OPINION

Imaging implicit perception: promise and pitfalls

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Abstract | The study of implicit perception — perception in the absence of awareness — has a long history. Decades of behavioural work have identified crucial theoretical and methodological issues that must be considered when evaluating claims of implicit perception. Neuroimaging methods provide an important new avenue for illuminating our understanding of perception both with and without awareness, but most imaging experiments have not met the rigorous conditions that the behavioural work has shown are necessary for inferring implicit perception. Here, we review the literature of both behavioural and neuroimaging studies, and note the pitfalls of studying implicit perception as well as the promise that neuroimaging studies have for providing insights about implicit perception when combined with appropriately rigorous behavioural measures of awareness.

There are many controversies involved in the study of implicit perception. Some proponents argue that it has a pervasive influence on thoughts and actions, whereas sceptics argue against its existence (BOX 1). Decades of behavioural research have led to a refined understanding of the theoretical and empirical pitfalls of studying implicit perception[1,2], but the debate over its existence and nature persists[3–14]. Neuroimaging methods can provide insights that would be unattainable using strictly behavioural measures, but their success requires full appreciation of the theoretical and empirical challenges involved in showing implicit perception. This article discusses the central theoretical issues, which have been derived from decades of behavioural work, identifies common shortcomings in the evidence for implicit perception, evaluates recent neuroimaging data in light of the behavioural evidence and methodological issues, and, finally, investigates how neuroimaging might be used to enhance our understanding of perception without awareness.

Behavioural approaches

Recent sceptical critiques of the evidence for implicit perception[15] have led to increased rigor and methodological creativity in attempts to document its existence. Although controversies remain, most proponents and sceptics agree on two central ideas: that the evidence for implicit perception cannot rely solely on participants to accurately report their state of awareness on each trial, and that qualitative differences in performance can support claims of implicit perception even if they are not definitive on their own.

Reliance on subjective reports. Most empirical approaches to studying implicit perception take the same form: they show the absence of conscious perception of a stimulus but show the influence of the stimulus using other measures, an approach known as the dissociation paradigm (BOX 2). To measure awareness, most studies of implicit perception, particularly in the neuroimaging and neuropsychology literatures, rely on the observers to report their state of awareness. The use of such subjective reports of awareness is intuitive and appealing; it trusts the observers to have optimal access to the level of their own awareness. After all, who can better identify the subjective state of awareness than the observers themselves? For example, when a patient with blindsight reports that they not aware of a light flashed briefly in their damaged visual field, but can still reach for and direct their eye movements appropriately toward that light, their performance is treated as definitive evidence of implicit perception[16–18] (BOX 3).

However, most behavioural researchers agree that using subjective reports of the absence of awareness provides, at best, weak support for implicit perception, and in many cases provides no evidence at all[15,19,20]. Subjective reports of awareness are based both on sensitivity to the presence of a stimulus and on the perceiver's decision criterion for reporting it. Importantly, observers are often under-confident about their perceptual experiences[21] — they treat uncertainty as a lack of perception and report no awareness even when more objective measures show that they can discriminate the presence of a stimulus from its absence to some extent. Moreover, people are particularly bad at recognizing chance performance in a number of domains, so the subjective experience of random guessing can be misleading[22,23]. In any given trial, reporting of awareness can be influenced by confidence or motivation as well as by sensitivity. In the case of blindsight, for example, patients adopt different criteria for reporting awareness when they are asked to indicate whether an object is present or not (yes/no response) compared with when they are asked to determine whether the object was shown at the beginning or the end of a trial (2-alternative forced-choice response). Yes/no responses are unduly influenced by an overly

Box 1 | What is implicit perception and why is it important?

Can perception occur in the absence of awareness? And, if so, how rich is that processing? Perceivers are certainly not aware of all aspects of visual sensation — we cannot report the state of a single photoreceptor in the retina, but that receptor still processes sensory information. The interest in implicit perception, and the resulting controversies about how best to measure it, result not from its effects on 'early' visual processing, but from claims that the meaning of a visual stimulus can be processed without awareness and that this information can influence higher cognitive functions.

Conclusive evidence of implicit perception would have far-reaching practical and theoretical implications. Models of attention typically posit some filtering of sensory input before conscious perception (for examples, see REFS 74–76), but there is some disagreement about the amount of processing that occurs before this filtering. Early-selection models indicate that processing of unattended information is limited to the earliest stages of perceptual analysis — semantic content is available only after the item has been selected for attention and so would necessarily be associated with awareness. The existence of implicit perception of meaning or object identity would provide strong support for a late-selection model, indicating that far more of our visual world is processed than conscious experience suggests and that such implicitly perceived information could affect our thoughts, beliefs and actions. These striking implications partly explain the appeal of implicit perception, but they also provoke sceptics to challenge its existence[12,15,77].

Box 2 | **Masking and implicit perception**

The typical example of the dissociation model, which has been applied in both behavioural and neuroimaging contexts, involves the use of visual masking to inhibit conscious perception of a prime stimulus. With appropriate timing and display parameters, a prime is rendered invisible by the presence of a mask. If the prime still influences performance in some way, the effects can be attributed to implicit perception. Competing neurophsyiological models of visual masking have been proposed, but a complete description of these models is beyond the scope of this paper (for discussion of the neural mechanisms of masking, see REFS 78–81).

Initial evidence from studies that used masked priming showed that even when observers could not distinguish between the presence and absence of prime stimuli, the meaning of the masked primes affected responses to semantically-related, visible target words[82] (see also REFS 83,84). In principle, results such as these could provide strong evidence for implicit perception. However, these investigations have been criticized, both for problems with reliability and for using insufficiently sensitive measures of awareness[15] — the measure of explicit awareness might not tap all relevant aspects of conscious experience[1,2,85]. Furthermore, observers are often under-confident about their perceptual experiences and report no awareness even when detection of stimuli by forced-choice methods is better than chance.

conservative response criterion — when tested in this fashion patients are biased to report that nothing was presented[24]. Such differences in criteria might have contributed to the dissociations that have been observed between the verbal reports and actions of such patients, thereby undermining claims that blindsight performance occurs in the complete absence of awareness. In summary, the problem with relying on subjective verbal reports to assess awareness is that subjects can erroneously indicate null awareness because the fleeting impression of a stimulus failed to surpass their criterion for reporting it[25].

