Conscious and Unconscious Perception

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Abstract: Contrasting the properties of conscious and unconscious processes is crucial for understanding how consciousness occurs in the brain. In this chapter, we review the theoretical framework and empirical methods used to delineate and contrast conscious vs. unconscious perception. After outlining the main approaches to measure unconscious influences on brain and behavior, we describe some of the psychophysical tools employed to render stimuli unconscious, including the depletion of sensory signals, attentional resources, and vigilance states. We then provide an overview of the extent and limits of unconscious perception, and conclude on the future of the contrastive approach to the study of consciousness.

One critical issue for understanding the human mind concerns the distinction between conscious and unconscious processes. Conscious and unconscious mental activities are often considered as two sides of the same coin. Therefore, a complete picture of mental life requires not only focusing on the nature and properties of consciousness, but also, by exclusion, on the multitude of mechanisms and processes occurring without consciousness. This 'contrastive analysis' originally put forward by Baars (1988) allows one to face one of the major difficulties when studying consciousness, namely its lack of definition. Although we do not know how consciousness occurs, not to mention why we are conscious at all, we at least know when it happens. By comparing situations in which consciousness happens with closely matched situations in which it does not (i.e., unconscious processing), one can study both its functional and neural specificity. This approach has not only been motivated by the need to understand the specificity of consciousness, but also by the will to characterize unconscious processes on their own. As such, a large part of the work on consciousness consists in determining the limits and extents of unconscious processes (Kouider and Dehaene 2007).

Experimental studies on consciousness have largely privileged the domain of visual perception, notably because of well-established methodologies and sophisticated tools issued from the long tradition of psychophysics. As we shall see below, while it is largely accepted that simple forms of processing (e.g. motor reflexes, sensory analysis) do not necessitate perceptual awareness, the existence of unconscious complex computations involving higher processing levels (e.g. executive functions) remains largely debated. In this chapter, we will first introduce the main methodological approaches for measuring unconscious influences. We will then give an overview of the main techniques for rendering perception unconscious and ensuring unawareness. Then, we will address the crucial issue of how elaborate are unconscious perceptual processes, and when do conscious processes take over. As we shall see, this issue has tremendous implications not only for our understanding of what distinguishes conscious and unconscious mental life, but also on the link between the brain and consciousness.

Unconscious perception

Measuring unconscious influences

Unconscious perception is inferred when a stimulus influences behaviors and/or neural activity while the subject reports being unaware of it. This issue has been mainly addressed through the use of subliminal stimulation methods, in which a stimulus is presented below the 'limen' or threshold for conscious perception. The predominant experimental approach for validating unconscious processing of a stimulus is to establish a dissociation between its processing and its conscious access. Such dissociation involves the joint use of a direct and an indirect measure. The direct measure allows one to assess stimulus awareness, by asking the observer to directly focus on the stimulus or one of its dimensions of interest. Researchers have disagreed on whether they should use subjective reports, in which participants indicate the content of their phenomenal experience of the stimulus (Cheesman and Merikle 1986), or rather objective perceptibility tests, which require participants to perform a forced-choice decision on the stimulus (Marcel, 1983). More specifically, objective measures include detection tasks (i.e., determine if the stimulus is present or not), discrimination tasks (i.e., recognize a specific feature of stimulus), or categorization tasks (i.e., distinguish two stimuli from different categories). In contrast to the direct measure, which serves to assess stimulus awareness, the indirect measure allows one to estimate the influence of the stimulus on behavior and/or on brain activity. Unconscious perception is demonstrated when the indirect measure reveals a positive effect (e.g., the stimulus influences the processing of a subsequent target stimulus, or activates a given brain region), while the direct measure remains null (e.g., chance-level performance on a discrimination task).

