The Hierarchical Nature and Richness of Consciousness: Two Approaches to Understanding Consciousness

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Abstract

The hierarchical nature of consciousness refers to whether conscious processing follows an "all-or-none" or a "gradual" mechanism, whereas the richness of consciousness concerns whether the representational content of consciousness is "rich" or "impoverished." These two dimensions explore conscious experience from the perspectives of processing quality and processing scope, respectively. They represent two important approaches to understanding consciousness—a fundamental scientific question for humanity—and any theory regarding the mechanisms of consciousness formation must provide comprehensive, accurate, and reasonable explanations for both. This paper first conducts a comprehensive review and analysis of the latest research progress on these two issues to clarify debates among different viewpoints; second, it examines the intrinsic connection between them, specifically that both trace back to the debate on whether consciousness formation necessarily depends on cognitive access; finally, it provides a review and research outlook on how to better advance studies of both issues and how to offer unified explanations for their complex manifestations across different contexts.

Full Text

The Gradedness and Richness of Consciousness: Two Pathways toward Decoding Consciousness

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Abstract

The Gradedness of consciousness refers to whether conscious processing follows an "all-or-none" or "gradual" mechanism, while the Richness of consciousness concerns whether conscious representations are "rich" or "sparse/impoverished." These two dimensions explore conscious experience from the perspectives of processing quality and processing scope, respectively. They represent two important pathways for decoding consciousness—one of humanity' s fundamental scientific questions—as any theory of consciousness formation must provide comprehensive, accurate, and reasonable explanations for both issues. This article first provides a thorough review and analysis of recent research progress on these two questions, aiming to clarify ongoing debates among different viewpoints. Second, it explores the intrinsic connection between the two issues, showing that both can be traced back to the debate over whether consciousness formation necessarily depends on cognitive access. Finally, we discuss how to better advance research on these questions and how to provide integrated explanations for their complex manifestations across different contexts.

Keywords: consciousness, gradedness, richness, cognitive and neural mechanisms, theory of consciousness formation

1. Introduction

Consciousness is considered a core feature of mental and psychic states (Kim, 2011) and has long been a focus of research in philosophy, psychology, and cognitive science (Seth & Bayne, 2022). However, the concept of "consciousness" carries rich extensions in both daily life and various research fields. It can refer to the overall conscious state accompanying cognitive activities, commonly known as "wakefulness," as well as to self-consciousness or consciousness as a mental entity in metaphysics (Van Gulick, 2022). This article focuses on "consciousness" as studied in cognitive psychology—namely, the conscious content and corresponding local conscious states generated by specific stimuli in particular cognitive processing tasks.

When encountering external stimuli (e.g., seeing a red dot), we form a subjective experience (such as the subjective experience of redness), which serves as the criterion for determining conscious states (Kim, 2011; Nagel, 1974). Simultaneously, we produce various responses to the stimulus, such as forming a memory (remembering that a red dot appeared), verbally reporting its existence ("there is a red dot"), or making judgments and decisions based on it (e.g., identifying it as a NOGO signal and deciding not to respond). This raises a critical question: Does the subjective conscious experience we form have content consistency with the information that is further acquired and utilized by cognitive systems (including subsystems for memory, language, decision-making, attentional selection, and response control)—that is, information that receives cognitive access (Block, 2011; Dehaene et al., 2017)? Are their formation mechanisms identical? The relationship between subjective conscious experience and cognitive access processing, along with the mechanisms of consciousness formation, constitutes an important direction in consciousness research (Fazekas & Overgaard, 2018; Van Gulick, 2022).

Although no universally accepted definition of consciousness exists, its most distinctive feature is individuals' subjective experience of their internal and external environments, which manifests in different aspects. From the perspective of processing quality, conscious representations exhibit varying degrees of clarity and stability—the Gradedness of Consciousness (e.g., Jimenez et al., 2021; Kim & Chong, 2021; Mashour et al., 2020). From the perspective of processing scope, conscious representations vary in their breadth and complexity—the Richness of Consciousness (e.g., Fu et al., 2021; Howe & Lee, 2021; Xu et al., 2020).

Different experimental paradigms can measure conscious experience from various angles. In recent years, some paradigms have approached the issue from processing quality—clarity and stability—to investigate the Gradedness question: whether consciousness formation and processing follow an "all-or-none," dichotomous pattern or a continuous, graded pattern that varies from low to high. For example, researchers have used the Perceptual Awareness Scale (PAS; ranging from 1 to 4 or 1 to 21 points, where 1 corresponds to no perception, 4 or 21 to completely clear perception, and intermediate points to varying perception levels) to measure participants' visual awareness of stimuli (Ramsøy & Overgaard, 2004; Sergent & Dehaene, 2004). Meanwhile, other paradigms have approached the issue from processing scope—breadth and complexity—to explore the Richness question: whether the conscious representations formed from external stimuli are rich or sparse/impoverished. For instance, researchers have employed the Massive Report Paradigm (MRP) to measure the breadth of conscious processing, where after viewing an image, participants are repeatedly shown portions of either the original or other images and asked to judge whether these portions belong to the original image (Qianchen et al., 2022). As researchers have used different paradigms to investigate subjective conscious experience, various theories and hypotheses have been proposed to explain different and even contradictory experimental results. Consequently, current explorations of the Gradedness and Richness of consciousness are enriching and developing theories of consciousness formation from the perspectives of experiential quality and scope, respectively.