A more 'objective' approach. Rather than relying on subjective reports of awareness, a more objective approach uses multiple trials to show that observers actually perform no better than chance when asked to report the presence or absence of a stimulus[19,20]. This approach uses signal detection methods to factor out the effects of confidence and decision criteria on measures of awareness. If sensitivity to the presence of a stimulus is demonstrably at chance, then the participant is presumably unaware of it. Any evidence for stimulus processing despite this objective lack of awareness can be attributed to implicit perception. The primary challenge for this approach is to provide definitive evidence that conscious awareness is entirely absent and that performance is truly at chance[1,2,11,12]. Distinguishing null sensitivity from low-level sensitivity requires many trials — more than have typically been used in studies of implicit perception[26]. Moreover, if conscious sensitivity varies over time, then even showing null sensitivity across a large set of trials might not provide sufficient evidence for the absence of awareness[3] (see also REFS 4–9). At a minimum, studies must determine the objective threshold (chance performance, where sensitivity in terms of signal detection theory is absent, or $d'=0$) separately for each observer because different individuals have different response strategies, decision criteria and sensitivity[5,27]. Unfortunately, few behavioural studies and almost no neuroimaging or patient studies meet these conditions satisfactorily[13]. The formidable challenge of showing null sensitivity for all the observers in a study has led to the development of several variants of the objective approach.

Variants of the 'objective' approach. Rather than trying to establish an objective threshold ($d'=0$) for each participant, one promising new approach uses linear regression to predict individual performance on an indirect (implicit) measure from that on a direct (explicit) measure (FIG. 1). Even if some observers show better than chance sensitivity, the regression line can be extrapolated to the point at which the direct measure shows null sensitivity. If the indirect measure at that point shows better than chance performance (that is, the y-axis intercept is greater than 0), then implicit perception is inferred[28–30]. However, extrapolation to null sensitivity on the direct measure might be inappropriate if the true relationship between the tasks is not linear at low levels of sensitivity[31–33] — that is, the relationship between performance on a direct measure and an indirect measure might differ between high and low levels of awareness, invalidating extrapolation from performance with some awareness to performance with no awareness.

Other approaches have been proposed to circumvent the pitfalls associated with the dissociation technique, although they have not been used in neuroimaging experiments. For example, in the relative sensitivity approach[1,2], if a task that relies more on conscious (explicit) processing shows worse performance than a comparable but less-conscious task, then the difference is attributed to implicit processes[34,35]. This approach bypasses the need to eliminate all explicit processing in order to infer the existence of implicit processing. However, it depends crucially on the assessment of which task relies more on conscious processing. In addition, because the approach does not eliminate conscious processing, any dissociation between the tasks might reflect the operation of two explicit processes rather than a difference between implicit and explicit perception[36]. The approach has promise as a means of investigating implicit perception in both behavioural and neuroimaging contexts, but has so far been used only sporadically.

The importance of qualitative differences. Explicit perception varies with stimulus intensity, and many claims of implicit perception have also shown that implicit measures of performance vary with stimulus intensity. When both explicit and purportedly implicit processes vary in the same fashion as a function of stimulus intensity, sceptics can argue that all of the effects are governed by the same explicit mechanisms. That is, functionally similar performance on two tasks does not provide strong evidence for a dissociation between two mechanisms; it seems more parsimonious to assume a single mechanism, with 'implicit' perception reflecting a weaker form of the same explicit mechanisms.

Moreover, when the two patterns are similar, it is possible that the presence of any conscious processing might mask or obscure implicit processing. According to one new

Box 3 | **Blindsight**

The term blindsight describes a phenomenon seen in patients who have sustained damage to the primary visual cortex or V1, most commonly as a result of head trauma, vascular accident or tumour. The damage produces a contralesional visual field defect. These patients report no awareness of a stimulus in their damaged field, but when forced to choose a property of the stimulus (for example, is it red or green, moving or not moving, or present or absent), they perform better than chance. Indeed, they often report that they see nothing at all and that their responses are just guesses. The neuropsychological condition of blindsight is defined by this disconnect between discriminative performance and subjective awareness (for reviews, see REFS 86,87).

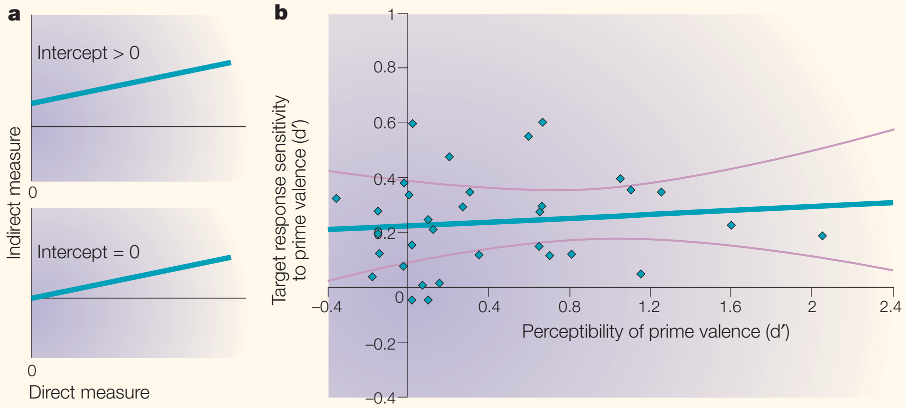

Figure 1 | **The regression approach. a** | Hypothetical data patterns for the linear regression approach. The top graph shows a pattern that is taken to reflect implicit perception — when performance on the direct (explicit) measure is extrapolated to 0, performance on the indirect (implicit) task is still greater than 0. The lower graph shows a pattern that indicates an absence of implicit perception — when performance on the direct measure is extrapolated to 0, performance on the indirect task is also 0. Adapted, with permission, from REF. 29 © (1995) American Psychological Association. **b** | An illustration of the regression analysis technique. The association between implicit effects and the perceptibility of prime stimuli is represented by the regression line (blue), with the line extrapolated to the point at which the direct measure reveals no sensitivity. The curves on either side of the regression line (purple) indicate a 95% confidence interval (CI) around the regression line. In this case, the CI shows that the regression line intercepts the y-axis above zero, so priming is reliable even when the direct measure shows no evidence for conscious perceptibility of the primes. Critics challenge the assumption that this approach infers implicit processing (see text). Adapted, with permission, from REF. 89 © (2000) American Psychological Society.

view, implicit perception can be reliably observed only when conscious performance is objectively at chance, because any effects of implicit perception are masked or obscured by the presence of conscious processing[10] (see also REFS 11–13). In essence, implicit processing is revealed when conscious sensitivity is absent and performance on an implicit task improves as stimulus intensity decreases. At its core, this model requires both null conscious sensitivity and a qualitative difference between the effects of stimulus intensity on implicit and explicit processes.

