (2010, p. 20110) carried out a task of selective attention to various sensory modalities and noted that they found that "Distinct clusters of the IPS exhibited differential connectivity to auditory, visual, somatosensory, and default mode networks, suggesting local specialization within the IPS region for different sensory modalities." The most caudal activity was found for attention to vision and for the task of constructing a title for the scene; more rostral activity was found for auditory attention; and still more rostral activity was found for somatosensory attention. Regenbogen et al. (2010) found that the IPS was involved in successful audiovisual integration, especially when the sensory input was not clear on its own. E.J. Anderson et al. (2010) found IPS activation not only for inefficient visual search, i.e., outward attention, but also for visual or verbal working memory, i.e., inward attention. Gossaries et al. (2018) found IPS working memory activity to be stronger in remembering three homogenous items (three directions of motion) compared to heterogeneous items (two colors and one direction of motion). This effect could indicate a role of the IPS in remembering the specific binding between directions of motion and their serial position in the list. The effect was absent in the most caudal part of the IPS, labeled IPS0 by Wang's topology, and stronger toward the rostral part, progressing to the largest effects in IPS3 through IPS5. It seems plausible that caudal IPS is more involved in simple item maintenance, whereas rostral IPS is more involved in retaining the relation between items, or between an item and its context, in working memory.

In sum, it seems clear that the IPS plays a critical role in the focus of attention and awareness, and the notion that this unitary attention could be further broken down into different specializations within it is thought-provoking. If there are subspecialties within consciousness, we will need to understand what function creates the glue that makes these subspecialties blend into a unified experience.

Levels of analysis. There have been proposals about consciousness and brain on various levels of analysis, and in the future it will be important to understand how the different levels converge. Here we make a few recommendations. On perhaps the most holistic level, Stender et al. (2016) have shown that there is a minimal level of glucose activity, shown with positron emission tomography, that seems necessary in the case of brain damage to advance to a minimally conscious state. One might propose that the areas involved in consciousness have a higher energy requirement than some vital biological functions of the brain, in which case the breakdown of consciousness could still be the result of the brain areas suggested rather than being attributed to the whole brain. On a more microscopic level both spatially and temporally, more work is needed to understand the role of oscillatory activity. Many studies have suggested that consciousness-related functions depend on brain rhythms or neural oscillations (e.g., Engel & Fries, 2016; Lisman & Idiart, 1995; Palva et al., 2010) and these oscillations break down in disorders of consciousness (Bai et al., 2023). The function of the patterns of oscillations has been debated but they are compatible with the functional anatomical descriptions that we have offered. For example, Jensen and Mazaheri (2010) and Gutteling et al. (2022) suggested that Alpha Band oscillations (8–13 Hz) can represent suppression of information from regions that are not in focus; focal activity is represented by information in the Gamma Band (30–100 Hz) and its combination with slower waves that carry it. Information is conveyed by phase synchrony between Gamma and slower waves.

Human consciousness versus other possible consciousness. Another fundamental question is whether the architecture and organization we have suggested for human consciousness, if it is correct, is the only way that consciousness can emerge or just one way. Certainly, evolution has found more than one way to create movement and sensitivity to the environment, and it is possible that there are also other organizations of neural networks that also have consciousness. Finally, while it seems impractical to try to determine whether computer display consciousness, emulating the human organization in their systems may yield important results advancing artificial intelligence. All of the extant theories might be best at determining what factors could be related to consciousness, somewhat worse at determining what factors could be sufficient for consciousness, and worst at determining what factors could be necessary for it.

Practical applications. Last, it should not escape notice that an examination of consciousness, despite all of the theoretical uncertainties, is an important topic to advance various practical applications. Regarding medicine we have already noted, for example, that it is important to distinguish between unconscious patients and those in a locked-in state who are conscious but need special arrangements to be able to communicate (Guger et al., 2017). As another example, repetitive magnetic stimulation has been shown to improve the recovery of some patients in a vegetative state (Zhang et al., 2021). Understanding consciousness and different levels of awareness and meta-awareness is likely to contribute to a better understanding of mechanisms that could be used to improve clinical psychology and educational practices.

Epilogue: **Application of Consciousness Research to Society**

Simcha Bunim, in the 19th century, was said to prescribe the following: "Everyone must have two pockets, with a note in each pocket, so that he or she can reach into one or the other, depending on the need. When feeling lowly and depressed, discouraged or disconsolate, one should reach into the right pocket, and, there, find the words [meaning] 'The world was created for me.' But when feeling high and mighty one should reach into the left pocket, and find the words [meaning] 'I am but dust and ashes'" (Nickerson, 2016). This thought provides a mooring to tie our emotions and needs to the debate regarding consciousness, a long-lasting and currently very active debate. We are made of the same kinds of particles and energy as doorknobs, bear traps, and everything else, yet we can feel very special indeed. How is our subjective consciousness to be reconciled with our basic physical machinery? We propose that if humans remain thoughtful regarding consciousness in themselves and others, it will help them learn to get along better. In line with Bunim, when needing a spiritual lift, a human can contemplate the wonder of how consciousness mysteriously emerges from the laws of physics; but when needing to forgive or explain others' actions or limit one's own arrogance (Cowan et al., 2019), a human can focus on how even their greatest thoughts are mere interactions among atoms. In addition to individual well-being, consciousness research may be applicable to society in terms of ethical and moral considerations (informing such discussions as animal rights, end-of-life care, and artificial intelligence technologies), education (informing curriculum that optimizes engagement), healthcare (developing interventions for pain management), and social change. With a more connected society, humans may be inspired to address global challenges and gain a deeper appreciation for the interconnectedness of all beings. We have presented a theory we find congenial with diverse evidence.

References

Allport, D. A. (1968). Phenomenal simultaneity and the perceptual moment hypothesis. *British Journal of Psychology, 59*, 395–406. https://doi.org/10.1111/j.2044-8295.1968.tb01154.x

Amir, Y. Z., Assaf, Y., Yovel, Y., & Mudrik, L. (2023). Experiencing without knowing? Empirical evidence for phenomenal consciousness without access. *Cognition, 238*, Article 105529. https://doi.org/10.1016/j.cognition.2023.105529

Anderson, E. J., Mannan, S. K., Rees, G., Sumner, P., & Kennard, C. (2010). Overlapping functional anatomy for working memory and visual search. *Experimental Brain Research, 200*, 91-107. doi:10.1007/s00221-009-2000-5

Anderson, J. S., Ferguson, M. A., Lopez Larson, M., & Yurgelun-Todd, D. (2010). Topographic maps of multisensory attention. *Proceedings of the National Academy of Sciences, 107*(46), 20110-20114. https://doi.org/10.1073/pnas.1011616107

Baars, B. J. (1988). *A cognitive theory of consciousness.* Cambridge University Press.

Baars, B. J., & Franklin, S. (2003). How conscious experience and working memory interact. *Trends in Cognitive Sciences, 7*(4), 166–172. https://doi.org/10.1016/S1364-6613(03)00056-1

Baars, B. J., Franklin, S., & Ramsoy, T. Z. (2013). Global workspace dynamics: cortical "binding and propagation" enables conscious contents. *Frontiers in Psychology, 4*, Article 200. https://doi.org/10.3389/fpsyg.2013.00200

Baars, B. J., Geld, N., & Kozma, R. (2021). Global Workspace Theory (GWT) and Prefrontal Cortex: Recent Developments. *Frontiers in Psychology, 12*, Article 749868. https://doi.org/10.3389/fpsyg.2021.749868

Bai, Y., Gong, A., Wang, Q., Guo, Y., Zhang, Y., & Feng, Z. (2024). Breakdown of oscillatory effective networks in disorders of consciousness. *CNS Neuroscience & Therapeutics, 30*(3), Article e14469. https://doi.org/10.1111/cns.14469

Baier, B., Karnath, H.-O., Dieterich, M., Birklein, F., Heinze, C., & Müller, N. G. (2010). Keeping memory clear and stable—The contribution of human basal ganglia and prefrontal cortex to working memory. *Journal of Neuroscience, 30*(29), 9788–9792. https://doi.org/10.1523/JNEUROSCI.1513-10.2010

Balota, D. A. (1983). Automatic semantic activation and episodic memory encoding. *Journal of Verbal Learning and Verbal Behavior, 22*(1), 88–104. https://doi.org/10.1016/S0022-5371(83)80008-5

Barton, A. U., Valle-Inclán, F., Cowan, N., & Hackley, S. A. (2022). Unconsciously registered items reduce working memory capacity. *Consciousness and Cognition, 105*, Article 103399. https://doi.org/10.1016/j.concog.2022.103399

Beiser, F. C. (2020). Gustav Theodor Fechner. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Spring 2020 Edition). https://plato.stanford.edu/archives/spr2020/entries/fechner/

Belletier, C., Doherty, J. M., Graham, A. J., Rhodes, S., Cowan, N., Naveh-Benjamin, M., Barrouillet, P., Camos, V., & Logie, R. H. (2023). Strategic adaptation to dual-task in verbal working memory: Potential routes for theory integration. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 49*, 51-77. https://doi.org/10.1037/xlm0001106

Birch, J., Ginsburg, S., & Jablonka, E. (2020). Unlimited Associative Learning and the origins of consciousness: a primer and some predictions. *Biological Philosophy, 35*, Article 56. https://doi.org/10.1007/s10539-020-09772-0

Block, N. (1995). On a confusion about a function of consciousness. *Behavioral and brain sciences*, *18*(2), 227-247. https://doi.org/10.1017/S0140525X00038188

Block, N. (2005). Two neural correlates of consciousness. *Trends in cognitive sciences*, *9*(2), 46-52. https://doi.org/10.1016/j.tics.2004.12.006

Block, N. (2011). Perceptual consciousness overflows cognitive access. *Trends in cognitive sciences*, *15*(12), 567-575. https://doi.org/10.1016/j.tics.2011.11.001

Blum, L., & Blum, M. (2022). A theory of consciousness from a theoretical computer science perspective: Insights from the Conscious Turing Machine. *Proceedings of the National Academy of Sciences*, *119*(21), e2115934119. https://doi.org/10.1073/pnas.2115934119

Boly, M., Faymonville, M.E., Peigneux, P., Lambermont, B., Damas, P., Del Fiore, G., Degueldre, C., Franck, G., Luxen, A., Lamy, M., Moonen, G., Maquet, P., & Laureys, S. (2004). Auditory processing in severely brain injured patients: differences between the minimally conscious state and the persistent vegetative state. *Archives of Neurololgy, 61*, 233-238. doi: 10.1001/archneur.61.2.233.