From a methodological standpoint, it is particularly important to note that previous experimental research on conscious and unconscious processing has found that individuals' consciousness thresholds can be divided into two types: objective and subjective thresholds (Cheesman & Merikle, 1984, 1986; Stein et al., 2021), with the latter typically being higher than the former. The objective threshold is primarily reflected in participants' objective behavioral responses, such as accuracy in stimulus discrimination tasks, where performance at or below chance level corresponds to the objective threshold. The subjective threshold is measured through participants' subjective reports (i.e., whether they perceived the stimulus presentation), where reports of no stimulus awareness correspond to the subjective threshold. At this point, a dissociation may occur between subjective reports and behavioral responses—forced-choice accuracy may be significantly above chance, or equal to or below chance. Research methods for Gradedness and Richness involve a mixed use of these two approaches, which complement each other. For example, in typical studies on Gradedness (Kim & Chong, 2021) and Richness (Del Pin et al., 2020), both subjective awareness measures like PAS and objective awareness measures like forced-choice accuracy are employed simultaneously. However, regardless of which measures are used, the research focus lies in comparing possible differences in conscious experience across experimental conditions within the same type of awareness measurement (subjective or objective).

Although Gradedness and Richness have developed from two different sets of paradigms, they are inextricably linked: they reflect different aspects of consciousness processing and representation formation mechanisms from distinct angles, revealing characteristics of subjective conscious experience across various dimensions. Moreover, both issues center on the debate over whether the formation of subjective conscious experience necessarily depends on cognitive access processing. In particular, recent theories in consciousness research, such as the Higher-Order Mnemonic Theory (HOMT) based on self-monitoring and memory (Lau et al., 2022) and the Dual Neural Network Theory of consciousness formation (Graziano, 2022), have conceptually addressed how to simultaneously achieve processing quality and scope in consciousness formation mechanisms (see "Summary, Discussion, and Outlook"). Therefore, joint consideration of these two questions not only helps resolve conflicts between different viewpoints within each issue but, more importantly, contributes to answering the fundamental scientific question of consciousness formation—namely, "What is consciousness, and how does it arise?" (Koch, 2018).

This article will first provide a comprehensive review and analysis of recent research progress on the Gradedness and Richness of consciousness, aiming to clarify ongoing debates among different viewpoints. Second, it will discuss the intrinsic connections between these two issues and consciousness formation mechanisms. Finally, we will review and prospect future research directions on how to better advance studies of Gradedness and Richness and how to provide integrated explanations for the opposing viewpoints and experimental phenomena within these two questions.

2. The Gradedness Issue in Conscious Processing Modes

Based on empirical findings, researchers have proposed four theoretical hypotheses regarding conscious processing modes, particularly the Gradedness issue. The first hypothesis posits that conscious processing follows an "all-or-none" mode (all-or-none access to conscious perception; e.g., Baars, 1988; Dehaene et al., 2017), where consciousness of information only forms when processing meets certain conditions; otherwise, no consciousness forms. The second hypothesis argues that the conditions required for consciousness formation are relatively low, and the quality of formed conscious representations gradually improves as brain region involvement increases—namely, a "graded" mode of conscious processing (graded visual awareness; Lamme, 2006; Zeki, 2003). The third hypothesis adopts the theoretical core of the "all-or-none" mode but decomposes conscious representations across different dimensions, explaining the graded appearance of consciousness through the summation of multiple independent dimensional conscious representations (i.e., all-or-none-based Gradedness of Consciousness) (e.g., Partial Awareness Hypothesis; Kim & Chong, 2021; Kouider et al., 2010). Recently, researchers have also conditionally integrated the "all-or-none" and "graded" modes to form a fourth hypothesis with composite characteristics (i.e., integrated view) (e.g., Level of Processing Hypothesis; Jimenez et al., 2021; Windey & Cleeremans, 2015). The following sections elaborate on these four hypotheses and corresponding research progress.

2.1 The All-or-None Processing Mode

Among theories advocating an "all-or-none" mechanism for conscious processing, the Global Workspace Theory (GWT) (Baars, 1988) has gained widespread acceptance due to substantial empirical support. GWT proposes that the human brain contains a "workspace" connecting sensory input, attention, memory, verbal report, action planning, and other brain functions. Sensory information only becomes conscious when it is "broadcast" within this workspace and received and processed by multiple brain regions. Therefore, information acquisition and utilization by cognitive (sub)systems within the workspace constitute necessary conditions for consciousness formation— "access precedes consciousness." Building on GWT, researchers (Dehaene et al., 1998, 2006, 2017) have further refined the theory' s neural mechanisms, proposing the Global Neuronal Workspace Theory (GNWT). GNWT suggests that information "broadcasting" within the workspace is regulated by a widely distributed population of long-axon pyramidal neurons (GNW neurons). These neurons form bidirectional connections with neurons in multiple brain regions responsible for motor, memory, and attention functions, enabling simultaneous reception and transmission of bottom-up and top-down information to activate or inhibit information processing across different brain regions. When a large number of GNW neurons are synchronously activated, they produce a nonlinear neural activity called "ignition" within the workspace (Gelbard-Sagiv et al., 2018), broadcasting sensory information and forming consciousness. GWT and GNWT posit that consciousness operates in only two "all-or-none" processing modes (similar to a "threshold" concept) without intermediate states—either a representation is broadcast to form full consciousness, or no consciousness forms.