Qualitative differences have previously been reported in the context of the opposition technique. In this procedure[37], subjects view word stimuli, which are presented for varying durations, and then try to complete word stems with words that were not presented. Conscious awareness of the studied words should lead the subjects to complete the word stems with other words as instructed. Consequently, if their stem completion performance includes many of the studied words, the effect is attributed to implicit processing — had they been aware of them they would have excluded the words. Implicit perception is indicated when trials in which subjects were aware and unaware elicit qualitatively different patterns of performance[38]. However, these effects can be influenced by decision criteria. With low confidence in their percept, the subjects might mistakenly report that they had not seen a word even if they did have some residual awareness. In fact, with increased motivation to exclude studied words, subjects show less implicit processing[39]. Like approaches that rely on subjective reports of awareness, the opposition technique does not provide a pure measure of implicit perception, but does provide important evidence for differences in processing above and below a subjective threshold (BOX 4). Only when combined with sufficiently rigorous methods for eliminating conscious awareness can qualitative differences provide a more convincing source of evidence for implicit perception.

Neuroimaging approaches

Although qualitative differences on their own do not provide conclusive evidence for implicit perception[15], they do provide converging evidence. Neuroimaging approaches might be most useful in exactly this context, as they reveal qualitative differences in processing without the need for a distinct behavioural measure of implicit processing. In other words, neuroimaging can uncover dissociations and test theories in ways that are not possible with strictly behavioural measures. For example, the Global Workspace Theory proposed by Baars attributes consciousness to distributed long-range connectivity among a set of non-conscious specialized processors or modules[40,41]. These modules might be mobilized and their outputs made available to consciousness as a result of top-down attentional amplification of neural activity[42,43]. Accordingly, implicit processes should be relatively localized to specialized modules, but explicit perception should result in distributed activity across a number of modules. This view of consciousness makes strong predictions about neural activity that can readily be tested using neuroimaging methods. However, unless such studies adopt rigorous behavioural controls to determine that conscious perception is entirely absent, qualitative differences in the distribution of activity could be attributed to variations in the confidence of explicit detection rather than to a distinct implicit mechanism.

In one study, neural activity was measured in response to masked words that were almost never named successfully[44]. Compared to a blank-screen control condition, these masked words activated brain regions that are associated with reading (for example, the left lateralized extrastriate cortex, fusiform gyrus and precentral sulcus), which indicates that the unseen stimuli were processed in a similar

Box 4 | Subjective assessment of awareness and qualitative differences

Subjective reports are insufficient for making inferences about perception in the absence of awareness — they measure what is reported, not what is reportable. Nonetheless, dissociations between performance with awareness and performance when subjects report no awareness are important to our understanding of perceptual processing. When a blindsight patient reports no awareness of a light flashed in their damaged visual field but still reaches appropriately for it, their performance might reflect implicit processing, but because the measurement of awareness is subjective, this is indeterminable — it could be that the patient uses a different decision criterion for a reaching response, one that is somewhat more liberal than for their judgment. However, even if the reaching performance is not truly implicit, it still shows that patients are able to act on a stimulus when they do not or cannot consciously report its presence. Moreover, qualitatively different performance above and below the subjective threshold indicates the presence of distinct processing mechanisms, although both of these might be conscious. Such dissociations are fertile grounds for neuroimaging research. The critiques raised in the main text apply to claims of perceptual processes that operate entirely in the absence of awareness.