Boly, M., Phillips, C., Tshibanda, L., Vanhaudenhuyse, A., Schabus, M., Dang-Vu, T.T., Moonen, G., Hustinx, R., Maquet, P., & Laureys, S. (2008). Intrinsic brain activity in altered states of consciousness: how conscious is the default mode of brain function? *Annals of the New York Academy of Science, 1129*, 119-129. doi: 10.1196/annals.1417.015.

Broadbent, D. E. (1958). *Perception and communication*. Pergamon Press. https://doi.org/10.1037/10037-000

Bronfman, Z. Z., Brezis, N., Jacobson, H., & Usher, M. (2014). We see more than we can report: "cost free" color phenomenality outside focal attention. *Psychological science*, *25*(7), 1394-1403. https://doi.org/10.1177/0956797614532656

Brown, A. S. (2003). A review of the déjà vu experience. *Psychological Bulletin, 129* (3), 394–413. https://doi.org/10.1037/0033-2909.129.3.394

Brown, R., Lau, H., & LeDoux, J. E. (2019). Understanding the higher-order approach to consciousness. *Trends in cognitive sciences*, *23*(9), 754-768. https://doi.org/10.1016/j.tics.2019.06.009

Bugden, S., Price, D. McLean, A., & Ansari, D. (2012). The role of the left intraparietal sulcus in the relationship between symbolic number processing and children's arithmetic competence, *Developmental Cognitive Neuroscience, 2*, 448-457. https://doi.org/10.1016/j.dcn.2012.04.001.

Cai, Y., Fulvio, J. M., Yu, Q., Sheldon, A. D., & Postle, B. R. (2020). The role of location-context binding in nonspatial visual working memory. *Eneuro*, *7*(6). https://doi.org/10.1523/ENEURO.0430-20.2020

Carls-Diamante, S. (2022). Where is it like to be an octopus?. *Frontiers in systems neuroscience*, *16*, 840022. https://doi.org/10.3389/fnsys.2022.840022

Carruthers, P. (2017). Block's overflow argument. *Pacific Philosophical Quarterly*, *98*, 65-70. https://doi.org/10.1111/papq.12152

Casali, A. G., Gosseries, O., Rosanova, M., Boly, M., Sarasso, S., Casali, K. R., ... & Massimini, M. (2013). A theoretically based index of consciousness independent of sensory processing and behavior. *Science translational medicine*, *5*(198), 198ra105-198ra105. https://doi.org/10.1126/scitranslmed.3006294

Chalmers, D. J. (1995). Facing up to the problem of consciousness. *Journal of Consciousness Studies*, *2*(3), 200-219. https://doi.org/10.1093/acprof:oso/9780195311105.003.0001

Chang, C., Crottaz-Herbette, S., & Menon, V. (2007). Temporal dynamics of basal ganglia response and connectivity during verbal working memory. *Neuroimage*, *34*(3), 1253-1269. https://doi.org/10.1016/j.neuroimage.2006.08.056

Charles, L., Van Opstal, F., Marti, S., & Dehaene, S. (2013). Distinct brain mechanisms for conscious versus subliminal error detection. *NeuroImage*, *73*, 80–94. https://doi.org/10.1016/j.neuroimage.2013.01.054

Chen, H., Carlson, R. A., & Wyble, B. (2018). Is source information automatically available in working memory? *Psychological Science*, *29*(4), 645–655. https://doi.org/10.1177/0956797617742158

Chittka, L. (2022). *The mind of a bee*. Princeton University Press.

Chong, S. C., & Treisman, A. (2003). Representation of statistical properties. *Vision Research*, *43*(4), 393–404. https://doi.org/10.1016/s0042-6989(02)00596-5

Chong, S. C., Joo, S. J., Emmmanouil, T.-A., & Treisman, A. (2008). Statistical processing: Not so implausible after all. *Perception & Psychophysics*, *7*0(7), 1327–1334. https://doi.org/10.3758/pp.70.7.1327

Christophel, T. B., Iamshchinina, P., Yan, C., Allefeld, C., & Haynes, J.-D. (2018). Cortical specialization for attended versus unattended working memory. *Nature Neuroscience,* *21*(4), 494–496. https://doi.org/10.1038/s41593-018-0094-4

Cogitate Consortium, Ferrante, O., Gorska-Klimowska, U., Henin, S., Hirschhorn, R., Khalaf, A., Lepauvre, A., Liu, L., Richter, D., Vidal, Y., Bonacchi, N., Brown, T., Sripad, P., Armendariz, M., Bendtz, K., Ghafari, T., Hetenyi, D., Jeschke, J., Kozma, C., … Melloni, L. (2023). An adversarial collaboration to critically evaluate theories of consciousness. *bioRxiv*, 2023-06. https://doi.org/10.1101/2023.06.23.546249

Cohen, M. A., Cavanagh, P., Chun, M. M., & Nakayama, K. (2012). The attentional requirements of consciousness. *Trends in Cognitive Sciences, 16*(8), 411–417. https://doi.org/10.1016/j.tics.2012.06.013

Coleman, M.R., Bekinschtein, T., Monti, M.M., Owen, A.M., & Pickard, J.D. (2009). A multimodal approach to the assessment of patients with disorders of consciousness. *Progress in Brain Research, 177*, 231-248. doi: 10.1016/S0079-6123(09)17716-6.

Cooper, J. (2019). Cognitive Dissonance: Where we've been and where we're going. *International Review of Social Psychology, 32*(1). https://doi.org/10.5334/irsp.277

Cowan, N. (1984). On short and long auditory stores. *Psychological Bulletin, 96*(2), 341–370. https://doi.org/10.1037/0033-2909.96.2.341

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information-processing system. *Psychological Bulletin, 104*(2), 163–191. https://doi.org/10.1037/0033-2909.104.2.163

Cowan, N. (1995). *Attention and memory: An integrated framework*. Oxford Psychology Series, No. 26. New York: Oxford University Press.

Cowan, N. (1999). An embedded-processes model of working memory. *Models of Working Memory*, 62–101. https://doi.org/10.1017/cbo9781139174909.006

Cowan, N. (2005). *Working memory capacity*. Psychology Press. [Psychology Press and Routledge Classic Edition with new foreword, 2016]

Cowan, N. (2017). The many faces of working memory and short-term storage. *Psychonomic Bulletin & Review, 24*, 1158–1170. DOI: 10.3758/s13423-016-1191-6

Cowan, N. (2019). Short-term memory based on activated long-term memory: A review in response to Norris (2017). *Psychological Bulletin, 145*(8), 822–847. https://doi.org/10.1037/bul0000199

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences, 24*, 87-185. DOI: https://doi.org/10.1017/S0140525X01003922

Cowan, N., Adams, E.J., Bhangal, S., Corcoran, M., Decker, R., Dockter, C.E., Eubank, A.T., Gann, C.L., Greene, N.R., Helle, A.C., Lee, N., Nguyen, A.T., Ripley, K.R., Scofield, J.E., Tapia, M.A., Threlkeld, K.L., & Watts, A.L. (2019). Foundations of arrogance: A broad survey and framework for research. *Review of General Psychology, 23*, 425-443. https://doi.org/10.1177/1089268019877138

Cowan, N., Bao, C., Bishop-Chrzanowski, B.M., Costa, A.N., Greene, N.R., Guitard, D., Li, C., Musich, M.L., & Ünal, Z.E. (2024). The relation between attention and memory. *Annual Review of Psychology, 75*, 183-214. https://doi.org/10.1146/annurev-psych-040723-012736

Cowan, N., Li, D., Moffitt, A., Becker, T. M., Martin, E. A., Saults, J. S., & Christ, S. E. (2011). A neural region of abstract working memory. *Journal of Cognitive Neuroscience, 23*(10), 2852–2863. https://doi.org/10.1162/jocn.2011.21625

Cowan, N., & Rachev, N. R. (2018). Merging with the path not taken: Wilhelm Wundt's work as a precursor to the embedded-processes approach to memory, attention, and consciousness. *Consciousness and Cognition, 63*, 228–238. https://doi.org/10.1016/j.concog.2018.06.001

Csikszentmihalyi, M., & Larson, R. (1987). Validity and reliability of the experience-sampling method. *Journal of Nervous and Mental Disease, 175*(9), 526-536. https://doi.org/10.1097/00005053-198709000-00004

Das, J.M., Anosike, K., & Asuncion, R.M.D. (2023). Locked-in syndrome. In *StatPearls*.