Unconscious discrimination. Early research on unconscious perception relied exclusively on subjective measures as the direct measure for probing stimulus awareness. Consider for instance the seminal study on unconscious perception by Pierce & Jastrow (1884). Subjects received a first pressure on a finger and then a second slightly stronger or slightly weaker pressure. They judged which one seemed the more intense by rating their estimation on a 0–3 scale. They also performed a forced-choice discrimination task between the two possibilities. Under subjective estimations of null awareness, subjects could still discriminate the two alternatives well above the 50% chance-level, suggesting the involvement of unconscious discriminative abilities. This very same approach is still widely used today. It allowed uncovering the phenomenon of blindsight, in which subjects with a lesion over the primary visual cortex report being unaware of stimuli in their blind field, yet perform much better than chance when forced to decide on their presence vs. absence, or on their discriminable features (e.g. leftward vs. rightward grating orientation; see Weiskrantz 1996).

Yet, subjective measures have been criticized for potentially reflecting biases in response criteria rather than a genuine description of subjective experience (Eriksen 1960). For instance, subjects are known to be underconfident: they may partially or even fully see the stimulus, yet claim that they have not seen it because they need a high level of certainty. Several sophistications have been proposed to deal with this issue. In the variant called post-decision wagering, subjects perform an objective task (e.g., discriminate the tilt on an oriented grating), and are not asked to give a confidence rating on their decision but actually have to place a wager on its outcome (Persaud, McLeod, and Cowey 2007). It is assumed that when the observer is confident that she saw the stimulus, she should maximize her reward by wagering a higher amount than when she was unaware of the stimulus. However this approach has been criticized on the grounds that gambling decisions are prone to risk- or loss-aversion. Another improvement, that avoids such problems, has been the derivation of second-order signal detection measures, which allows one to inspect confidence judgments on a task, independently from the task performance (Maniscalco and Lau 2012). These recent developments allow for quantifying the second-order knowledge one has about one's own performance (i.e., metacognition, or "knowing about knowing"). In this framework, high metacognitive capacities imply that participants rate their confidence as lower after an erroneous judgment (e.g., indicating that the stimulus was tilted rightward while it was tilted leftward) than after a correct judgment and vice versa. Metacognition is therefore considered as the capacity to match confidence judgments with performance, irrespective of any general tendency to be over-confident or under-confident.

Objective measures and partial awareness. In order to confront the issue that subjective measures might be 'too subjective', research on unconscious perception, starting with the seminal work on masked semantic priming by Marcel (1983), tended to shift towards the use of objective measures for probing awareness. This approach is radically different since now force-choice tasks such as discrimination or detection are not used any more for demonstrating a positive effect, but rather to show null sensitivity to the stimulus. For instance, observers are asked to guess whether a grating stimulus is tilted rightward or leftward, and the stimulus is considered to be invisible if performance over multiple trials does not exceed chance-level (here, 50% accuracy). Yet, whether invisibility is taken as granted from unawareness on subjective or objective tests, an important issue is whether the awareness test is exhaustive of the feature to be processed. For instance, situations of partial awareness have been described in which observers have access to specific features of a stimulus like its color or location, but not others like its orientation. In this situation, observers are likely to perform at chance-level for some features but not for others. The lack of consistency in the assessment of stimulus awareness is particularly problematic in the light of the fact that these situations of partial awareness are known to potentially drive supposedly unconscious effects (Kouider & Dupoux, 2004). In order to refine the level of awareness associated with one or the other technique, objective measures may be used in synergy with subjective ones using either continuous or discrete scales. In such settings, the observer is asked to rate the subjective percept she had of the stimulus over several dimensions. Importantly, each measure may be performed at the single trial level, in order to account for training or fatigue effects. This is particularly relevant in situations where stimuli are presented for long periods of time during which awareness may fluctuate.