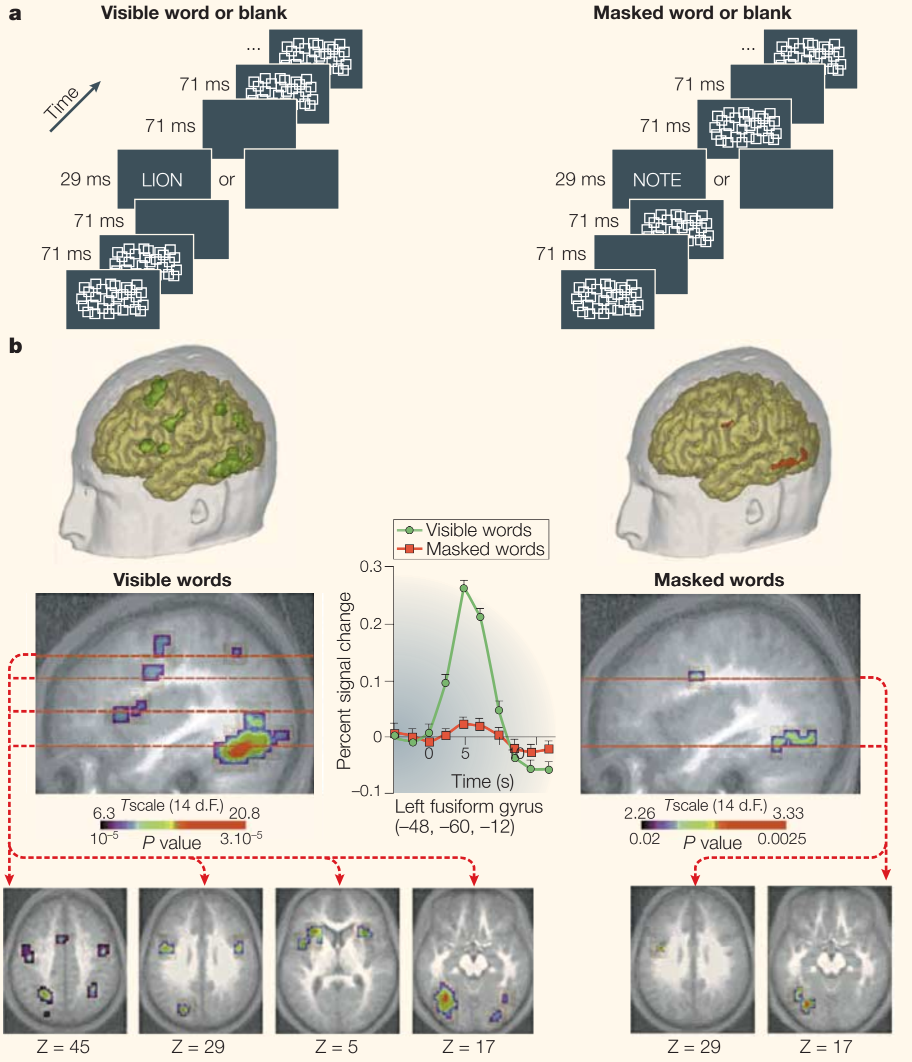

Figure 2 | **Visible words and masked words. a** | A word or blank screen was presented amid a series of masking stimuli and blank screens, and perceptibility of the word was manipulated. Masks consisted of a semi-random array of square and diamond shapes and covered the part of the screen where the word would otherwise have appeared. In the illustration above, the word "LION" (left) was surrounded by blank screens and was visible to participants, whereas the word "NOTE" (right) was surrounded by masking stimuli and so was not reportable. **b** | Functional MRI activity that was elicited by visible and masked words, respectively. The top figure shows activations that were seen in the left hemisphere in a group of participants, plotted in a translucent, three-dimensional reconstruction of the brain and skull of one participant. The bottom figure shows group activations plotted in Talairach space from sagittal and axial views, superimposed on the mean anatomical image of all participants. The middle figure depicts peak activation in the left fusiform gyrus, which shows an increase in activation for trials in which the word was visible (not masked) that is 12 times the magnitude of activation that was seen when the words were masked. Consistent with the Global Workspace Theory of consciousness, visible words elicited activity that was both more robust and more extensive than that elicited by masked words. Nonetheless, masked words elicited activity in brain regions associated with reading (for example, left lateralized extrastriate cortex, fusiform gyrus and precentral sulcus). Error bars are inter-subject standard errors of the mean. *T*scale, statistical t-distribution (Weibull distribution); *P* value, probability of activation of that magnitude or greater based on the *T*scale; Z, location of the axial slice according to Talairach coordinates. Adapted, with permission, from REF. 44 © (2001) Macmillan Magazines Ltd.

way to visible words. However, activity in response to masked words was smaller in magnitude and less widely distributed than that for consciously perceived words, which also elicited activity in the parietal, prefrontal and cingulate cortices (FIG. 2). Although this pattern is consistent with the Global Workspace Theory, it does not provide convincing evidence for implicit processing because, like most studies, it did not include a sufficient assessment of awareness. Explicit perceptibility of the prime stimulus was measured by the subjects' ability to name it — a task that probably induces a conservative criterion for responses and thereby underestimates conscious perception. Reduced neural activity in brain regions associated with reading in response to masked words might be attributable to conscious awareness that is too weak to permit naming, rather than implicit perception of the masked word. Such pitfalls are common in neuroimaging studies of implicit perception.

Despite consensus in the behavioural literature that subjective reports alone are inadequate as measures of awareness and that optimally sensitive explicit measures are needed, most neuroimaging studies of implicit perception rely exclusively on subjective measures that are heavily influenced by confidence and response biases. Consequently, in most cases, these studies do not provide convincing evidence for perception without awareness. For example, one experiment measured an event-related potential (ERP) correlate of motor cortex activation — the lateralized readiness potential (LRP)[45] — to determine whether activation persisted even when participants reported no awareness of a stimulus (FIG. 3). Numeric primes were presented between two displays of arbitrary characters (these 'masking' displays reduce the visibility of the primes) and subjects reported whether a subsequent target was greater or less than five. Although subjects reported no awareness of the prime, responses were slower when the prime and target fell on different sides of five. The existence of covert motor activity in response to an 'unaware' prime stimulus, measured by way of the LRP, indicates that semantic information about the prime (that is, whether it was greater or less than five) was processed without awareness[46] (see also REF. 47). However, such studies often used different subjects to assess the explicit perceptibility of the prime and to participate in the imaging component[46] (see also REF. 48), which raises the possibility that individual differences in sensitivity affected whether the prime was consciously perceived.

Many studies also infer the existence of implicit perception from findings of similar activation patterns for implicit and explicit processes. However, as noted earlier, similar patterns could readily result from a single mechanism. For example, repeating a word that is not consciously reported leads to a systematic decrease in the magnitude of neural activity in response to that word[44,48,49], a phenomenon known as repetition suppression. Presenting the same number as a masked ('implicit') prime and as a target produces bilateral repetition suppression in the intraparietal sulcus. Similar reductions in activity have been observed in the visual word form area (VWFA), a region of the left fusiform gyrus that has been implicated in the invariant recognition of visible words[44,49]. These findings have been taken to reflect implicit perception, because the same areas are affected by repetitions regardless of whether or not the words and numbers are consciously perceived[47]. Yet, when supposedly implicit processes show the same pattern as known explicit processes, it seems plausible that the 'implicit' measures simply reflect weak explicit perception. In this case, the weaker neural activation could be attributed to a smaller extent of explicit perception. So far, most neuroimaging findings of implicit perception have failed to eliminate the possibility that activity patterns result from weak explicit processing; the methods insufficiently eliminate the possibility of conscious perception, either by relying exclusively on subjective reports of awareness or by inadequately establishing that performance is objectively at chance[12]. Such studies fall prey to the same criticisms that are levied against behavioural research carried out using the dissociation paradigm.

Rather than dwelling on these inadequacies, we now focus on those few studies that have approached the rigor that is needed to support claims of implicit perception. We then highlight how neuroimaging promises to provide insights that are not available through strictly behavioural methods, provided that sufficiently sensitive methods are used to determine whether a stimulus is consciously perceptible.

Improved imaging methods

Several neurophysiological experiments[50–53] have investigated the effect of an implicitly perceived prime word on the semantic processing of a subsequently presented target word by measuring modulation of the N400, a negative-going ERP component that is sensitive to manipulations of semantic relatedness [54]. In one of the most promising of these experiments, Stenberg *et al.*[51] systematically manipulated target visibility and collected trial-by-trial reports of perceptual awareness as well as electrophysiological responses to the target. Rather than using a simple report, as in most previous neuroimaging studies, they obtained several measures of awareness that varied in their sensitivity. They used the most sensitive measure of awareness to exclude consciously perceived words from further analyses, and showed that performance for the remaining words was no better than chance (d′=0). Despite the use of this more systematic test of awareness, the N400 effect persisted (albeit much reduced). Crucially, consciously reported targets were associated with a left-lateralized positive-going waveform, whereas unreported targets elicited more distributed or right-lateralized activity. This difference indicates that trials with and without awareness activate qualitatively different neural populations. Other investigations of semantic priming have had less success in