Statpearls Publishing. Retrieved from https://www.ncbi.nlm.nih.gov/books/NBK559026/

Davies, D.R., & Parasuraman, R. (1982). *The psychology of vigilance*. Academic Press.

Deco, G., Vidaurre, D. & Kringelbach, M.L. (2021). Revisiting the global workspace orchestrating the hierarchical organization of the human brain. *Nature Human Behavior, 5*, 497–511. https://doi.org/10.1038/s41562-020-01003-6

de Haan, E.H.F., Corballis, P.M., Hillyard, S.A., Marzi, C.A., Seth, A., Lamme, V.A.F., et al. (2020). Split-brain: what we know now and why this is important for understanding consciousness. *Neuropsychology Review, 30*(2), 224-233. https://doi.org/10.1007/s11065-020-09439-3

Dehaene S., & Changeux, J.P. (2011). Experimental and theoretical approaches to conscious processing. *Neuron*, *70*(2), 200-27. https://doi.org/10.1016/j.neuron.2011.03.018

Dehaene, S., Kerszberg, M., & Changeux, J. P. (1998). A neuronal model of a global workspace in effortful cognitive tasks. *Proceedings of the National Academy of Sciences*, *95*(24), 14529-14534. https://doi.org/10.1073/pnas.95.24.14529

Demertzi, A., Tagliazucchi, E., Dehaene, S., Deco, G., Barttfeld, P., Raimondo, F., Martial, C., Fernández-Espejo, D., Rohaut, B., Voss, H.U., Schiff, N.D., Owen, A.M., Laureys, S., Naccache, L., Sitt, J.D. (2019). Human consciousness is supported by dynamic complex patterns of brain signal coordination. *Science Advances*, *5*(2), eaat7603. https://doi.org/10.1126/sciadv.aat7603

Dennett, D.C. (1991). *Consciousness explained.* Little, Brown & Company.

Dijkstra, N., & Fleming, S.M. (2023). Subjective signal strength distinguishes reality from imagination. *Nature Communications, 14*, 1627. https://doi.org/10.1038/s41467-023-37322-1

Doerig, A., Schurger, A., Herzog, M,H. (2021). Hard criteria for empirical theories of consciousness. *Cognitive Neuroscience, 12*(2), 41-62. https://doi.org/10.1080/17588928.2020.1772214

Doesburg, S. M., Green, J. J., McDonald, J. J., & Ward, L. M. (2009). Rhythms of consciousness: Binocular rivalry reveals large-scale oscillatory network dynamics mediating visual perception. *PloS one, 4*(7), e6142. https://doi.org/10.1371/journal.pone.0006142

Dunbar, J., Gilbert, J.E., & Lewis, B. (2020). Exploring differences between self-report and electrophysiological indices of drowsy driving: a usability examination of a personal brain-computer interface device. *Journal of Safety Research*, *74*, 27-34. https://doi.org/10.1016/j.jsr.2020.04.006

Dupont, W., Papaxanthis, C. Lebon, F., & Madden-Lombardi, C. (2024). Mental simulations and action language are impaired in individuals with aphantasia. *Journal of Cognitive Neuroscience, 36*, 261–271. doi: https://doi.org/10.1162/jocn_a_02084

Eagleman, D.M. (2001). Visual illusions and neurobiology. *Nature Reviews Neuroscience, 2*, 920-926. https://doi.org/10.1038/35104092

Eagleman, D.M., & Vaughn, D.A. (2021). The defensive activation theory: REM sleep as a mechanism to prevent takeover of the visual cortex. *Frontiers in Neuroscience, 15*, 632853. https://doi.org/10.3389/fnins.2021.632853

Economist (2023). *Thousands of species of animals probably have consciousness*. 28 June. Retrieved 16 December 2023 from https://www.economist.com/science-and-technology/2023/06/28/thousands-of-species-of-animals-likely-have-consciousness?utm_medium=cpc.adword.pd&utm_source=google&ppccampaignID=172

10591673&ppcadID=&utm_campaign=a.22brand_pmax&utm_content=conversion.direct-response.anonymous&gad_source=1&gclid=Cj0KCQiAsvWrBhC0ARIsAO4E6f-DcYEOCCdc6XOe7y9u6hVXlqqJzVwTPb9UBkPrkMiGp0Lo_V7LjHUaAq6fEALw_wcB&gclsrc=aw.ds

Edelman, D. B., & Seth, A. K. (2009). Animal consciousness: A synthetic approach. *Trends in Neurosciences, 32*(9), 476–484. https://doi.org/10.1016/j.tins.2009.05.008

Engel, A.K., & Fries, P. (2016). Neuronal Oscillations, Coherence, and Consciousness, In S. Laureys, O. Gosseries, & G. Tononi (eds.), *The Neurology of Conciousness* (Second Edition),Academic Press. https://doi.org/10.1016/B978-0-12-800948-2.00003-0.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review, 87*(3), 215–251. https://doi.org/10.1037/0033-295X.87.3.215

Farah, M.J. (1989). The neural basis of mental imagery. *Trends in Neuroscience, 12*, 395-399. https://doi.org/10.1016/0166-2236(89)90079-9

Fechner, G. (1851/1901). Zend-Avesta oder über die Dinge des Himmels und des Jenseits. Vom *Standpunkt der Naturbetrachtung*. Leipzig: Leopold Voß. Second edition, Kurd Laßwitz (ed.).

Festinger, L., & Carlsmith, J. M. (1959). Cognitive consequences of forced compliance. The *Journal of Abnormal and Social Psychology, 58*(2), 203–210. https://doi.org/10.1037/h0041593

Finkel, E. (2023). Consciousness hunt yields results but not clarity. *Science, 380*, 1309-1310. https://doi.org/10.1126/science.adj4498

Fleming, S., Frith, C., Goodale, M., Lau, H., LeDoux, J. E., Lee, A. L., ... & Slagter, H. A. (2023). *The integrated information theory of consciousness as pseudoscience*.

https://doi.org/10.31234/osf.io/zsr78

Fontan A, Lindgren L, Pedale T, Brorsson C, Bergström F, Eriksson J. (2021). A reduced level of consciousness affects non-conscious processes. *Neuroimage, 244*, 118571. Https://doi.org/10.1016/j.neuroimage.2021.118571

Frässle, S., Sommer, J., Jansen, A., Naber, M., & Einhäuser, W. (2014). Binocular rivalry: frontal activity relates to introspection and action but not to perception. *The Journal of Neuroscience, 34*(5), 1738–1747. https://doi.org/10.1523/JNEUROSCI.4403-13.2014

Gazzaniga, M.S. (2011). *Who's in charge? Free will and the science of the brain*. HarperCollins.

Gazzaniga,M.S., Bogen, J.E., & Sperry, R.W. (1962). Some functional effects of sectioning the cerebral commissures in man. *Proceedings of the National Academy of Sciences of the United States of America, 48*(10) 1765–1769. https://doi.org/10.1073/pnas.48.10.1765

Gossaries, O., Yu, Q., LaRocque, J.J., Starrett, M.J., Rose, N.S., Cowan, N., & Postle, B.R. (2018). Parietal-occipital interactions underlying control- and representation-related processes in working memory for nonspatial visual features. *Journal of Neuroscience, 38*, 4357– 4366. https://doi.org/10.1523/JNEUROSCI.2747-17.2018

Guger, C., Coyle, D., Mattia, D., De Lucia, M., Hochberg, L., Edlow, B.L. et al. (2017). Trends in BCI research I: Brain-computer interfaces for assessment of patients with locked-in syndrome or disorders of consciousness. In: C. Guger, B. Allison, & M. Lebedev (eds), *Brain-computer interface research* (pp. 10-125). Springer. https://doi.org/10.1007/978-3-319-64373-1_11

Gutteling, T.P., Sillekens, L,, Lavie, N., & Jensen, O. (2022), Alpha oscillations reflect suppression of distractors with increased perceptual load, *Progress in Neurobiology, 214*, 102285. https://doi.org/10.1016/j.pneurobio.2022.102285

Guttman, N., & Julesz, B. (1963). Lower limits of auditory periodicity analysis. *Journal of the Acoustical Society of America, 35*, 610. https://doi.org/10.1121/1.1918551

Halford, G.S., Cowan, N., & Andrews, G. (2007). Separating cognitive capacity from knowledge: A new hypothesis. *Trends in Cognitive Sciences, 11*, 236-242. https://doi.org/10.1016/j.tics.2007.04.001

Halligan P. W. (2002). Phantom limbs: The body in mind. *Cognitive Neuropsychiatry, 7*(3), 251–269. https://doi.org/10.1080/13546800244000111

Hameroff, S. (2021). 'Orch OR' is the most complete, and most easily falsifiable theory of consciousness. *Cognitive Neuroscience*, *12*, NO. 2, 74–76. https://doi.org/10.1080/17588928.2020.1839037

Hameroff, S., & Penrose, R. (1996). Orchestrated reduction of quantum coherence in brain microtubules: A model for consciousness. *Mathematics and Computers in Simulation*, *40*(3), 453–480. https://doi.org/10.1016/0378-4754(96)80476-9