Unconscious adaptation. The most commonly used indirect measure to demonstrate that the presumed unconscious stimulus nevertheless influences behavior is based on sensory adaptation, whereby a change of responsiveness follows the processing of a specific feature. Adaptive measures are reflected by changes of reaction times or accuracy for a task performed on a subsequent target stimulus, thus offering the possibility to measure the influence of the unconscious adaptive stimulus on subjects even if they deny seeing it. At the behavioral level, sensory adaptation is responsible for two phenomena with opposite consequences. The first is a positive effect classically referred to as priming and reflects a facilitation when processing a target preceded by a stimulus that shares some physical (e.g., angular orientation) or conceptual (e.g., semantic) properties with the target. The second one is referred to as sensory habituation and follows the same approach as priming, except that it reflects, on the contrary, an inhibitory effect whereby overexposure to a stimulus impairs the processing of a related target. These two effects have been extensively used for probing the neural and cognitive processes underlying perception, by following the assumption that a given stimulus property is indeed processed whenever the system shows adaptive responses on a subsequent target sharing this property. This logic is well suited to the domain of unconscious perception, not only because priming and habituation can be observed even when observers are not aware of the adaptation stimulus, but also through manipulation of the type of information shared with the target, which allows one to determine which levels of representation are activated by the unconscious adaptive stimulus.

Unconscious neural responses. An additional approach to characterizing unconscious perception consists in studying the impact of an unconscious stimulus on the brain. While measuring unconscious neural responses requires the use of objective or subjective behavioral measures to assess stimulus unawareness, it does not require an indirect behavioral measure to assess unconscious processing. Instead, it is by inspecting brain response that one can infer unconscious discrimination (e.g., activity in face-sensitive vs. object-sensitive brain regions) or unconscious adaptation effects (repetition suppression, i.e., reduced activity for target stimuli sharing properties with the unconscious adaptive stimulus). This approach is useful for delineating the brain structures or neural mechanisms that are necessary and sufficient for consciousness (hereafter termed the neural correlates of consciousness, or NCC), as first proposed by Crick & Koch (1998). As they put it, "We can state bluntly the major question that neuroscience must first answer. It is probable that at any moment some active neuronal processes in your head correlate with consciousness, while others do not: what is the difference between them?".(page 97) Below we address more specifically how this approach allows one to draw the border between unconscious and conscious neural mechanisms.

Rendering perception unconscious

Three main approaches are used to render a stimulus invisible: the first relies on the disruption of sensory signals, the second on the depletion of attentional resources to be deployed on sensory signals, and the third on the reduction of vigilance states.

Unconscious perception through disruption of sensory signals. For a long time, the most prevalent method used to disrupt visual signals and make them invisible was masking. All variants of masking involve the presentation of a very brief stimulus in temporal contiguity with noise mask patterns that make the stimulus impossible to detect or discriminate. Masking has been extremely fruitful in describing both the architecture of the visual system and the properties of unconscious vision (Kouider and Dehaene 2007), as well as other modalities including audition and touch. In vision, masked stimuli become visible when presented for longer than a few 10s of milliseconds, so masking is not well suited for the investigation of cognitive functions requiring sustained stimulation such as temporal integration, learning, etc. Alternative approaches were recently developed to fill this gap, and allow sustained invisibility despite long stimulation durations—notably, by presenting a stimulus of interest surrounded by distractors in the periphery of the visual field (visual crowding, Levi 2008), or by presenting a stimulus of interest to one eye while the other eye is flashed with a stream of rapidly changing patterns (continuous flash suppression; Tsuchiya and Koch 2005). With these techniques, one can induce periods of invisibility for several seconds. Importantly, each of these techniques implies different levels of invisibility: masking and continuous flash suppression usually prevent stimulus detection (i.e., the presence vs. absence of one feature of interest or the whole stimulus is not detected), while crowding prevents discrimination (i.e., one feature of interest is not consciously perceived, although the stimulus presence vs. absence is detected). Given that restrictions on unconscious cognition might be related to such methodological rather than theoretical limitations, an important question for future research is to better characterize the inherent differences in the amount of information let through by these different methods.