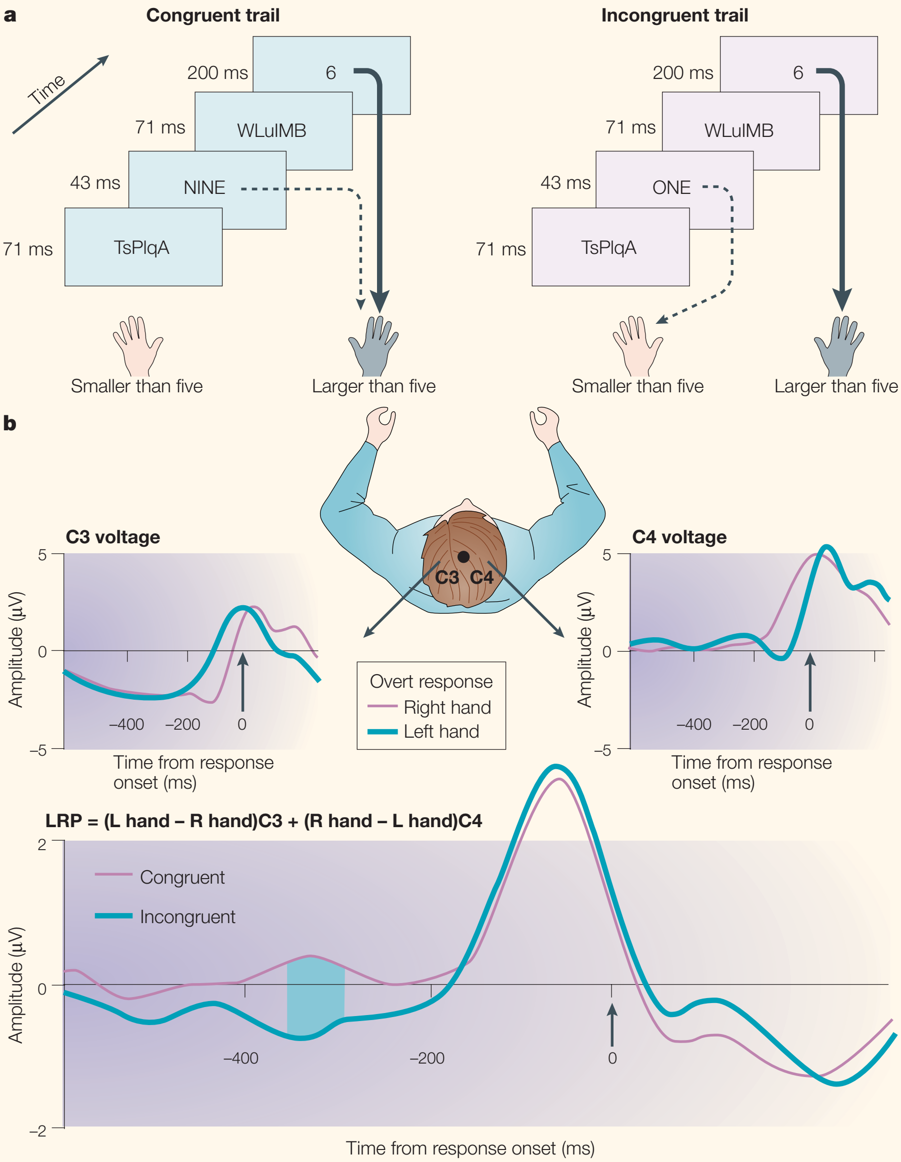

Figure 3 | **Lateralized readiness potential to masked words. a** | In each trial a set of masking characters, a numerical prime stimulus, a second mask and a target number were presented in sequence. Subjects were not informed of the presence of the numerical prime and were simply told to classify each target as larger or smaller than five. For half of the trials, the prime and target fell on the same side of five (congruent) and for the remainder they fell on opposite sides of five (incongruent). **b** | The lateralized readiness potential (LRP), an index of motor activation that precedes a behavioural response, was derived from the event-related potential data. Positive deflections from zero indicate preparation of the correct motor response, whereas negative deflections indicate preparation of an erroneous response. Neural activity was averaged with respect to the timing of behavioural responses (made through key pressing). The top panel illustrates large changes in voltage at electrodes C3 and C4 in opposite directions before left- and right-handed responses, respectively, reflecting activity in the motor cortex. The bottom panel illustrates the LRP. The LRP is the average of the differences in activity at electrodes C3 and C4, and was calculated according to the formula that is shown. Before the main positive-going waveform that reflects correct overt motor response preparation, incongruent trials elicited an LRP that was significantly more negative than congruent trials (shaded area), reflecting incorrect motor preparation in association with the masked prime stimulus. Adapted, with permission, from REF. 46 © (1998) Macmillan Magazines Ltd.