Hameroff, S., & Penrose, R. (2014). Consciousness in the universe: A review of the "Orch OR" theory. *Physics of Life Reviews*, *11*(1), 39–78. https://doi.org/10.1016/j.plrev.2013.08.002

Harmon-Jones, E. (Ed.). (2019). *Cognitive dissonance: Reexamining a pivotal theory in psychology* (second edition). American Psychological Association. https://doi.org/10.1037/0000135-000

He, B. J. (2023). Next frontiers in consciousness research. *Neuron*, *111*(20), 3150–3153. https://doi.org/10.1016/j.neuron.2023.09.042

Heinke, W., & Schwarzbauer, C. (2001). Subanesthetic isoflurane affects task-induced brain activation in a highly specific manner: A functional magnetic resonance imaging study. *Anesthesiology*, *94*(6), 973–981. https://doi.org/10.1097/00000542-200106000-00010

Holyoak, K. J., & Monti, M. M. (2021). Relational integration in the human brain: A review and synthesis. *Journal of Cognitive Neuroscience*, *33*(3), 341–356. https://doi.org/10.1162/jocn_a_01619

Hurlburt, R. T., & Akhter, S. A. (2006). The Descriptive Experience Sampling method. *Phenomenology and the Cognitive Sciences*, *5*(3–4), 271–301. https://doi.org/10.1007/s11097-006-9024-0

Hutchinson, B. T. (2019). Toward a theory of consciousness: A review of the neural correlates of inattentional blindness. *Neuroscience and Biobehavioral Reviews*, *104*, 87–99. https://doi.org/10.1016/j.neubiorev.2019.06.003

Hutchinson, D. M. (2018). *Plotinus on consciousness*. Cambridge University Press.

Iamshchinina, P., Christophel, T.B., Gayete, S., & Rademaker, R.L. (2021). Essential considerations for exploring visual working memory storage in the human brain. *Visual Cognition, 29*, 425–436. https://doi.org/10.1080/13506285.2021.1915902

Ibáñez, V., Silva, J., & Cauli, O. (2018). A survey on sleep questionnaires and diaries. *Sleep Medicine*, *42*, 90–96. https://doi.org/10.1016/j.sleep.2017.08.026

Imas, O. A., Ropella, K. M., Ward, B. D., Wood, J. D., & Hudetz, A. G. (2005). Volatile anesthetics disrupt frontal-posterior recurrent information transfer at gamma frequencies in rat. *Neuroscience Letters*, *387*(3), 145–150. https://doi.org/10.1016/j.neulet.2005.06.018

Inouchi, M., Matsumoto, R., Taki, J., Kikuchi, T., Mitsueda-Ono, T., Mikuni, N., ... & Ikeda, A. (2013). Role of posterior parietal cortex in reaching movements in humans: Clinical implication for ‘optic ataxia’. *Clinical Neurophysiology, 124*, 2230-2241. https://doi.org/10.1016/j.clinph.2013.05.011

Jackson-Nielsen, M., Cohen, M. A., & Pitts, M. A. (2017). Perception of ensemble statistics requires attention. *Consciousness and Cognition: An International Journal*, *48*, 149–160. https://doi.org/10.1016/j.concog.2016.11.007

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language*, *30*(5), 513–541. https://doi.org/10.1016/0749-596X(91)90025-F

Jacoby, L.L., Woloshyn, V., & Kelly, C. (1989). Becoming famous without being recognized: Unconscious influences of memory produced by divided attention. *Journal of Experimental Psychology: General, 118*(2), 115-125. https://doi.org/10.1037/0096-3445.118.2.115

James, William, 1890 [1981], *The principles of psychology*, Cambridge, MA: Harvard University Press.

Jensen, O., Kaiser, J., & Lachaux, J. P. (2007). Human gamma-frequency oscillations associated with attention and memory. *Trends in Neuroscience, 30*(7), 317-324. https://doi.org/10.1016/j.tins.2007.05.001

Jensen, O., & Mazaheri, A. (2010). Shaping Functional Architecture by Oscillatory Alpha Activity: Gating by Inhibition. *Frontiers in Human Neuroscience, 4*. https://doi.org/10.3389/fnhum.2010.00186

Johns, M. W. (1991). A new method for measuring daytime sleepiness: The Epworth sleepiness scale. *SLEEP, 14*(6), 54-545. https://doi.org/10.1093/sleep/14.6.540

Kanai, R., Muggleton, N. G., & Walsh, V. (2008). TMS over the intraparietal sulcus induces perceptual fading. *Journal of Neurophysiology, 100*(6), 3343-3350. https://doi.org/10.1152/jn.90885.2008

Kentridge, R. W., Nijboer, T. C., & Heywood, C. A. (2008). Attended but unseen: Visual attention is not sufficient for visual awareness. *Neuropsychologia, 46*(3), 864-869. https://doi.org/10.1016/j.neuropsychologia.2007.11.036

Kihlstrom, J. F. (2017). Time to lay the Libet experiment to rest: Commentary on Papanicolaou (2017). *Psychology of Consciousness: Theory, Research, and Practice, 4*(3), 324–329. https://doi.org/10.1037/cns0000124

Koch, C., Massimini, M., Boly, M., & Tononi, G. (2016). Neural correlates of consciousness: Progress and problems. Nature Reviews Neuroscience, 17(5), 307-321. https://doi.org/10.1038/nrn.2016.22

Kouider, S., Dehaene, S., Jobert, A., & Le Bihan, D. (2007). Cerebral bases of subliminal and supraliminal priming during reading. *Cerebral Cortex, 17*(9), 2019-2029. https://doi.org/10.1093/cercor/bhl110

Lau, H. (2023). *What is a pseudoscience of consciousness? Lessons from recent adversarial collaborations.* PsyArxiv Preprints. https://doi.org/10.31234/osf.io/28z3y

Lau, H., & Rosenthal, D. (2011). Empirical support for higher-order theories of conscious awareness. *Trends in Cognitive Sciences*, *15*(8), 365–373. https://doi.org/10.1016/j.tics.2011.05.009

Laureys, S., Faymonville, M.E., Degueldre, C., Fiore, G.D., Damas, P., Lambermont, B., Janssens, N., Aerts, J., Franck, G., Luxen, A., Moonen, G., Lamy, M., & Maquet, P. (2000). Auditory processing in the vegetative state. *Brain, 123*, 1589-601. doi: 10.1093/brain/123.8.1589

LeDoux, J., Birch, J., Andrews, K., Clayton, N. S., Daw, N. D., Frith, C., ... & Vandekerckhove, M. M. (2023). Consciousness beyond the human case. *Current Biology*, *33*(16), R832-

R840. https://doi.org/10.1016/j.cub.2023.06.067

Lee, H., Mashour, G. A., Noh, G. J., Kim S., & Lee, U. (2013). Reconfiguration of network Hub structure after propofol-induced unconsciousness. *Anesthesiology*. *119*(6), 1347-1359. https://doi.org/10.1097/ALN.0b013e3182a8ec8c

Lee, U., Ku, S., Noh, G., Baek, S., Choi, B., & Mashour, G. A. (2013a). Disruption of frontal-parietal communication by ketamine, propofol, and sevoflurane. *Anesthesiology*, *118*, 1264–1275. https://doi.org/10.1097/ALN.0b013e31829103f5

Lenharo, M. (2023). Decades-long bet on consciousness ends – and it's philosopher 1, neuroscientist 0. *Nature*, *619*, 14-15. https://doi.org/10.1038/d41586-023-02120-8

Lewis-Peacock, J. A., Drysdale, A. T., Oberauer, K., & Postle, B. R. (2012). Neural evidence for a distinction between short-term memory and the focus of attention. *Journal of Cognitive Neuroscience*, *24*, 61-79. https://doi.org/10.1162/jocn_a_00140

Li, D., Christ, S. E., Cowan, N. (2014). Domain-general and domain-specific functional networks in working memory. *Neuroimage*, *102*, 646-656. https://doi.org/10.1016%2Fj.neuroimage.2014.08.028

Libet, B., Gleason, C. A., Wright, E. W., & Pearl, D. K. (1983). Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential). The unconscious initiation of a freely voluntary act. *Brain*: *A Journal of Neurology*, *106*(3), 623-642. https://doi.org/10.1093/brain/106.3.623

Lisman, J. E., Idiart, M. A. P. (1995). Storage of 7 ± 2 short-term memories in oscillatory subcycles. *Science*, *267*, 1512-1515. https://doi.org/10.1126/science.7878473

Maciejewicz, B. (2022). Neuroscience of consciousness in the locked-in syndrome: Prognostic and diagnostic review. *International Brain Research Organization Reports*, *12*(1), 12077.

https://doi.org/10.1002%2Fibra.12077

Maier, A., Tsuchiya, N. (2021). Growing evidence for separate neural mechanisms for attention and consciousness. *Attention, Perception, & Psychophysics*, *83*(2), 558-576. https://doi.org/10.3758/s13414-020-02146-4

Majerus, S., Attout, L., D'Argembeau, A., Degueldre, C., Fias, W., Maquet, P., ... & Balteau, E. (2012). Attention supports verbal short-term memory via competition between dorsal and ventral attention networks. *Cerebral Cortex, 22*, 1086-1097. doi:10.1093/cercor/bhr174.