The "all-or-none" processing mode of consciousness has received support from numerous empirical studies (see review, Mashour et al., 2020). For example, Sergent and Dehaene (2004) used the attentional blink (AB) paradigm to provide behavioral evidence for the "all-or-none" processing of consciousness. Dehaene and Changeux (2011) compared neural activity under conscious versus unconscious conditions and found that neural activity suddenly exhibited nonlinear differential changes within a time window of 200-300 ms after stimulus presentation, providing neural evidence for the nonlinear "ignition" postulated by GNWT. Additionally, Sanchez et al. (2020) confirmed the cross-modality universality of "ignition" neural activity by comparing perceptual consciousness processing across visual, auditory, and tactile modalities.

However, GNWT' s account of the neural mechanisms underlying consciousness has faced challenges (e.g., Förster et al., 2020). As described above, GNWT posits that "ignition" occurs 200-300 ms after stimulus presentation, leading to consciousness, and therefore predicts that the EEG component P3 may be a marker of consciousness formation (see Section 4.2). Nevertheless, Koivisto et al. (2016) compared P3 amplitudes under GO and NOGO task conditions and found that P3 amplitude enhancement under conscious conditions depended on subjective reports in the GO condition. Researchers further employed a no-report paradigm and discovered that even when participants could clearly perceive stimuli, no significant P3 component was generated when they were not required to report stimulus categories (animals, objects, or none) (Cohen et al., 2020). These results suggest that P3 emergence may not be a marker of consciousness formation but rather related to whether individuals execute reports. While these findings do not completely overturn GNWT' s theoretical framework, they weaken its explanatory power regarding the Gradedness of consciousness to some extent.

2.2 The Graded Processing Mode

This class of theories posits that consciousness can be formed through information processing within local neural cortices, and the quality of formed consciousness (such as representation clarity and stability) varies with the brain regions involved in processing (Eiserbeck et al., 2021; Lamme, 2006; Zeki, 2003). Unlike GWT/GNWT, the "graded" view maintains that information broadcasting and cognitive access are not necessary conditions for consciousness formation. Instead, local neural processing can produce non-reportable, low-quality consciousness, while further involvement of higher-level cortices enhances the quality of conscious representations and partially enables cognitive access processing— "consciousness does not require access; consciousness can precede partial access." Among these, the Micro-consciousness Theory (MCT) suggests that consciousness of specific attributes can form within the cortical regions processing those attributes, and when information spreads across more cortical areas, multiple attribute consciousness can be bound to form macro-consciousness and eventually unified consciousness (Zeki, 2003). Another more representative theory, the Recurrent Processing Theory (RPT), argues that rapid feedforward sweeps in lower-level sensory cortices alone are insufficient for consciousness. Instead, recurrent processing between different hierarchical modules in sensory cortices—where information circulates between cortical regions, forming closed loops between feedforward and feedback signals—constitutes a sufficient condition for forming conscious representations of varying quality. Consciousness based on local recurrent processing is attention-free; only when frontoparietal neural networks and higher-level cortices related to language participate in recurrent processing does high-quality consciousness emerge that can be subjectively reported through language or behavior (Lamme, 2006). Since both MCT and RPT propose that consciousness can arise in lower-quality forms (specific to particular attributes and not verbally reportable) and can form higher-quality forms (involving multiple attributes and subjectively reportable) as more brain regions become involved, their claims can be summarized as a "graded" processing mode of consciousness representation quality from low to high.

Compared to the "all-or-none" mode, a key advantage of the "graded" mode is its compatibility with and ability to provide reasonable explanations for graded consciousness phenomena. Such phenomena were first discovered by Zeki and Ffytche (1998) in studies of blindsight patients. Blindsight is a visual deficit caused by damage to brain regions responsible for visual processing; patients lack subjective visual experience in a specific area of their visual field yet can perform above chance level in forced-choice tasks for stimuli presented in that area (Mazzi et al., 2019). Previous studies often attributed blindsight symptoms to unconscious processing, but Zeki and Ffytche found that patients did not completely lose visual consciousness in their blind field; instead, they retained a certain degree of vague vision (i.e., their visual consciousness level in that area was higher than in blindfolded conditions). Ramsøy and Overgaard (2004) presented threshold-level stimuli to healthy participants and used an improved four-point Perceptual Awareness Scale (1-4 corresponding to: no perception, vague perception, almost clear perception, completely clear perception) to measure visual awareness levels. Their results showed that as stimulus presentation duration increased, participants' PAS scores changed in a "graded" manner, indicating that individuals' consciousness levels may lie between unconscious and fully conscious states, thereby providing direct experimental evidence for the "graded" processing mode.

However, the "graded" consciousness processing mode has also faced criticism. For instance, some argue that theories like MCT and RPT, while proposing that local processing can produce consciousness, fail to strictly define the conditions required for consciousness formation. This may lead to an overgeneralization of the consciousness concept— "participants may have consciousness even when they report none" —creating difficulties in determining consciousness presence (Cohen & Dennett, 2011). Additionally, recent researchers (Michel & Doerig, 2021) have pointed out that such theories cannot adequately explain long-lasting postdiction phenomena occurring on the 300-400 ms timescale (Drissi-Daoudi et al., 2019).

2.3 Upgrading All-or-None to Explain Graded Consciousness

Early research on the "all-or-none" processing mode rejected graded consciousness phenomena. For example, Sergent and Dehaene (2004) used a 21-point

PAS scale in an AB experiment to assess participants' consciousness levels of the second target and found that consciousness ratings could be fully explained by two predictors—unconsciousness and maximal consciousness—without needing intermediate consciousness scores. However, recent studies have found that whether graded consciousness phenomena appear correlates with scale length and experimental paradigms. Overly long scales may cause participants to actively abandon intermediate states (e.g., the middle portion of a 21-point scale may be ambiguous to participants), whereas when using 3- or 4-point scales and masking paradigms, graded consciousness becomes highly significant (Pretorius et al., 2016). Consequently, recent proponents of the "all-or-none" processing mode (e.g., Kim & Chong, 2021; Kouider et al., 2010) have attempted to explain why graded consciousness phenomena can emerge from an "all-or-none" core without resorting to a "graded" processing mode by decomposing conscious representations across multiple dimensions.