Unconscious perception through depletion of attentional resources. The second category of methods used to leave the content of consciousness empty does not rely on the disruption of sensory signals, but rather on the depletion of attentional resources. In the attentional blink phenomenon (Raymond, Shapiro, and Arnell 1992), observers attending to one target among a rapid succession of stimuli typically fail to detect a second subsequent target, as a result of limited resources focused on the first target. Importantly, the second target becomes visible when observers don't have to attend to the first one, demonstrating that it reflects a depletion of attentional resources rather than a mere disruption of sensory signals. Likewise in inattentional blindness (Mack and Rock 1998), observers engaged in a demanding task fail to detect an unexpected stimulus that would normally be fully visible (see also chapter x). These two examples illustrate the tight links between attention and consciousness: one usually consciously sees that to which one attends. While there is now clear evidence that the processing of unconscious stimuli can be modulated by attentional manipulations (e.g., attentional load, attentional cueing), the opposite situation in which a stimulus is consciously perceived without attention remains to be proven. As of today, the nature of the links between attention and consciousness remains debated, some researchers arguing that consciousness and attention are two dissociable functions (Koch and Tsuchiya 2007), others that consciousness requires attention (Cohen et al. 2012), or that consciousness actually consists in a perceptual reconstruction of attention (Graziano and Kastner 2011). Whether conscious access to a stimulus is prevented by signal disruption or attentional depletion, some of its features remain processed in the absence of consciousness.

Unconscious perception through the disruption of vigilance states. While subjects in classical subliminal perception experiments can be unconscious of a specific content, they remain fully conscious in the sense of experiencing self-consciousness and having introspective access to their goal-directed behaviours in order to perform a specific task. Indeed, the effects of unconscious stimuli in adaptation/priming paradigms are considered only by measuring their influence on the conscious processing of visible targets. Consequently, studies in this research field might thus only be testing the intermixing of unconscious and conscious processes, rather than unconscious cognition per se. Instead of manipulating the content of consciousness, an alternative possibility is to manipulate its level (Laureys 2005), for example in studies of cognition in the unconscious brain during anesthesia, neurological conditions, or sleep. Sleep results in losing sensory awareness and the inability to interact with the environment. During dreamless sleep stages, one can examine the neural consequences of perceptual processes while the subject remains unconscious. Furthermore, sleep offers the opportunity of using sensory stimuli that are not degraded in any manner. Hence, studying sleep might offer the advantage of establishing the properties of a broader and more natural type of unconscious cognition.

While sleep was traditionally considered as the brain shutting down to external inputs, it is now acknowledged that incoming stimuli can still be processed, at least to some extent, during sleep. For instance, sleepers can create novel sensory associations between tones and odours (Arzi et al. 2012) or reactivate existing semantic associations, as evidenced by EEG event-related potentials such as the N400. Up to now, this research field has been primarily limited to the study of basic processes involving associations and conditioned response. Indeed, studying the involvement of complex processing stream during sleep has proven to be problematic from a methodological standpoint, because of the difficulty in instructing sleeping subjects on a new task. To overcome this issue, Kouider et al. (2014) relied on an induction strategy in which awake subjects first perform a semantic classification task (animal vs. object) on auditory words while transitioning towards sleep. Lateralized readiness potentials (LRPs) over the motor cortex revealed that subjects continue performing covert response preparation towards the correct category when sleeping. Importantly, subjects, after they woke up, were unable to discriminate 'old' words (i.e., presented during sleep) from 'new' words. These findings show that despite the absence of overt responses and awareness of the external world, sensory information during sleep can be processed in a flexible manner, all the way up to the preparation of relevant actions.

Neural distinction of unconscious and conscious perception

Neural correlates of consciousness. To circumvent the problem of reducing mental states to elementary brain structures, Crick and Koch (1998) proposed to leave that issue aside, for the time being, and rather focus on "correlating" mental and neural events to find out about their relations. This strategy of searching for neural correlates of consciousness (hereafter NCCs) is known to be limited but it is believed to ultimately lead to a better understanding of the neural processes that support consciousness. An NCC is defined as the minimal set of neuronal mechanisms jointly sufficient for a specific conscious percept or experience. In practice, this strategy implies a contrastive analysis, but aimed here at characterizing the neural rather than cognitive features that are specifically involved during conscious as opposed to unconscious processing. A robust NCC would thus be involved only during conscious experience and never in its absence.