Majerus, S., Cowan, N., Péters, F., Van Calster, L., Phillips, C., & Schrouff, J. (2016). Cross-modal decoding of neural patterns associated with working memory: Evidence for attention-based accounts of working memory. *Cerebral Cortex, 26*, 166-179. DOI: 10.1093/cercor/bhu189

Majerus, S., Péters, F., Bouffier, M., Cowan, N., & Phillips, C. (2018). The dorsal attention network reflects both encoding load and top-down control during working memory. *Journal of Cognitive Neuroscience, 30*, 144-159. DOI: 10.1162/jocn_a_01195https://doi.org/10.3389/fpsyg.2016.01522

Mansell, W. (2022, online ahead of print). An integrative control theory perspective on consciousness. *Psychological Review*. https://doi.org/10.1037/rev0000384

Marcel, A. J. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology*, *15*, 197-237. https://doi.org/10.1016/0010-0285(83)90009-9

Mashour, G. A., Palanca, B. J., Basner, M., Li, D., Wang, W., Blain-Moraes, S., et al. (2021). Recovery of consciousness and cognition after general anesthesia in humans. *eLife*, *10*, e59525. https://doi.org/10.7554/eLife.59525

Montagnese, M., Leptourgos, P., Fernyhough, C., Waters, F., Larøi, F., Jardri, R et al. (2021). A review of multimodal hallucinations: Categorization, assessment, theoretical perspectives, and clinical recommendations. *Schizophrenia Bulletin, 47*(1), 237-248. https://doi.org/10.1093/schbul/sbaa101

Mortley, R. (2013). *Plotinus, self and the world*. Cambridge University Press.

Melloni, L., Schwiedrzik, C. M., Müller, N., Rodriguez, E., & Singer, W. (2007). Expectations change the signatures and timing of electrophysiological correlates of perceptual awareness. *Journal of Neuroscience*, *27*(47), 11952–11962. https://doi.org/10.1523/jneurosci.4570-10.2011

Müller, J. (1826). Zur vergleichenden Physiologie des Gesichtssinnes des Menschen und der Tiere, Leipzig: C. Knobloch.

Naccache, L., Blandin, E., & Dehaene S. (2002). Unconscious masked priming depends on temporal attention. *Psychological Science*, *13*(5), 416-424. https://doi.org/10.1111/1467-9280.00474

Nagel, T. (1974). What is it like to be a bat? *Philosophical Review, 83*(4), 435–450. https://doi.org/10.2307/2183914

Nedergaard, J. S. K. & Lupyan, G. (2024, Online First). Not everybody has an inner voice: Behavioral consequences of anendophasia. *Psychological Science*. doi.org/10.1177/09567976241243004.

Nickerson, R. J. (2016). *Yom Kippur 2016/5777: Two pockets*. Retrieved May 28, 1996, from https://www.templeisaiah.com/pdf/1481327848_sermon_pdf_2016_Rabbi_Joel_

Nieder, A., Wagener, L., & Rinnert, P. (2020). A neural correlate of sensory consciousness in a corvid bird. *Science, 369*(6511), 1626-1629. https://doi.org/10.1126/science.abb1447

Nisbett, R. E., & Wilson, T. D. (1977). Telling more than we can know: verbal reports on mental processes. *Psychological Review, 84*(3), 231–259. https://doi.org/10.1037/0033-295X.84.3.231

Norman, E., Pfuhl, G., Sæle, R. G., Svartdal, F., Låg, T., & Dahl, T. I. (2019). Metacognition in psychology. *Review of General Psychology, 23*(4), 403-424. https://doi.org/10.1177/1089268019883821

Norrsell, U., Finger, S. & Lajonchere, C. (1999) Cutaneous sensory spots and the "law of specific nerve energie": history and development of ideas. *Brain Research Bulletin, 48*(5), 457-465. https://doi.org/10.1016/s0361-9230(98)00067-7

Northoff, G., & Lamme, V. (2020). Neural signs and mechanisms of consciousness: is there a potential convergence of theories of consciousness in sight? *Neuroscience & Biobehavioral Reviews*, *118*, 568-587. https://doi.org/10.1016/j.neubiorev.2020.07.019

Nourbakhshi, H. (2023) The role of imagination and recollection in the method of phenomenal contrast. *Theoria*, *89*(5), 710-733. https://doi.org/10.1111/theo.12489

Oberauer, K. (2019). Working memory capacity limits memory for bindings. *Journal of Cognition, 2*(1), 40. https://doi.org/10.5334/joc.86

Odegaard, B., Chang, M. Y., Lau, H., & Cheung, S. H. (2018). Inflation versus filling-in: why we feel we see more than we actually do in peripheral vision. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 373*(1755), 20170345. https://doi.org/10.1098/rstb.2017.0345

Odegaard, B., Knight, R.T., & Lau, H. (2017). Should a few null findings falsify prefrontal theories of conscious perception? *Journal of Neuroscience, 37*, 9593-9602. doi: 10.1523/JNEUROSCI.3217-16.2017

Olin, R. (1999). Auditory hallucinations and the bicameral mind. *Lancet, 354*(9173), 166. HTTPS://DOI.ORG/10.1016/S0140-6736(05)75304-6

Ovadia-Caro, S., Nir, Y., Soddu, A., Ramot, M., Hesselmann, G., Vanhaudenhuyse, A., et al, (2012) Reduction in inter-hemispheric connectivity in disorders of consciousness. *PLoS One, 7*(5), e37238. https://doi.org/10.1371/journal.pone.0037238

Palva, J. M., Monto, S., Kulashekhar, S., & Palva, S. (2010). Neuronal synchrony reveals working memory networks and predicts individual memory capacity. *Proceedings of the National Academy of Sciences, U.S.A., 107*, 7580–7585. DOI: 10.1073/pnas.0913113107

Papanicolaou, A. C. (2017). The myth of the neuroscience of will. *Psychology of Consciousness: Theory, Research, and Practice, 4*(3), 310–320. https://doi.org/10.1037/cns0000116

Peters, M.A.K., Ketridge, R.W., Phillips, I., & Block, N. (2017). Does unconscious perception really exist? Continuing the ASSC20 debate. *Neuroscience of Consciousness*, *3*(1), nix015. https://doi.org/10.1093/nc/nix015

Pinto, Y., Sligte, I. G., Shapiro, K. L., & Lamme, V. A. F. (2013). Fragile visual short-term memory is an object-based and location-specific store. *Psychonomic Bulletin & Review*, *20*(4), 732-739. https://doi.org/10.3758/s13423-013-0393-4

Power, J.D., Schlaggar, B.L., Lessov-Schlaggar, C.N., & Peterson, S.E. (2013). Evidence for hubs in human functional brain networks. *Neuron, 79*, 798–813. DOI: 10.1016/j.neuron.2013.07.035

Premack, D, & Woodruff, G. (1978). Does the chimpanzee have a theory of mind? *Behavioral and Brain Sciences. 1*(4), 515–526. https://doi.org/10.1017/S0140525X00076512

Raccah, O., Block, N., & Fox, K. C. R. (2021). Does the prefrontal cortex play an essential role in consciousness? Insights from intracranial electrical stimulation of the human brain.

Journal of Neuroscience, 41(10), 2076-2087. https://doi.org/10.1523/JNEUROSCI.1141-20.2020

Ramachandran, V. S. (1995). Anosognosia in parietal lobe syndrome. *Consciousness and Cognition*, *4*(1), 22-51. https://doi.org/10.1006/ccog.1995.1002

Ramachandran, V. S., and Rogers-Ramachandran, D. (1996). Denial of disabilities in anosognosia. *Nature*, *382*(6591), 501. https://doi.org/10.1038/382501a0

Redinbaugh, M. J., Phillips, J. M., Kambi, N. A., Mohanta, S., Andryk, S., Dooley, G. L., Afrasiabi, M., Raz, A., & Saalmann, Y. B. (2020). Thalamus modulates consciousness via layer-specific control of cortex. *Neuron*, *106*(1), 66-75. https://doi.org/10.1016/j.neuron.2020.01.005

Regenbogen, C., Seubert, J., Johansson, E., Finkelmeyer, A., Andersson, P., & Lundström, J. N. (2018). The intraparietal sulcus governs multisensory integration of audiovisual information based on task difficulty. *Human Brain Mapping, 39*, 1313-1326. doi:10.1002/hbm.23918

Reinhart R.M., and Woodman, G.F. (2014). High stakes trigger the use of multiple memories to enhance the control of attention. *Cerebral Cortex*, *24*(8), 2022–2035. https://doi.org/10.1093/cercor/bht057

Rhodes, S., & Cowan, N. (2018). Attention in working memory: Attention is needed but it yearns to be free. *Annals of the New York Academy of Science, 1424*, 52-63. doi: 10.1111/nyas.13652

Ropper, A.H., & Zafonte, R.D. (2015). Sciatica. *The New England Journal of Medicine*, *372* (13), 1240–8. https://doi.org/10.1056/NEJMra1410151

Rose, N. S., LaRocque, J. J., Riggall, A. C., Gosseries, O., Starrett, M. J., Meyering, E. E., &

Postle, B. R. (2016). Reactivation of latent working memories with transcranial magnetic stimulation. *Science*, *354*(6316), 1136-1139. https://doi.org/10.1126/science.aah7011