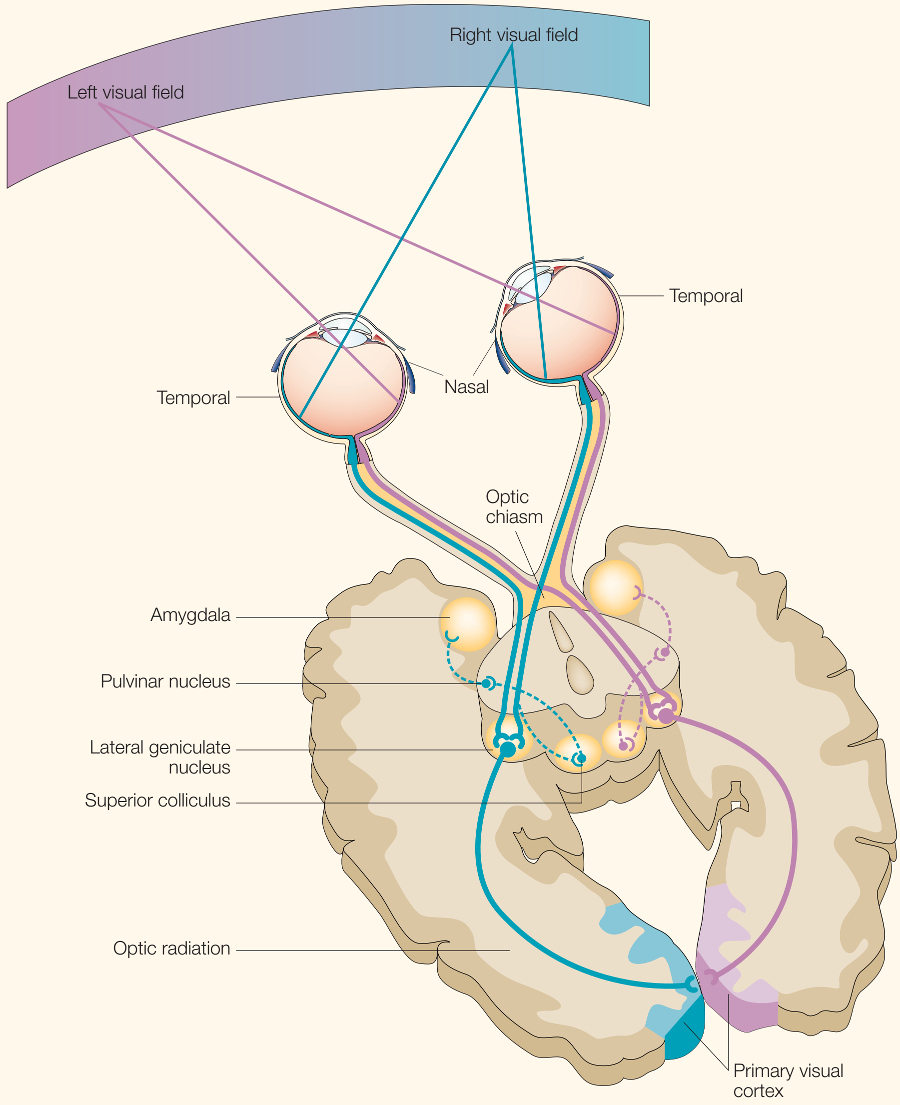

Figure 4 | **Subcortical visual pathway.** Converging neuroscientific evidence indicates that there is a subcortical visual pathway (dashed line), which is distinct from and phylogenetically older than the primary visual processing pathway (solid line) that projects to the primary visual cortex before reaching higher level processors. Although still speculative, this subcortical pathway is thought to pass information from the retina to the superior colliculus to the posterior thalamic nuclei (including the pulvinar), and then to the amygdala, quickly providing the amygdala with information about the presence of emotionally-relevant, fear-inducing or dangerous stimuli in the environment[57,58,63,64,71]. This pathway could provide the necessary information for the amygdala to mediate aspects of emotional processing, especially of fear, rapidly and automatically, even in conditions in which the critical stimulus is outside either awareness or the focus of attention. Adapted, with permission, from REF. 90 © (2002) W. W. Norton & Co.

finding an N400 for implicitly perceived stimuli[55,56]. The absence of an N400 in these experiments might be the result of using a relatively long delay between the prime and target, which would make the measures insensitive to any short-lived implicit effects. However, one of these experiments[56] indicated a different dissociation. Target words that were preceded by semantically related masked primes (versus target words preceded by unrelated masked primes) and presented at individually determined objective thresholds (that is, with chance detection performance) elicited a larger amplitude of N200; by contrast, visible primes elicited the standard modulation of the N400. Together with careful measurement of conscious awareness, this qualitative difference indicates that unique neural populations are recruited during implicit and explicit prime perception, which strengthens claims that these are separable processes.

The promise of neuroimaging

Qualitative differences alone provide insufficient grounds on which to infer implicit perception, but combined with rigorous measures of conscious perception and evidence from other approaches, these differences can provide crucial, converging evidence that would be unavailable from behavioural approaches alone. For example, neuroimaging or physiological evidence might reveal brain circuits or pathways that are distinct from those typically responsible for conscious processing. If neuroimaging evidence indicates that those regions are activated in the objective absence of awareness but not by a consciously perceived stimulus, it can increase our confidence in claims of implicit perception.

One excellent example of this convergence comes from studies of the implicit perception of emotional or threatening stimuli. A short-latency tecto-thalamic pathway that projects directly to the amygdala and bypasses the visual cortex has been implicated in the implicit processing of fearful faces and aversively conditioned visual stimuli[57,58]. This pathway might provide a mechanism for implicit processing of emotion (FIG. 4); as such, neuroimaging studies can look for activation in this pathway in the absence of awareness. Indeed, the amygdala is active in response to fearful, angry and aversively conditioned masked faces[59–61] (but see also REF. 62) (FIG. 5). Moreover, amygdala activity that is elicited by masked emotional faces covaries with activity in the posterior thalamic nuclei (pulvinar) and the superior colliculus in neurologically intact individuals and in a blindsight patient with damage to the left occipital lobe[63,64]. These finding are consistent with the presence of a subcortical pathway for processing emotional stimuli. Similarly, the implicit perception of fear and corresponding amygdala activation are observed in patients with parietal neglect syndrome. Such patients fail to report a stimulus in their contralesional visual field when it is presented simultaneously with a stimulus in their ipsilesional visual field[65,66] — that is, they show amygdala activation for stimuli they do not report. Importantly, in binocular rivalry studies of implicit perception of emotional faces, high-level visual processing areas that are sensitive to faces (for example, the fusiform face area) were not active, which indicates that amygdala activity cannot be attributed to processing in the geniculostriate visual stream[67].

Further evidence for the implicit processing of emotion in a separate pathway comes from ERP experiments, in which masked fearful

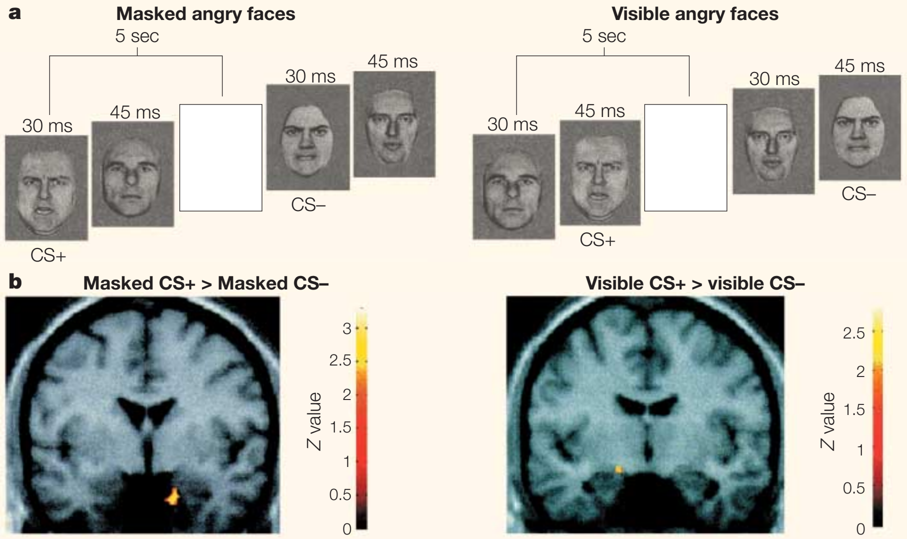

Figure 5 | **Masking face stimuli. a** | Before imaging, an angry face was paired repeatedly with aversive white noise to produce a conditioned response. During scanning, visibility of this conditioned angry face (CS+) and an unconditioned angry face (CS–) was systematically manipulated. Each trial consisted of a target face, followed immediately by the presentation of a second face, which served as a mask. Subjects failed to report the presence of angry faces only when they were masked with a neutral-expression face (left). **b** | Amygdala activity was evident regardless of stimulus visibility, although there were qualitative differences in lateralization of amygdala activity as a function of visibility. A comparison of the activation seen for masked CS+ and masked CS– faces revealed greater activation in the right amygdala in response to CS+ faces, and the same comparison for visible faces revealed greater activity in the left amygdala in response to CS+ faces. Adapted, with permission, from REF. 60 © (1998) Macmillan Magazines Ltd.

faces elicited a P1 component within the first 100 ms of processing, as well as an enhanced N2 component, each thought to reflect automatic aspects of face processing. By contrast, visible fearful faces modulated later ERP components, such as the N400, and a late P3 component, which are implicated in the conscious integration of emotional content[68,69].