A typical representative of this approach is the Partial Awareness Hypothesis (PAH) proposed by Kouider et al. (2010). PAH suggests that individuals' conscious processing of objects can be decomposed into a series of independent "all-or-none" conscious processes across different attribute dimensions (e.g., physical energy, visual features, object names, object semantics). At any given moment, representations in some dimensions reach conscious states through an "all-or-none" mechanism, while representations in other dimensions do not. An individual' s consciousness of the entire object equals the summation of multiple "all-or-none" -based conscious states, thereby forming an intermediate conscious state between overall unconsciousness and overall full consciousness.

Various experimental paradigms have confirmed independent conscious processing across different attributes, providing support for PAH. For example, Elliott et al. (2016) used the AB paradigm and found that participants performed worse when required to report both color and letter identity of a colored letter stimulus simultaneously compared to reporting only one attribute. Critically, when participants could not report letter identity, they could correctly report its color, indicating independent conscious processing of target color and identity. Studies using continuous flash suppression also found inconsistent performance between localization and categorization tasks for target stimuli, reflecting separation and differences between location and category consciousness processing (Kobylka et al., 2017). A recent study (Kim & Chong, 2021) extended PAH' s vertical dimension decomposition (e.g., from low-level physical attributes to high-level semantic processing) to parallel horizontal dimensions within a single feature (e.g., different spatial frequency levels). They found that decomposition and independent processing of conscious representations involve not only vertical hierarchical mechanisms but also horizontal parallel mechanisms. Specifically, using a temporal summation paradigm with repeated stimuli, Kim and Chong (2021) found that as inter-stimulus intervals increased, participants' conscious processing of high spatial frequency stimuli (high-frequency gratings, local Navon letter orientation, detailed scene categorization) decayed faster than for low spatial frequency stimuli (low-frequency gratings, global Navon letter orientation, coarse scene categorization). Under specific temporal interval conditions, dissociations emerged where participants were conscious of low but not high spatial frequency stimuli. Overall, the upgraded "all-or-none" processing mode can explain many experimentally observed graded manifestations of conscious processing through vertical and/or parallel decomposition of conscious content.

2.4 Integration of All-or-None and Graded Modes

Additionally, recent researchers (Jimenez et al., 2021; Thiruvasagam & Srinivasan, 2021; Windey & Cleeremans, 2015) have integrated the "all-or-none" and "graded" processing modes, proposing the Level of Processing Hypothesis (LoP). This hypothesis suggests that stimulus attribute features or task demands determine which processing mode consciousness adopts. Specifically, conscious processing of low-level physical attributes like color and shape follows a "graded" mode, whereas processing of high-level features containing semantic or conceptual information, such as words, numbers, and categories, follows an "all-or-none" mode. Unlike PAH, LoP considers conscious representations to be indivisible.

LoP' s assignment of different processing modes to different attribute features aligns with their cognitive processing levels. On one hand, differences and changes in physical attributes are often gradual and quantifiable—for instance, color changes continuously and linearly with light wavelength, and identifying color at any point in a color patch can generalize to the entire patch. Therefore, corresponding low-level conscious processing follows a continuous "graded" mode. On the other hand, differences between concept- and semantics-related attribute features are often qualitative—analogous to switching between different labels. For example, when consciously processing the word "BIG," a processing deviation in the middle letter "I" yields dramatically different results: processing it as "A" produces "BAG," while processing it as "E" produces "BEG." Moreover, recognizing a single letter cannot determine recognition of the entire word. Consequently, corresponding high-level conscious processing follows a dichotomous "all-or-none" mode.

LoP has been confirmed in multiple studies. For instance, combining visual masking paradigms with PAS, researchers (Jimenez et al., 2021; Windey et al., 2013) found that in low-level feature discrimination tasks (e.g., stimulus color), participants selected intermediate PAS ratings more frequently, and the relationship between PAS scores and objective response accuracy was more linear. In high-level tasks such as digit magnitude (Windey et al., 2013) or image category discrimination (Jimenez et al., 2021), participants selected intermediate PAS ratings less frequently, and the relationship between PAS scores and objective accuracy became more nonlinear and dichotomous. Additionally, researchers (Thiruvasagam & Srinivasan, 2021) compared psychometric curve slopes and thresholds across different tasks and found that changes in consciousness levels were more graded in low-level tasks (global letter discrimination tasks).

3. The Richness Issue in Conscious Representation Content

Consciousness involves not only the Gradedness issue of processing quality but also the Richness issue of processing scope (Fu et al., 2021; Howe & Lee, 2021; Xu et al., 2020). When an image flashes before us, we feel we have seen the entire picture and have formed some visual awareness of its contents. Yet if asked about the specific contents, we may be unable to describe them or can only provide vague descriptions of some parts. In such cases, is the experience of "having seen the entire picture" reliable? Is this conscious experience based on genuine cognitive processing, or is it merely an illusory hallucination?