Rosenthal, D. M. (2008). Consciousness and its function. *Neuropsychologia, 46*(3), 829–840. https://doi.org/10.1016/j.neuropsychologia.2007.11.012

Rouder, J. N., and Morey, R. D. (2009). The nature of psychological thresholds. *Psychological Review, 116*(3), 655–660. https://doi.org/10.1037/a0016413

Salanova, V. (2012). Parietal lobe epilepsy. *Journal of Clinical Neurophysiology, 29*(5), 392-396. https://doi.org/10.1097/WNP.0b013e31826c9ebc

Sanders, R. D., Tononi, G., Laureys, S., Sleigh, J. W., & Warner, D. S. (2012). Unresponsiveness ≠ unconsciousness. *Anesthesiology, 116*(4), 946–959. https://doi.org/10.1097/ALN.0b013e318249d0a7

Seager, W., & Allen-Hermanson, S. (2009). Panpsychism. In *Stanford Encyclopedia of Philosophy.* Retrieved from the web, 2 September, 2023. https://plato.stanford.edu/Archives/spr2009/entries/panpsychism/

Seth, A. K., and Bayne, T. (2022). Theories of consciousness. *Nature Reviews Neuroscience, 23*(7), 439-452. https://doi.org/10.1038/s41583-022-00587-4

Sfeir, N., & Aleksander, I. (2023). Cognitive Phenomenology Neuroscience and Computation. *Cognitive Computation*, *15*(5), 1613–1619. https://doi.org/10.1007/s12559-023-10144-5

Shapero, B.G., Greenberg, J., Pedrelli, P., de Jong, M., & Desbordes, G. (2018). Mindfulness-based interventions in psychiatry. *Focus*, *16*(1), 32-39. https://doi.org/10.1176/appi.focus.20170039

Shiffman, S., Stone, A. A., & Hufford, M. R. (2008). Ecological Momentary assessment. *Annual Review of Clinical Psychology*, *4*(1), 1–32.

https://doi.org/10.1146/annurev.clinpsy.3.022806.091415

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review*, *84*(2), 127–190. https://doi.org/10.1037/0033-295x.84.2.127

Simons, D. J. (2000). Attentional capture and inattentional blindness. *Trends in Cognitive Sciences*, *4*(4), 147–155. https://doi.org/10.1016/s1364-6613(00)01455-8

Sokolov, E.N. (1963). *Perception and the conditioned reflex*. NY: Pergamon Press.

Soto, D., & Silvanto, J. (2014). Reappraising the relationship between working memory and conscious awareness. *Trends in Cognitive Sciences*, *18*(10), 520–525. https://doi.org/10.1016/j.tics.2014.06.005

Sperling, G. (1960). The information available in brief visual presentations. *The Psychological Monographs*, *74*(11), 1–29. https://doi.org/10.1037/h0093759

Stender, J., Mortensen, K.N., Thibaut, A., Darkner, S., Laureys, S., Gjedde, A., & Kupers, R. (2016). The Minimal Energetic Requirement of Sustained Awareness after Brain Injury. *Current Biology, 26*, 1494-1499. doi: 10.1016/j.cub.2016.04.024.

Sumner, P., Tsai, P., Yu, K., & Nachev, P. (2006). Attentional modulation of sensorimotor processes in the absence of perceptual awareness. *Proceedings of the National Academy of Sciences of the United States of America*, *103*(27), 10520–10525. https://doi.org/10.1073/pnas.0601974103

Sutherland, S. (1989). Consciousness. *Macmillan Dictionary of Psychology*. Macmillan.

Swisher, J.D., Halko, M.A., Merabet, L.B., McMains, S.A., & Somers, D.C. (2007). Visual topography of human intraparietal sulcus. *Journal of Neuroscience, 27*, 5326-5337. doi: Doi: 10.1523/JNEUROSCI.0991-07.2007

Tononi, G. (2008). Consciousness as integrated information: a provisional manifesto. *The Biological Bulletin, 215*(3), 216-242. https://doi.org/10.2307/25470707

Tononi, G., & Koch, C. (2015). Consciousness: here, there and everywhere? *Philosophical Transactions of the Royal Society B*, *370*, 20140167. http://dx.doi.org/10.1098/rstb.2014.0167

Treisman, A. (1988). Features and objects: the fourteenth bartlett memorial lecture. *Quarterly Journal of Experimental Psychology, 40*A, 201-237. https://doi.org/10.1080/02724988843000104

Tsuchiya, N., & Koch, C. (2016). The relationship between consciousness and Top-Down attention. In S. Laureys, O. Gosseries & G. Tononi (Eds), *The neurology of consciousness*, Second edition. Elsevier. (pp. 71–91). https://dx.doi.org/10.1016/B978-0-12-800948-2.00005-4

Tsuchiya, N., Wilke, M., Frässle, S., & Lamme, V. a. F. (2015). No-report paradigms: Extracting the true neural correlates of consciousness. *Trends in Cognitive Sciences*, *19*(12), 757–770. https://doi.org/10.1016/j.tics.2015.10.002

Tulving, E. (1985). Memory and consciousness. *Canadian Psychology / Psychologie Canadienne*, 26(1), 1–12. https://doi.org/10.1037/h0080017

Unsworth, N., & Miller, A.L. (2021). Individual differences in the intensity and consistency of attention. *Current Directions in Psychological Science, 30*, 391-400. https://doi.org/10.1177/09637214211030266

Van Bavel, J.J., Sternisko, A., Harris, E., & Robertson, C. (2020). The social function of rationalization: An identity perspective. *Behavioral and Brain Sciences,15*, 43:e52. https://doi.org/10.1017/S0140525X19002097 van den Heuvel, M.P., & Sporns, O. (2013). Network hubs in the human brain. *Trends in Cognitive Science, 17*, 683-96. doi: 10.1016/j.tics.2013.09.012.

Vandenberghe, R., Molenberghs, P., & Gillebert, C.R. (2012). Spatial attention deficits in humans: the critical role of superior compared to inferior parietal lesions. *Neuropsychologia, 50*(6), 1092-103. https://doi.org/10.1016/j.neuropsychologia.2011.12.016

Vandekerckhove, M., & Panksepp, J. (2009). The flow of anoetic to noetic and autonoetic consciousness: a vision of unknowing (anoetic) and knowing (noetic) consciousness in the remembrance of things past and imagined futures. *Consciousness and Cognition, 18*(4), 1018–1028. https://doi.org/10.1016/j.concog.2009.08.002

Vanhaudenhuyse, A., Noirhomme, Q., Tshibanda, L. J., Bruno, M. A., Boveroux, P., Schnakers, et al. (2010). Default network connectivity reflects the level of consciousness in non-communicative brain-damaged patients. *Brain: A Journal of Neurology, 133*(Pt 1), 161–171. https://doi.org/10.1093/brain/awp313

Velichkovsky B.B. (2017). Consciousness and working memory: Current trends and research perspectives. *Consciousness and Cognition, 5*5, 35-45. https://doi.org/10.1016/j.concog.2017.07.005

Wang, L., Mruczek, R.E., Arcaro, M.J., & Kastner, S. (2015). Probabilistic maps of visual topography in human cortex. *Cerebral Cortex, 25*, 3911-31. doi: 10.1093/cercor/bhu277.

Wearing, D. (2005). *Forever today: a memoir of love and amnesia*. Random House.

Wikipedia. (2023). *Consciousness*. Downloaded from the worldwide web, 17 October, 2023. https://en.wikipedia.org/wiki/Consciousness

Wittmann, M. (2011). Moments in time. *Frontiers in Integrative Neuroscience, 5*, 66.

https://doi.org/10.3389/fnint.2011.00066

Wu, S. J., Li, X., Lin, Q., Chen, Y., Chen, X., Li, F., ... & Chen, L. (2020). Consciousness detection in a complete locked-in syndrome patient through multiscale approach analysis. *Entropy, 22*(12), 1411. https://doi.org/10.3390/e22121411

Wyart V, Tallon-Baudry C. (2008). Neural dissociation between visual awareness and spatial attention. *Journal of Neuroscience, 28*(10), 2667-2679. https://doi.org/10.1523/JNEUROSCI.4748-07.2008

Zaretskaya, N., Thielscher, A., Logothetis, N.K., & Bartels, A. (2010). Disrupting parietal function prolongs dominance durations in binocular rivalry. *Current Biology, 20*(23), 2106-11 https://doi.org/10.1016/j.cub.2010.10.046

Zhang, X., Song, W., Chen, Y., Yue, R., Li, T., & Yu, T. (2021). The clinical effect of repetitive transcranial magnetic stimulation on the disturbance of consciousness in patients in a vegetative state. *Frontiers in Neuroscience, 15*, 647517. doi: 10.3389/fnins.2021.647517

Zimmer, C. (2023). Two leading theories of consciousness square off. *New York Times,* 1 July*,* Retrieved 7 December, 2023 from https://www.nytimes.com/2023/07/01/science/consciousness-theories.html

Appendix

Scientific, Empirical Topics in the Scope of the Theory

The topics of the study of consciousness can be divided according to the states involved, the distinction between consciousness and attention, the specific contents of consciousness, and the methods used to explore these issues. We describe these in turn. The intent is to illustrate the enormous backdrop of research to which a theory of consciousness may apply, so that there is an understanding that a general model of information processing (such as the embedded processes approach) would be useful to relate psychological, behavioral, and neural phenomena to the understanding of consciousness.