The parieto-frontal network. Nowadays, the most popular NCC is the parieto-frontal network, whether it concerns the contents of consciousness (e.g., conscious vs. unconscious perceptual contents, see Dehaene and Changeux, 2011, for a review) or its levels (e.g., normal subjects vs. vegetative patients, see Laureys, 2005, for a review—see also chapter x). Experiments using fMRI to contrast conscious and subliminal perception illustrates the importance of this network. A word or a face presented very briefly (less than 50 msec) and followed by masking patterns become invisible. Yet, it activates visual areas dealing with reading (Visual Word Form Area,) or face processing (Fusiform Face Area), respectively. When the stimulus is made visible, by removing the masks, a large majority of studies show that neural activity increases in these visual areas and, crucially, a parieto-frontal network is activated exclusively in this conscious situation. Studies using EEG, which offers a better temporal resolution, reveal that the processing dynamics leading to conscious access are only involved at a late stage and preceded by a cascade of neural events operating in an unconscious manner. Indeed, perceiving a brief stimulus involves a two-stage process with distinct electrophysiological signatures (Del Cul, Baillet, and Dehaene 2007). During the first stage, lasting for about 200–300 msec, occipitotemporal areas of the brain are activated and increase linearly as a function of stimulus energy/duration, irrespective of whether the stimulus is consciously seen. By contrast, the second stage is characterized by a non-linear, essentially all-or-none change occurring specifically for seen trials. Here, providing that neuronal activity induced by the stimulus exceeds a certain threshold, it spreads to the prefrontal cortex and is broadcast to other cortices, creating a pattern of global ignition across brain areas that allow perceptual regions to interact with other, task-relevant regions. This leads to a large and long-lasting pattern of activity allowing for the maintenance of perceptual representations long after the external stimulus is gone. This two-stage process with distinct electrophysiological signatures has recently been evidenced in infants as young as 5 months, a population for which one cannot obtain verbal report of subjective experience, providing the first evidence that babies betray the same capacity for consciousness as adults, although with much slower mechanisms (Kouider et al. 2013).

Controversies on the frontier between conscious and unconscious perception

The mere existence of subliminal influences has been one of the most controversial issues in psychology (Eriksen 1960; Holender 1986; Velmans, 1991; Merikle and Daneman 1998). While the existence of subliminal perception is no longer denied, the controversy has shifted to the depth of processing in absence of awareness, that is to what extent unconscious perceptual information can be processed. Bluntly stated, research over the last few decades has rather focused on whether the unconscious mind involves 'dumb' or 'smart' processes (Loftus and Klinger 1992). This issue of levels of processing has over the past few decades been debated primarily in the context of semantic processing (Holender 1986; Kouider and Dehaene 2007). While this literature has long been controversial, it is now more or less resolved, given the substantial number of reports of robust subliminal semantic effects. Today, the main controversies are about the existence of executive processing and information integration in the absence of consciousness.

Executive processing. As described above, one of the most prominent NCC is the parieto-frontal network. In particular, the prefrontal cortex is assumed to trigger the mechanisms of conscious access, whereby it initiates an interplay with the sensory cortex that brings the stimulus representation to consciousness. This assumption is at the heart of the global neuronal workspace theory of consciousness (Dehaene and Changeux 2011). However, recent studies challenged the assumption that the prefrontal cortex is specifically involved in conscious access, by revealing that unconscious stimulus processing is not necessarily restricted to perceptual systems, but can also trigger activations in prefrontal regions under certain circumstances, such as when cognitive control and executive functions are heavily involved. For instance, Lau & Passingham (2007) used a paradigm where participants receive a word (e.g., table) preceded by a square or rectangle cue setting up the task on that word: subjects had to perform a phonological task (one vs. two syllables word) when the word is preceded by a square or a semantic task (concrete/abstract word) when the word is preceded by a rectangle. In other terms, subjects had to perform top-down cognitive control based on the cue (square or diamond). Importantly, the authors showed that priming the visible cue with an invisible and incompatible cue (e.g., an invisible rectangle preceding a square) leads to an impairment in performance. Furthermore, they showed that the neural locus of this unconscious modulation of behavior is found in the premotor and inferior prefrontal cortices associated with phonological and semantic processing task, respectively (Lau and Passingham 2007). Because the invisible primes trigger activations in task- sensitive areas of the prefrontal cortex, this suggests that top-down cognitive control can be performed in the absence of consciousness.