Two main viewpoints exist in the field. One perspective (Block, 2011; Howe & Lee, 2021) holds that the feeling of "having seen the entire picture" is authentic and credible. In such situations, we do process the entire picture' s contents and form corresponding conscious representations, but these preliminarily processed representations quickly disappear. Only some representations receive further processing through cognitive access, such as being retained in working memory and processed by language cortex, enabling them to be reported. The opposing view (Cohen et al., 2016; Dehaene et al., 2006; Gibbs et al., 2016) argues that the feeling of "having seen the entire picture" is merely an illusion—we actually form conscious representations of only a small portion of reportable content. In short, the former believes conscious representation content is rich, with broad processing scope exceeding the capacity of cognitive access like working memory (the "Rich View" of conscious representation content), while the latter believes conscious representation content is sparse, with cognitive access being a necessary condition for consciousness formation, thus limiting the scope and content of conscious processing (the "Sparse View" of conscious representation content). Previous research has provided abundant supporting evidence for both perspectives.

3.1 The Rich View of Conscious Representation Content

The Rich View of conscious representation content originates from Block' s (2011) interpretation of Sperling' s (1960) iconic memory experiment. In this experiment, researchers simultaneously presented participants with 12 letters arranged in 3 rows and asked them to report the briefly presented (50 ms) letters. Results showed that while participants claimed to have seen all letters, they could only accurately report 3 or 4 of them. However, when the procedure was slightly modified by using sounds of different pitches after letter presentation to cue which row to report, participants could accurately report 3 or 4 letters from the cued row. Block argued that this phenomenon occurred because, during the brief presentation time, participants could extensively process the presented letters, forming conscious representations far exceeding working memory capacity and producing the experience of "having seen all letters." However, only those conscious representations successfully stored in working memory could be further processed by higher-level cortices like language areas and thus be accurately reported, accounting for the difference between cued and uncued conditions. According to RPT (Lamme, 2010), consciousness can form in local information cycles independent of attention, so conscious processing has broad scope and can generate numerous conscious representations. However, most of these representations cannot reach frontoparietal and language centers through attentional selection, resulting in only limited access to "rich" conscious representations.

Recent studies have provided empirical support for the Rich View and Block' s (2011) "overflow" claim (i.e., that conscious representations exceed cognitive access capacity). Researchers have successively discovered "overflow" phenomena at various cognitive processing levels including memory, attention, and subjective reporting (see review, Fu et al., 2021). For example, Sligte et al. (2008) combined Sperling' s (1960) iconic memory paradigm with a change detection paradigm, presenting participants with multiple rectangles of different orientations in a memory frame. After a blank interval, a test frame appeared, and participants judged whether the rectangle indicated by a cue had changed orientation. Results showed that when the cue was presented during the blank interval—measuring "fragile visual short-term memory" between iconic memory and working memory—performance was significantly better than when the cue appeared immediately after the test frame (measuring working memory). This difference reflected that conscious representation processing can exceed working memory capacity limitations. Another study (Bronfman et al., 2014) combined the iconic memory paradigm with a color discrimination task, presenting colored letters and cueing which row to report. Participants not only correctly reported the colors of letters in the cued row but also accurately assessed color diversity in non-cued rows without impaired task performance. These two studies demonstrate that conscious representation processing can exceed the limitations of working memory and focused attention— "Consciousness overflows working memory and focused attention." Other researchers (Agarwal et al., 2020; Matthews et al., 2018) used divided attention tasks and found that participants could form conscious representations of both centrally attended core objects and peripherally unattended objects, further confirming that conscious representation processing can exceed focused attention. Additionally, Chen and Wyble (2015) incorporated occasional letter identity report tasks into a target letter location report task and found that participants could not correctly report letter identity attributes, even though processing identity attributes was necessary for completing the location report task—demonstrating "Consciousness overflows reportability." Subsequent studies using similar paradigms further found attribute amnesia for theoretically fully consciously processed attributes such as fill color of words or squares (Chen et al., 2018), emotions expressed in simultaneously or sequentially presented faces or words (Xu et al., 2020), and sound location and pitch quantity (Howe & Lee, 2021). These findings further confirm the "overflow" of conscious representation processing beyond working memory or subjective report capacity. All these studies support the "Richness" property of conscious representation content through "overflow" phenomena.

3.2 The Sparse View of Conscious Representation Content

The Sparse View of conscious representation content argues that consciousness formation requires information to be processed by cognitive access to be subjectively reportable, thus individuals can only form limited conscious representations (Cohen et al., 2016; Dehaene et al., 2006; Gibbs et al., 2016). Proponents of this view (Dehaene et al., 2006) contend that when individuals cannot report what they see, their feeling of "having seen the entire picture" or "having seen all stimulus objects" is a false experience similar to the "refrigerator-light illusion"—the illusion that the refrigerator light is always on even when the door is closed, simply because it illuminates whenever the door opens.

Supporters of the Sparse View argue that experimental phenomena found in studies like Sperling (1960) can be reasonably explained without invoking representation "overflow" beyond cognitive access. Some researchers (Cohen & Dennett, 2011; Kouider et al., 2010) suggest that in Sperling' s experiment, cues enabled participants to correctly report letters they could not report without cues because most letters in the uncued condition were not processed by cognitive access but merely temporarily stored unconsciously. The addition of cues allowed some of these unconscious letters to be processed by higher-level cognitive cortices like attention and language, thereby forming conscious representations of the cued letters. Similarly, Sligte et al.' s (2008) "fragile visual short-term memory" phenomenon exceeding working memory capacity can also be explained by unconscious processing. Moreover, the experimental phenomena in divided attention tasks supporting the Rich View have been questioned: participants' ability to form conscious representations of peripheral objects does not necessarily indicate "overflow" of consciousness beyond attention—this phenomenon may result from insufficient difficulty of the central task or the central processing requiring only minimal attentional resources. For instance, studies have found that when attentional demands of the core task increase, participants no longer become conscious of other peripheral objects (Mack & Clarke, 2012).