States of Consciousness

The study of consciousness can be directed at an understanding of the state of awareness of an individual at a given moment (e.g., alert, drowsy, dreaming, asleep but not dreaming, brain-damaged in some relevant manner, or in a coma). It can examine influences that change the state temporarily (e.g., anesthesia, psychedelic drugs, exercise, meditation). There can be predictions about what brain circuits will covary with the states of consciousness (e.g., Casali et al., 2013), to which we will return in the section on theories. Learning about these topics also provides limits for what kinds of information can be accessed consciously.

The state of consciousness can be probed with respect to multiple modalities for a better understanding of the state of consciousness in brain damage (Coleman et al., 2009). For example, Laureys et al. (2000, p. 1589) found that in patients in a vegetative state, “despite altered resting metabolism, the auditory primary cortices were still activated during external stimulation, whereas hierarchically higher-order multimodal association areas were not” (cf. Boly et al., 2004).

Distinction Between Consciousness and Attention

A fair amount of work has been directed toward understanding whether consciousness is identical to what is termed attention or whether the two concepts are different. It seems clear from this research that they are not identical. Researchers seem to agree that it is possible to have attention to an event without the event entering consciousness. This conclusion is borne out by many kinds of phenomena considered together (for reviews see Cohen et al., 2012; Maier & Tsuchiya, 2021; Tsuchiya & Koch, 2016). To take just one example, it is possible to present an item at an attended visual location followed by a mask, so quickly that the participant judges that no stimulus was presented before the mask; yet, that attended and unseen stimulus causes semantic priming, i.e., more rapid perceptual analysis of a following, semantically related stimulus (Balota, 1983; Marcel, 1983; see also Kouider et al., 2007).

A more debatable assertion (Maier & Tsuchiya, 2021; Tsuchiya & Koch, 2016) is that it is possible to have consciousness of an item without attention. For example, it is sometimes argued that participants become aware of the gist of a scene even without devoting any attention to the scene. Cohen et al. (2012) argue to the contrary, that attention is necessary but not sufficient for consciousness.

A further distinction is that it might be possible to be conscious without "top-down" attention (Tsuchiy & Koch, 2016), which refers to the deliberate direction of attention. Top-down attention is experimentally demonstrated when the experimenter provides an abstract instruction as to where to attend (using what is termed an endogenous cue, like a central arrow pointing in the direction to be attended) without automatically drawing attention to that place via a bottom-up attention cue (an exogenous cue, like a flash of light at the location to be attended).

Specific Contents of Consciousness

In contrast to states of awareness, the focus of research can be on examining the experiences reported and information accessed by consciousness in a given episode. This can include not only perceptual but also conceptual information, and it can include not only information about external events (perceptions and thoughts regarding stimuli presented) but also about internal events (e.g., bodily sensations, pain, daydreams, hallucinations, and mental images).

Table A1 provides a summary of some of the topics that have been associated with investigations of the nature and contents of consciousness, with key references and an explanation of the relevance of each topic and some key findings.

Table A1

Some key empirical topics related to the study of consciousness, their theoretical relevance, and some important results and related arguments.

Topic Related to Consciousness	**Theoretical Relevance**	**Some Important Results and Arguments**
Unconscious perception leading to semantic priming of a subsequently presented item.	It is possible to show that a stimulus so weak that participants claim not to detect it can affect later processing.	Balota (1983) and Marcel (1983) both showed that a stimulus, followed so quickly by a mask that the participant claims not to have seen it at all, still can cause semantic priming. Balota found no long-term recognition of the unconscious stimulus. Others argue about effects of bias on calling the stimulus unconscious (e.g., Peters et al., 2017; Rouder & Morey, 2009).
Bistable perception (e.g., binocular rivalry; Necker cube): an unchanging stimulus gives rise	It is possible to present one stimulus and examine what happens in the brain and behavior	In binocular rivalry, brain activity reflects spontaneous changes in the percept. One can influence the rate of perceptual alternation with magnetic stimulation to key scalp locations (Zaretskaya et al., 2010). Optokinetic movement to contrasting left- and right-eye movements can

to alternating percepts.	when there is a spontaneous shift from one reported percept to another	reveal binocular rivalry percepts in non-verbal states or organisms (Frässle et al., 2014). Suppressed information still can affect working memory (Barton et al., 2022).
Free will (studied in a procedure with spontaneous movements and self-judged time of the decision to make the movement)	A conscious decision to make a movement at a self-determined time can be compared to brain activity accompanying the decision	Libet et al. (1983) found that the judged time when a decision to move was made (judged by the participant's concurrent observation of a rotating clock hand) was preceded by brain activity. However, others have concerns about the conclusion because the clock observation and the spontaneous decision must share attention (Kihlstrom, 2017; Papanicolaou, 2017).
Psychological moment (the short amount of time for which two events are judged to have occurred simultaneously)	The psychological moment can be considered to be the shortest unit of consciousness, and therefore a basic unit of qualia (moments of experience)	Allport (1968) set up an oscilloscope so that 12 lines occurred in succession at a rate allowing 11 of them to be perceived at any moment. The shadow of the 12th, unseen line moved in a direction indicating a continuous, sliding window of the present moment; discrete moments predicted the wrong direction. See also Wittman (2011) for a broader recent review.
Psychological present (the period during which memory of the past is most vivid)	The psychological present might be seen as the time period of persistent sensation	Guttman and Julesz (1963) presented a repeating segment of white noise and found that if the repetition occurred within several seconds, the repetition could be detected. For reviews of longer sensory memory see Cowan (1984, 1988) and cf. Pinto et al. (2013).
Memory familiarity without awareness versus recollection	Awareness of the source of a remembered item	Jacoby et al. (1989) presented names in undivided or divided attention situations and found that when names were presented in

only with awareness	differs from familiarity, which can be automatic	divided attention, participants were often unaware of the source at the time of test and thus attributed familiarity to the name being famous.
Divided-attention procedures	Costs of dividing attention between two tasks that are dissimilar suggests that they both depend on selective attention and awareness.	Jacoby et al. (1989) found that recollection is dependent on focused attention at learning, resulting in awareness of the learning incident, unlike familiarity, which can occur based on an episode occurring during divided attention.
Attribute amnesia (forgetting task-irrelevant features of an object just seen and attended)	Rapid forgetting here suggests attended features do not always enter working memory	Chen et al. (2018, Expt. 2) presented a color word and then a color patch on each trial, or vice versa (interleaved with color masks), and asked if these matched. When the color was last and did not match the prior color word, in a surprise test the color of the patch could not be recalled.
Anesthesia induced by drugs.	A state thought to be unconscious can be examined for the brain state compared to a waking state.	A low level of brain integration is found in anesthesia compared to a wakeful state (Casali et al., 2013). Surprisingly, the frontal areas are the first to recover from anesthesia (Mashour et al. 2021), though its role in wakeful thought still could be optional (Koch et al., 2016). One can also be unresponsive but nevertheless conscious (Sanders et al., 2012).
Blindsight	One can manipulate attention to spatial areas to which an individual is consciously blind,	Directing attention to areas which a blindsight patient cannot consciously see can nevertheless enhance the pickup information from those areas as judged by tests in which the participant must make a guess about the unseen information (Kentridge et al., 2008).

	but still able to pick up information	
Comparative studies across species	The presence of signs of consciousness in species very different from humans suggests that consciousness need not be restricted to brains like our own.	Nieder et al. (2020) recorded cells in crows' brains while presenting faint stimuli to be detected, with a variable rule about when to respond. They obtained a two-phase response, the first related to the stimulus intensity and the second related to the crow's selected detection response. These were taken as correlates of sensory consciousness in crows. An octopus arm may have its own consciousness (Carls-Diamante, 2022). There is evidence that even bees may be conscious (Chittka, 2022).

A truly enormous variety of additional topics can be relevant to the understanding of consciousness, including for example the law of specific nerve energies (perception based on what nerves are stimulated, as when one sees stars by rubbing one's eyes; e.g., Müller, 1826; Norsell et al., 1999), referred pain (pain that the brain represents as coming from a place different from where the injury is, as in sciatic nerve pain originating in a back injury but seemingly hurting in the leg, e.g., Ropper & Zafonte, 2015), locked-in syndrome (consciousness in an individual who may seem unconscious, e.g., Guger et al., 2017), phantom limb pain (pain caused by nerve activity for an amputated limb: Halligan, 2002), split-brain preparations (individuals who seem to have separate consciousness in the left and right hemispheres after the corpus collosum is severed to treat severe epilepsy; de Haan et al., 2020), stroke and brain injury (debilitation in some aspects of consciousness but not others, e.g., Ramachandran & Rogers-Ramachandran, 1996), mental imagery (verbal report of awareness of items that are not physically present, e.g., Farah, 1989), illusions (awareness that does not strictly depend on the reality of the stimulus but on heuristics in the brain interpreting the stimulus, e.g., Eagleman, 2001), dreams (states mimicking waking consciousness in some ways, during sleep, e.g., Eagleman & Vaughn, 2021), hallucinations (consciousness of something that is present only in the brain representation, e.g., Montagnese et al., 2021), meditation (deliberate achievement of an unusual state of awareness, e.g., Shapero et al., 2018), the role of beliefs in consciousness (e.g., attributing a thought to oneself versus to an intruding god, spirit, or muse, e.g., Olin, 1999), theory of mind (e.g., awareness of what someone else's state of mind may be, which governs how consciousness affects social interactions, e.g., Premack & Woodruff, 1978), and metacognition (awareness of one's own thoughts, e.g., Norman, 2019).