Despite converging evidence for a separate neural pathway underlying the implicit processing of emotion, other evidence indicates that these pathways are not entirely distinct. For example, in a recent intracranial electrophysiological study, amygdala activity did not differentiate visible fearful faces from visible faces that expressed other emotions until 200 ms after face presentation. This finding seems to be inconsistent with a direct, short-latency visual pathway that mediates rapid, unconscious processing of fearful faces[70]. However, the 'implicit' pathway might be enlisted only for unattended or visually degraded displays[71], and the stimuli used in this study were fully visible. A more problematic recent finding is that the amygdala only discriminates between emotional and neutral faces when sufficient attention is devoted to the faces — when subjects attend to a competing task the amygdala is not automatically engaged by emotional faces[72]. This finding raises concerns that previous studies of implicit fear perception, like most studies of implicit perception, did not sufficiently eliminate conscious processing of the emotional content of the faces.

In fact, none of these studies of the implicit perception of emotion established an individual conscious perceptibility threshold for each participant. Rather, thresholds were either adopted from earlier research conducted by Esteves & Ohman[73] (see also REFS 59,60,63) or were established using a separate group of subjects before the imaging experiments were conducted[61,62,67,68]. These thresholds might have been affected by overly conservative responses. For example, in one experiment, masked angry faces were not detected by any of the subjects, but 100% of visible angry faces were detected[60], which indicates that subjects only reported the presence of an angry face when it was clearly visible. Consequently, the processing of masked fearful faces might not have been completely outside the subjects' awareness, meaning that the results do not provide conclusive support for implicit perception.

Despite these drawbacks, converging evidence strengthens the case for implicit processing by implicating the existence of an anatomically and functionally distinct short-latency pathway that mediates rapid responses to threatening stimuli and that could operate outside awareness. Neuroimaging evidence indicates that implicit processing of emotion might operate through this pathway, whereas explicit processing occurs in regions that typically mediate slower, cognitively driven evaluative responses. This evidence provides a dissociation that would be unavailable using strictly behavioural measures. In this case, a separate implicit pathway is particularly plausible — it could confer a distinct evolutionary advantage by providing a mechanism to alert an organism to focus attention on threatening objects[57]. So, even if the evidence does not meet the stringent conditions that are required to show implicit perception, the presence of theory-driven reasons about why implicit processing of emotion might be beneficial, coupled with evidence for several neural pathways for emotional processing, makes this a particularly promising domain for future studies of implicit perception. However, as for other behavioural and imaging studies of implicit perception, this promise remains unfulfilled without more systematic measures of conscious perceptibility.

Future perspectives

Neuroimaging techniques, when combined with appropriately sensitive measures of conscious awareness, provide an important new avenue for identifying qualitative differences between implicit and explicit processes, and promise to reveal dissociations that are unavailable using strictly behavioural measures. For example, neuroimaging can reveal distinct neural signatures — different brain regions or different time courses of activation — for implicit and explicit processes. However, most imaging experiments have used measures of conscious awareness that are insufficiently rigorous, and have not met the conditions that are necessary for inferring implicit perception. As for behavioural studies of implicit perception, it is crucial to establish separate thresholds for awareness for individual subjects and, ideally, awareness should be assessed on a trial-by-trial basis. Measures of sensitivity to the presence of the stimulus, such as d', are rarely reported in neuroimaging studies. Consequently, most 'implicit' effects can plausibly be attributed to partial awareness of the stimulus. This is particularly applicable when the same structures are active during implicit and explicit perception. When the activity that is elicited by masked words is simply reduced compared with that elicited by visible stimuli, the pattern is consistent with low-level conscious perception and cannot unequivocally support claims of implicit perception (BOX 5).

Box 5 | A problem that is specific to neuroimaging

Unless the materials used to measure implicit and explicit perception are comparable, any differences in perception might result from differences in the displays themselves. Therefore, the displays used to measure implicit and explicit perception must be comparable[1,2]. Researchers have long known the importance of equating display conditions for all variables except the one of interest. Although the different conditions in the imaging session are often carefully equated, in many cases the thresholds for conscious perceptibility are measured outside the scanner, and those thresholds are then used during the imaging session. Unfortunately, conscious perceptibility of a stimulus may differ under these separate viewing conditions, due to both the change in context for the subject and the displays themselves. Liquid crystal displays (LCDs) and thin-film transistor (TFT) technology, which are increasingly being used in neuroimaging studies, are not well suited to masking experiments because they are less accurate at maintaining temporal precision across trials than are slide projectors with mechanical shutters or cathode-ray monitors[88]. If different displays are used to establish thresholds outside the imaging environment, then stimuli that were not consciously perceptible in the tests used to determine conscious thresholds might be consciously perceptible in the scanning environment. It is crucial to measure the thresholds for conscious perceptibility using the same displays and in the same testing situation that will be used for neuroimaging.

Despite these concerns, evidence for qualitative differences in the time course, scalp distribution and extent of activity that is elicited by visible and masked words lends support to claims of implicit processing. The ability to show qualitative differences in neural activity, especially in the absence of such differences in behavioural measures, is paramount to the promise of these techniques in providing convincing support for implicit perception. For instance, the superior temporal resolution of ERPs could reveal differences in the time course of neural responses to implicit and visible primes, even when such differences are not detectable using behavioural measures of priming[52]. Similarly, differences in the scalp distribution (or topography) of neural responses to implicit and visible stimuli might indicate the recruitment of different underlying neural populations[51]. An optimal approach would use careful behavioural measures to show that conscious perception is objectively absent, and would then use neuroimaging to seek evidence of qualitative differences in activation for implicit and explicit perception. The added sensitivity that is provided by neuroimaging measures can provide insights about implicit perception that are unattainable using strictly behavioural measures.