On the other hand, other empirical studies have challenged the Rich View. Research on change blindness (Gibbs et al., 2016) and inattentional blindness (Ward & Scholl, 2015) reveals that individuals may fail to form conscious representations of salient stimuli presented within their visual field, reflecting limitations in conscious processing scope. Furthermore, de Gardelle et al. (2009) modified Sperling' s paradigm by arranging letters in each row to form complete English words while occasionally presenting pseudowords without real meaning. They found that even when pseudowords were presented, participants unconsciously "substituted" some letters and still reported seeing real words. This suggests that participants may not have formed clear consciousness of the letter stimuli at all, and their conscious experience may not be a true reflection of the external world. The so-called experience of "having seen the entire picture/all stimulus objects" may merely be a later construction based on expectations and prior experience (Kouider et al., 2010).

4. Connections Between the Two Issues

4.1 Association with Cognitive Access Processing

The Gradedness issue examines the quality of conscious processing and the clarity/stability of formed representations, while the Richness issue examines the scope of conscious processing and the richness/complexity of representations. These two issues reflect different aspects of consciousness processing and representation formation mechanisms, revealing characteristics of subjective conscious experience across different experimental paradigms. Debates between different viewpoints in both issues can be traced back to questions about the relationship between subjective conscious experience and cognitive access—namely, whether subjective conscious experience formation necessarily depends on cognitive access processing, or whether cognitive access mechanisms constitute the sole mechanism for consciousness formation. This question is considered central to consciousness formation mechanisms (Fazekas & Overgaard, 2018).

Regarding this core question, one viewpoint holds that cognitive access processing is the only mechanism for consciousness formation (Naccache, 2018). This view manifests as support for the "all-or-none" processing mode in the Gradedness issue—only information receiving cognitive access can form full conscious representations; otherwise, no consciousness forms (e.g., Baars, 1988; Dehaene et al., 2006, 2017). In the Richness issue, this view argues that conscious representation formation presupposes cognitive access processing, thus being limited by cognitive capacity and forming only sparse, limited conscious representations (e.g., Cohen et al., 2016; Ward et al., 2016).

The alternative view posits that subjective experience formation does not depend on cognitive access and that consciousness formation mechanisms are independent of cognitive access processing mechanisms. This perspective reflects support for the "graded" mode in the Gradedness issue—processing within local regions alone can produce consciousness, and involvement of additional regions and higher-level cortices gradually improves consciousness quality (e.g., Lamme, 2006; Zeki, 2003). In the Richness issue, this view advocates that conscious processing has broad scope and can form rich conscious representations unconstrained by cognitive access capacity (e.g., Block, 2011; Bronfman et al., 2014; Howe & Lee, 2021).

4.2 Association with Neural Mechanisms of Consciousness

The two issues of Gradedness and Richness are also closely related to the neural mechanisms of consciousness (e.g., Eiserbeck et al., 2021; Filimonov et al., 2022; Mashour et al., 2020). On one hand, empirical research on these issues involves investigating corresponding neural mechanisms. On the other hand, clarifying the neural mechanisms of consciousness helps resolve debates between different viewpoints. Therefore, we introduce the claims and explanations regarding neural mechanisms from different perspectives, as well as neural correlates of consciousness (NCCs) discovered through brain imaging and EEG techniques.

GNWT emphasizes that information achieves consciousness formation through "ignition" activity of GNW neurons broadcasting to multiple brain regions. It has found that "ignition" and "broadcasting" activities are highly correlated with gamma oscillations generated by pyramidal neurons (Mashour et al., 2020). Consequently, GNWT posits that the prefrontal cortex (PFC), where pyramidal neurons are densely aggregated, plays an important role in consciousness formation, particularly in global broadcasting of information. Regarding EEG components, the "all-or-none" processing mode and the Sparse View of representation content, which 主张 that consciousness formation requires information to be accessed by higher-level cognitive cortices like attention, have primarily focused on the P3 component. This component has a later time window (peaking around 300 ms post-stimulus) and originates from frontoparietal cortex, also known as P300 or Late Positivity (LP). The emphasis on PFC and the P3 component by the "all-or-none" mode and Sparse View has received support from relevant studies. For example, research using single-cell recordings in awake macaques (van Vugt et al., 2018) and functional magnetic resonance imaging (Dehaene & Changeux, 2011) have found that neural activity in PFC and other cortices participates in conscious processing. EEG studies have also confirmed the association between the P3 component and consciousness formation, such as significant correlations between P3 amplitude and both consciousness rating levels and objective response accuracy in dual-task experiments (Jimenez et al., 2018), and P3 components reflecting consciousness processing and formation in change blindness paradigms (Scrivener et al., 2019).