Sources of Evidence About Consciousness

For both states of awareness and experiences perceived and accessed, studies of consciousness can include verbal reports and manual responses in which the instructions for the participant are to indicate the nature of some experience; they can also include other behavioral responses used to infer experience, and physiological or neurological indices taken as signatures of consciousness because of their relation to verbal and behavioral reports. They can include studies of non-human animals to determine aspects of possible consciousness, using nonverbal techniques, and they can include studies of computers and abstract, philosophical arguments. More than one method can be used in combination.

Verbal and Manual Deliberate Reports of Conscious Experiences

The science of consciousness can add a few assumptions to allow it to collect evidence. It can include peoples' verbal and manual reports of conscious experiences, with the proviso that these reports also can be inaccurate. People may lie, may be somewhat inept at explaining what they are experiencing, may forget some of what they are experiencing, or may change the narrative to be more in line with their own self-conceptions.

Verbal and manual reports. In psychology, since the middle of the 19th century when quantitative introspective methods appeared, introspection has been at the center of the methods employed for the study of mind. James writes "introspective observation is what we have to rely on first and foremost and always" (1890 [1981, p. 185]). Nisbett and Wilson (1977) take the opposing perspective that verbal reports are generally inaccurate, particularly when they are on the topic of one's cognitive processes (i.e., "how did you reach this conclusion?"). If, somehow, the subject does offer an accurate report, according to Nisbett and Wilson, that is from causal inference, not actual insight. It is, as their title says, "telling more than we can know." Conversely, Ericsson and Simon (1980) argue that verbal reports should be used as data, while taking into careful consideration the circumstances under which the verbal reports were provided (e.g., the instructions provided; information that the subjects are asked to report). They maintained that many studies used methods that would lead to participants not having the necessary information available in short-term memory to report verbally what was asked for.

The method of introspection has also evolved over the decades. Introspective reports can be quite variable across individuals and it is not clear how to separate individual differences in experience (which one would want to know about) from individual differences in the manner of reporting those experiences (which might be considered noise). One more recent method to improve reports involves training and then later prompting participants to report about themselves at specific intervals throughout the day (Csikszentmihalyi and Larson, 1987), which improves replicability. In Descriptive Experience Sampling (DES), immediate, unfiltered responses from participants are captured at random times (Hurlburt & Akhter, 1991). Such methods have been refined and made more quantitative and statistically sophisticated in the Experience Sampling Method (Shiffman et al., 2008). There are techniques to check responses such as asking a question two different ways to see if the answers align.

Some limitations in verbal and manual reports. Individuals may change a report because they find certain actual experiences to be embarrassing, humiliating, noncomplementary, or implausible, leading to changes in what is reported. A famous example come from studies of individuals with split brains, due to operations for epilepsy that severed the corpus collosum route connecting the hemispheres. In one such case, a divided screen had been used to show the split-brain patient a chicken claw to the verbal left hemisphere and a winter snow scene to the nonverbal right hemisphere. The participant was allowed to use both hands to point to objects from a display relevant to what had been shown. The right hand, controlled by the verbal left hemisphere, pointed to a chicken claw. The left hand, controlled by the more nonverbal right hemisphere, pointed to a shovel. When asked to explain the choices, the left hemisphere answered without having any access to the snow scene. The chicken was correctly explained but instead of admitting not knowing why the shovel was chosen, the patient said it was chosen to clean out the chicken shed. This process was termed the left-hemisphere interpreter (Gazzaniga, 2011). Such patients have been shown also to laugh at something shown to the nonverbal hemisphere and then make up a spurious reason for the laughter. These are examples of a process of confabulation. In another neurological example of confabulation, right-sided stroke patients can have a combination of left-sided hemiplegia (paralysis) and anosognosia, the unawareness of this physical disability. Patients would deny the paralysis and some, but not others, denied paralysis in another individual who was clearly shown to be paralyzed (Ramachandran & Rogers-Ramachandran, 1996).

Although these examples seem extreme, a lot of the experimentation in social psychology comes from situations in which normal individuals are unable to report their own motivations completely. In experiments on cognitive dissonance, for example, it can be shown that people often seem unaware that they were influenced by experimental manipulations, indicating instead that they made their decisions independently (e.g., Cooper, 2019; Harmon-Jones 2019). For example, if an experimenter convinces a participant to make an argument they don't actually believe in, the participant could justify making the argument based on a payoff; but if the payoff is too small, the participant is more likely to assume they must have made that argument because they believed in it, and the participant's stated beliefs tend to shift toward that argument (Festinger & Carlsmith, 1959; Harmon-Jones & Harmon-Jones, 2019). There has been considerable subsequent work in the field of social psychology on that and related topics of people rationalizing their behavior with potentially faulty accounts of their own thought processes (e.g., Van Bavel et al., 2020).

Inferences from Behaviors other than Verbal Reports of Conscious Experiences

The science of consciousness also can cover behaviors that appear to co-occur with reports of consciousness or allow inferences about consciousness. For one thing, we will see that there is research not only on verbal reports indicating what the participant is perceiving, but also on behaviors that indicate the level at which a participant is conscious. For example, one can generally surmise that a participant is asleep if eyes are shut and there are snoring noises. There are also behaviors allowing inferences about what was or was not perceived. If a bird flies into a glass window, resulting in great harm, we typically assume that the bird did not see the glass. For a human, the inference is usually similar, though we might need to know more. (Was the person a daredevil trying to break through the glass as a stunt? Was the person trying to escape an even greater threat? Did the person possibly have suicidal tendencies?)

Behaviors indicating the level or state of consciousness. It is possible for some verbal report type scales rating a conscious state to be cross-tabulated with physiological indices of the state to provide convergent information. That is the case, for example, for scales of drowsiness and sleepiness (Ibáñez et al., 2018), such as the Epworth scale for daytime sleepiness (Johns, 1991), which can be checked against electrophysiological indices of sleepiness versus alertness, based on electrical recordings from the scalp indicating neural activity (e.g., Dunbar et al., 2020). There are many studies aimed at understanding the state of attention, such as how vigilant the person is (Davies & Parasuraman, 1982) and how intense and consistent their attention is (Unsworth & Miller, 2021).

Behaviors indicating the contents of consciousness. Although the gold standard for a window into consciousness behavior, there are some problems with the use of verbal behavior. It is not available for some individuals who might be conscious, including conscious humans with the inability to speak due to very young age, disability, or brain damage to speech-related regions, and of course nonhuman animals. When looking at brain indices of consciousness, verbal report may add areas of activity that are due not to consciousness per se, but to the need to make a verbal or manual report of consciousness (Tsuchiya et al., 2015).

Verbal reports seem most useful when combined with objective, behavioral or physiological data along with a theoretical account for how the two fit together. For example, exemplifying the use of convergent behavioral data, Belletier et al. (2023) examined memory for lists of letters under single and dual task situations and also asked participants to report what strategies they used (rehearsal, imagery, trying to limit the number of items in working memory, etc.). Greater success could be matched up with certain reported strategies, and changes in reported strategies when participants were under a dual-task constraint or had to repeat a word over and over (articulatory suppression) while encoding a list for recall. The reports contributed to a fairly coherent account of how memory performance operated.

Inferences from Physiological Data

Our understanding of consciousness has benefited from evidence from many brain imaging techniques: electroencephalography (providing temporal precision), magnetic resonance imaging and optical imaging (providing spatial precision in the brain), magnetoencephalography (providing some temporal and spatial precision but with higher modeling demands), and intracranial recording of nerve cell activity all have contributed to our understanding of consciousness. They have contributed to both an understanding of states of consciousness and the contents of consciousness.

State of consciousness. It has long been a concern that individuals who seem behaviorally unresponsive (without even eye movements to stimulation) may nevertheless be fully conscious and in some cases suffering, a fully locked-in state. It has been said that "Locked-in syndrome is caused by any lesion affecting the ventral pons, and midbrain; this includes vascular lesions, masses, infections, traumas, and demyelinating disorders" (Das et al., 2023). This state of consciousness sometimes can be revealed by using electroencephalography or magnetic resonance imaging to ask questions to which the participant gives an imagined response that indicates their state of mind, e.g., *Imagine playing tennis if your name is John but not if your name is Ralph.* This method, once established in an individual, can be used for further communication (see Maciejewicz, 2022; Wu et al., 2020).

To the extent that theories of consciousness depend on physiological states of the individual, scientists of consciousness must be cautious not to mistake locked-in syndrome for a coma. Then the question becomes, what brain states can distinguish between coma, impaired state of minimal consciousness, anesthesia, non-dream versus dreaming sleep, drowsiness, drugged states, and an alert state? Such brain differences have been found to be related to a measure of the degree of integration of information across brain areas, which can be described as different areas activated independently from one another but in a coordinated manner (Casali et al., 2013; Demertzi et al., 2019; Mashour et al., 2021; Vanhaudenhuyse et al., 2010). Integration entails neither too little synchrony of brain areas with one another (which can be found in a comatose state) or too much synchrony with one another (which can be found in an epileptic state) (Northoff & Lamme, 2020). Overall, we believe that the strongest inferences about consciousness come from a combination of physiological evidence about the brain when combined with verbal reports and other behavioral measures.