Unconscious cognitive control was also studied using go/no-go paradigms, in which participants are asked to respond as fast as possible to a target if it is preceded by a go cue (e.g., a square), but to inhibit that response if it is preceded by a no-go cue (e.g., a diamond). In several experiments, invisible no-go cues were shown to slow down responses on the target, reflecting an incomplete activation of response inhibition, and therefore suggesting that cognitive control is enabled in the absence of awareness (van Gaal et al. 2010). This effect involved the Pre-Supplementary Motor Area, a region typically associated with cognitive control, including unconscious control of actions driving the suppression of motor decisions. Finally, another cognitive function that is typically held to require consciousness is working memory, whereby newly formed or stored information is transiently processed to meet current goals. The finding that masked stimuli can be discriminated above chance-level performance a few seconds after their display while observers report no conscious experience of the stimulus suggests that information does not need to be accessed consciously to enter working memory (Soto and Silvanto 2014). Interestingly, such unconscious working memory was found to involve the superior frontal and dorsolateral prefrontal cortices, brain regions that are typically linked to the global neural workspace for consciousness. Importantly, evidence for unconscious effects does not rule out the possibility that consciousness might play a functional role in executive functions, notably when it comes to apply them in a flexible manner, within a novel, non-stereotypic context (Dehaene & Changeux, 2011).

Information integration. Starting from the phenomenological observation that conscious percepts are experienced as wholes rather than sums of disparate features, several theories propose that consciousness and information integration are tightly linked, if not mutually dependent. Conversely, these theories hold that unconscious information integration should be limited, if not absent. Recent experimental results demonstrated that unconscious integration is possible, as stimuli made of physical features spread in space, and time, semantic domains or sensory modalities can be integrated even when not accessed consciously. However, the literature also indicates that the scope of unconscious integrative processes is more limited, and effect sizes are smaller than conscious ones, suggesting that consciousness still plays a role in integrative processes in accordance with prominent theories in the field (Mudrik, Faivre, and Koch 2014).

Conclusion

Over the years, researchers have developed finer and finer psychophysical tools to estimate stimulus awareness, and to measure unconscious processing. If the existence of subliminal perception is now unequivocal, the complexity, flexibility, and integrative capacities of the unconscious brain remains to be fully described. This challenge will not only require methodological breakthroughs at the behavioral and neural level, but also a broadening of investigations to include all sensory modalities beyond vision. In addition, the contrast between conscious and unconscious vision is likely to be most accurate when performed in ecological conditions that mimic the environment. Indeed, as with any sensory organs, the visual system is tuned according to the physical properties naturally present in the environment. Yet, experiments on unconscious perception have traditionally been constrained to very rigid and controlled laboratory conditions, some of which we have described above. Interestingly, not all of these methods share the same ecological value: while crowding or attentional depletion are natural phenomena potentially occurring during the observation of any realistic visual scene, masking and continuous flash suppression are never or almost never encountered in real life. Whether ecological relevance actually matters for unconscious processing remains an important question for future research, and one way to further address this issue and generalize unconscious findings to ecologically valid conditions is the use of virtual reality. Indeed, recent technological advancements allow one to study unconscious perception for a variety of situations and tasks, with fine controls over the stimulation parameters together with the immersive feeling of being in a real environment. However challenging this might be, describing the myriad of unconscious processes taking place in the brain will be instrumental to better understand the neural bases of consciousness.

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