Nevertheless, the association between PFC and P3 with consciousness formation has faced challenges from various quarters (Förster et al., 2020). First, regarding brain regions for consciousness generation, Integrated Information Theory (IIT) holds different views. IIT (Tononi et al., 2016) proposes that consciousness is an intrinsic property of material systems with specific organizational forms—only systems possessing irreducible intrinsic causal power (the ability to affect themselves or others) are conscious. Therefore, consciousness is not limited to living organisms; any material system with specific organizational forms and intrinsic properties can generate consciousness. For the specific biological system of the human brain, consciousness relates to how the brain integrates information. Consequently, posterior cortical regions (including parietal, temporal, and occipital lobes) may be more strongly associated with forming specific conscious content than PFC (Boly et al., 2017; Koch et al., 2016; Tononi et al., 2016), as these regions possess neuroanatomical characteristics more suitable for generating high levels of integrated information. Researchers using intracranial electrical stimulation have also found that the prefrontal cortex is not universally involved in consciousness formation (Raccah et al., 2021). Moreover, the P3 component has been questioned as reflecting post-perceptual processing rather than consciousness formation. For instance, the studies by Koivisto et al. (2016) and Cohen et al. (2020) discussed in Section 2.1 found that the P3 component depends on participants' subjective reports in experiments, suggesting that P3 may reflect post-perceptual processing related to subjective reporting.

Studies using inattentional blindness (Pitts et al., 2014) and inattentional deafness (Schlossmacher et al., 2021) paradigms found that task-irrelevant stimuli, whether consciously perceived or not, did not elicit significant P3 amplitude changes, indicating that P3 may reflect post-perceptual processing related to task relevance. In summary, these studies challenge the association between P3 and consciousness formation.

On the other hand, theories supporting the "graded" processing mode posit that consciousness can be formed through information circulation within local regions alone, thus localizing NCCs to early sensory cortices, such as identifying visual consciousness formation in occipital cortex regions like V5 (Lamme, 2010; Zeki, 2003). Regarding EEG components associated with consciousness, proponents of the "graded" mode and Rich View have correspondingly focused on the earlier time-window N2 component, particularly the Visual Awareness Negativity (VAN) originating from occipitotemporal cortex in visual consciousness research. The association between VAN and consciousness formation has been confirmed in multiple empirical studies. For example, in experiments combining the AB paradigm with PAS evaluation, participants' average EEG amplitudes during the N2 time window showed stepwise negative shifts with increasing PAS scores (Eiserbeck et al., 2021). In experiments combining high- and low-level tasks with PAS evaluation, VAN amplitudes were effectively modulated by consciousness levels and showed significant negative shifts correlated with PAS scores in low-level tasks (Jimenez et al., 2018, 2021) or both task levels (Derda et al., 2019). Furthermore, researchers (Dembski, 2021; Filimonov et al., 2022) conducted comprehensive reviews of perceptual consciousness across visual, auditory, and somatosensory modalities and found early negative components within the N2 time window corresponding to specific perceptual modalities and originating from different perceptual processing brain regions, suggesting that Perceptual Awareness Negativity (PAN) may exist for conscious processing across different modalities. In source localization of VAN, researchers using magnetoencephalography (Liu et al., 2012) localized VAN to occipitotemporal visual cortex.

However, the association between VAN or PAN and perceptual consciousness has also faced skepticism. Some studies failed to detect significant VAN amplitude changes when participants consciously perceived stimuli, leading to suggestions that VAN may reflect only pre-conscious processing (Salti et al., 2012) or that VAN is not a necessary condition for consciousness formation (Koivisto et al., 2009). Additionally, some researchers (Bola et al., 2021) argue that VAN or PAN reflects only a specific type of attentional processing rather than consciousness formation itself.

5. Summary, Discussion, and Outlook

In summary, recent research on the Gradedness of conscious processing modes and the Richness of representation content has made considerable progress. Gradedness and Richness explore conscious experience from the perspectives of processing quality and scope, respectively. Regarding whether conscious processing follows "all-or-none" or "graded" mechanisms, no consensus has been reached, but recent research offers two new dimensions for understanding this question: first, decomposing conscious representations along parallel or vertical dimensions (e.g., Kim & Chong, 2021; Kouider et al., 2010), and second, considering the Gradedness issue within the context of stimulus attributes or task demands (e.g., Jimenez et al., 2021; Thiruvasagam & Srinivasan, 2021). Regarding the Richness of conscious representation content, recent studies have provided support for the "Richness" view through numerous "overflow" phenomena at cognitive processing levels including attention, memory, and reportability (e.g., Fu et al., 2021; Howe & Lee, 2021; Xu et al., 2020). However, substantial experimental evidence also supports the view that conscious representations may be "sparse," with 所谓的 "Richness" being merely a later construction based on expectations and prior experience (e.g., Cohen et al., 2016; Gibbs et al., 2016). More importantly, an intrinsic connection exists between the Gradedness and Richness issues, as both can be traced back to debates over whether consciousness formation necessarily depends on cognitive access processing (Fazekas & Overgaard, 2018; Fu et al., 2021; Naccache, 2018). Furthermore, recent advances in research on neural correlates of consciousness (e.g., Eiserbeck et al., 2021; Filimonov et al., 2022; Mashour et al., 2020) have directly provided experimental evidence for the cognitive and neural mechanisms underlying Gradedness and Richness while also helping to clarify debates between different explanatory viewpoints and contributing to the exploration of these issues and the fundamental scientific question of consciousness formation.

However, current research on Gradedness and Richness still has room for further development. Future research could explore several potential avenues and theoretical directions more deeply:

First, combine refined experimental manipulations to more thoroughly explore influencing factors and their mechanisms in Gradedness and Richness manifestations. As research progresses, an increasing number of factors have been found to affect conscious processing quality and representation content richness. Regarding Gradedness, different object attributes (Kouider et al., 2010), different dimensions of attributes (Kim & Chong, 2021), and processing levels required by tasks (Jimenez et al., 2021; Windey & Cleeremans, 2015) all influence conscious processing quality and representation clarity/stability. Regarding Richness, factors such as processing difficulty of the core task and attentional resource requirements in divided attention tasks determine whether peripheral objects can be processed (Agarwal et al., 2020; Mack & Clarke, 2012; Matthews et al., 2018). The mechanisms through which these factors influence subjective conscious experience require more detailed exploration.

Second, combine "consciousness dissociation" paradigms with cognitive neuroscience techniques to resolve debates about neural mechanisms related to Gradedness and Richness. Although researchers have used combined brain imaging, EEG, and behavioral experiments to localize NCCs related to Gradedness and

Richness to early sensory cortices (Lamme, 2010) and/or frontoparietal cortices (Mashour et al., 2020), and have identified relevant EEG components as VAN/N2 (Eiserbeck et al., 2021) and/or P3 (Scrivener et al., 2019), the opposing viewpoints urgently require further critical evidence for resolution. To exclude confounds from pre-conscious attentional processing and post-perceptual processes like reporting and responding, future research needs improved experimental paradigms that can dissociate neural correlates of conscious processing from those of other cognitive processes. For example, Cohen et al. (2020) used a combination of visual masking and no-report paradigms with EEG recording to isolate EEG components corresponding to subjective report processing.

Third, innovate experimental paradigms and measurement methods to expand the scope of Gradedness and Richness phenomena in perceptual consciousness. Current research on Gradedness and Richness is largely based on visual consciousness experiments, likely due to the mature manipulations and easier measurements in visual experiments. Whether Gradedness and Richness phenomena exist in other perceptual consciousness modalities and whether their manifestations differ across modalities require future research to build upon visual experimental paradigms and measures like PAS. For example, researchers (Schlossmacher et al., 2021) have combined inattentional deafness paradigms with event-related potential (ERP) technology to examine consciousness-related EEG components in the auditory modality. Investigating the patterns of Gradedness and Richness phenomena across different sensory modalities can help compare similarities and differences between visual consciousness and other perceptual consciousness, thereby advancing research on modality-general and modality-specific conscious processing mechanisms.

Fourth, beyond deepening and refining current theoretical frameworks, future research should actively explore new theoretical hypotheses to provide integrated explanations for Gradedness, Richness, and the opposing viewpoints and experimental phenomena within them. The Gradedness and Richness issues reflect characteristics of subjective conscious experience across different experimental paradigms, both focusing on the relationship between consciousness and cognitive access. The two issues are closely connected, yet current theoretical explanations cannot provide a unified framework for Gradedness and Richness, nor can they fully and comprehensively explain why consciousness Gradedness and Richness produce numerous differential experimental results across different contexts. A possible future development direction is to introduce multiple cognitive modules and processing mechanisms into theories of consciousness formation, providing unified explanatory frameworks for Gradedness and Richness and their opposing viewpoints through interactions between different modules and mechanisms.

On one hand, Graziano’ s (2022) recently proposed Dual Neural Network Theory of consciousness formation may provide an integrated explanatory framework for Gradedness and Richness. This theory posits that consciousness and cognitive information are processed by two independent neural networks with bidirectional interactions: subjective conscious experience formation depends on the theory-of-mind network' s reconstruction of information processed by the cognitive network, while the generated subjective conscious experience in turn influences information processing in the cognitive network. Since this interactive process does not involve precise copying of information between the two networks but contains certain biases, our conscious experience does not always faithfully reflect stimulus cognitive information, leading to phenomena like illusions and blindness. The Gradedness and Richness issues we focus on may be products of the consciousness network' s reconstruction of cognitive network-processed information from different angles across various experimental paradigms.

On the other hand, the Higher-Order Mnemonic Theory (HOMT; Lau et al., 2022) organically combines three elements: a mental quality space based on relational coding, self-monitoring based on implicit memory, and memory replay based on explicit memory. This theory may provide a compatible, integrated explanation for the complex manifestations of Gradedness and Richness across different situations. Based on the HOMT framework, we speculate that in the Gradedness issue, different graded levels of conscious processing modes may stem partly from self-monitoring' s quantitative evaluation of perceptual information processing quality and partly from coding characteristics of the mental quality space (Morton & Preston, 2021). The "all-or-none" dichotomy found in high-level processing (Windey & Cleeremans, 2015) may arise when explicit memory actively participates in conscious representation, with memory replay (Dasgupta et al., 2018) combining with the mental quality space in a symbolic and categorical manner (Wittkuhn et al., 2021). Furthermore, based on HOMT analysis, we believe that in the Richness issue, both the Rich View and Sparse View are reasonable under certain conditions, potentially representing different manifestations of consciousness formation mechanisms based on mental quality space and (implicit and explicit) memory. On one hand, "rich" subjective conscious experience may have three sources: relational coding in mental quality space causing whole-space activation during single stimulus processing; the implicit and procedural nature of self-monitoring operations within mental quality space causing rich experience to "overflow" language report capacity; and contributions from multiple information channel inputs, information integration, and interactions among multiple cognitive processing operations. On the other hand, the Sparse View characterizes the later construction of conscious representations by participants when explicit memory introduces complex categorical, schematic, and emotional information channels during conscious processing (Kouider et al., 2010). Both the Dual Neural Network Theory (Graziano, 2022) and HOMT (Lau et al., 2022) currently remain primarily theoretical constructs. Whether they can provide more comprehensive and accurate explanations for Gradedness and Richness awaits further empirical testing. However, the applicability of new consciousness formation theories to the Gradedness and Richness issues may be a direction worth continuous attention in future research.

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Note: Figure translations are in progress. See original paper for figures.