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1. Reingold, E. M. & Merikle, P. M. Using direct and indirect measures to study perception without awareness. *Percept. Psychophys.* **44**, 563–575 (1988).
2. Reingold, E. M. & Merikle, P. M. On the inter-relatedness of theory and measurement in the study of unconscious processes. *Mind Lang.* **5**, 9–28 (1990).
3. Erdelyi, M. H. Subliminal perception and its cognates: theory, indeterminacy, and time. *Conscious. Cogn.* **13**, 73–91 (2004).
4. Bachmann, T. Inaptitude of the signal detection theory, useful vexation from the microgenetic view, and inevitability of neurobiological signatures in understanding perceptual (un)awareness. *Conscious. Cogn.* **13**, 101–106 (2004).
5. Bornstein, R. F. Subliminality, consciousness, and temporal shifts in awareness: implications within and beyond the laboratory. *Conscious. Cogn.* **13**, 613–618 (2004).
6. Erdelyi, M. H. Comments on commentaries: Kihlstrom, Bachmann, Reingold, and Snodgrass. *Conscious. Cogn.* **13**, 430–433 (2004).
7. Kihlstrom, J. F. Availability, accessibility, and subliminal perception. *Conscious. Cogn.* **13**, 92–100 (2004).
8. Reingold, E. M. Unconscious perception: assumptions and interpretive difficulties. *Conscious. Cogn.* **13**, 117–122 (2004).
9. Snodgrass, M. The dissociation paradigm and its discontents: how can unconscious perception or memory be inferred? *Conscious. Cogn.* **13**, 107–116 (2004).
10. Snodgrass, M., Bernat, E. & Shevrin, H. Unconscious perception: a model-based approach to method and evidence. *Percept. Psychophys.* **66**, 846–867 (2004).
11. Haase, S. J. & Fiske, G. D. Valid distinctions between conscious and unconscious perception. *Percept. Psychophys.* **66**, 868–871 (2004).
12. Holender, D. & Duscherer, K. Unconscious perception: the need for a paradigm shift. *Percept. Psychophys.* **66**, 872–881 (2004).
13. Reingold, E. M. Unconscious perception and the classic dissociation paradigm: a new angle? *Percept. Psychophys.* **66**, 882–887 (2004).
14. Snodgrass, M., Bernat, E. & Shevrin, H. Unconscious perception at the objective detection threshold exists. *Percept. Psychophys.* **66**, 888–895 (2004).
15. Holdender, D. Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: a survey and appraisal. *Behav. Brain Sci.* **9**, 1–66 (1986).
16. Poppel, E., Held, R. & Frost, D. Residual visual function after brain wounds involving the central visual pathways in man. *Nature* **243**, 295–296 (1973).
17. Weiskrantz, L., Warrington, E. K., Sanders, M. D. & Marshall, J. Visual capacity in the hemianopic field following a restricted occipital ablation. *Brain* **97**, 709–728 (1972).
18. Blythe, I. M., Kennard, C. & Ruddock, K. H. Residual vision in patients with retrogeniculate lesions of the visual pathways. *Brain* **110**, 887–905 (1987).
19. Eriksen, C. W. in *Nebraska Symposium on Motivation* Vol. 6 (ed. Jones, M. R.) 169–227 (Univ. Nebraska Press, Lincoln, Nebraska, 1958).
20. Eriksen, C. W. Discrimination and learning without awareness: a methodological survey and evaluation. *Psychol. Rev.* **67**, 279–300 (1960).
21. Bjorkman, M., Juslin, P. & Winman, A. Realism of confidence in sensory discrimination: the underconfidence phenomenon. *Percept. Psychophys.* **54**, 75–81 (1993).
22. Tversky, A. & Kahneman, D. Judgment under uncertainty: heuristics and biases. *Science* **185**, 1124–1131 (1974).
23. Kunimoto, C. Miller, J. & Pashler, H. Confidence and accuracy of near-threshold discrimination responses. *Conscious. Cogn.* **10**, 294–340 (2001).
24. Azzopardi, P. & Cowey, A. Blindsight and visual awareness. *Conscious. Cogn.* **7**, 292–311 (1998).
25. Wolfe, J. M. in *Fleeting Memories: Cognition of Brief Visual Stimuli* (ed. Coltheart, V.) 71–94 (MIT Press, Cambridge, Massachusetts, 1999).
26. Macmillan, N. A. The psychophysics of subliminal perception. *Behav. Brain Sci.* **9**, 38–39 (1986).
27. Snodgrass, M., Shevrin, H. & Kopka, M. The mediation of intentional judgments by unconscious perceptions: the influence of task strategy, task preference, word meaning, and motivation. *Conscious. Cogn.* **2**, 169–193 (1993).
28. Draine, S. C. & Greenwald, A. G. Replicable unconscious semantic priming. *J. Exp. Psychol. Gen.* **127**, 286–303 (1998).
29. Greenwald, A. G., Klinger, M. R. & Schuh, E. S. Activation by marginally perceptible (‘subliminal’) stimuli: dissociation of unconscious from conscious cognition. *J. Exp. Psychol. Gen.* **124**, 22–42 (1995).
30. Klauer, K. C., Greenwald, A. G. & Draine, S. C. Correcting for measurement error in detecting unconscious cognition: comment on Draine & Greenwald. *J. Exp. Psychol. Gen.* **127**, 318–319 (1998).
31. Dosher, B. A. The response-window regression method — some problematic assumptions: comment on Draine and Greenwald (1998). *J. Exp. Psychol. Gen.* **127**, 311–317 (1998).
32. Merikle, P. M. & Reingold, E. M. On demonstrating unconscious perception: comments on Draine and Greenwald. *J. Exp. Psychol. Gen.* **127**, 304–310 (1998).
33. Miller, J. Measurement error in subliminal perception experiments: simulation analyses of two regression methods. *J. Exp. Psychol. Hum. Percept. Perform.* **26**, 1461–1477 (2000).
34. Kunst-Wilson, W. R. & Zajonc, R. B. Affective discrimination of stimuli that cannot be recognized. *Science* **207**, 557–558 (1980).
35. Merikle, P. M. & Reingold, E. M. Comparing direct (explicit) and indirect (implicit) measures to study unconscious memory. *J. Exp. Psychol. Learn. Mem. Cogn.* **17**, 224–233 (1991).
36. Whittlesea, B. & Price, J. Implicit/explicit memory versus analytic/nonanalytic processing: rethinking the mere exposure effect. *Mem. Cogn.* **29**, 234–246 (2001).
37. Jacoby, L. L. A process dissociation framework: separating automatic and intentional uses of memory. *J. Mem. Lang.* **30**, 513–541 (1991).
38. Debner, J. & Jacoby, L. L. Unconscious perception: attention, awareness and control. *J. Exp. Psychol. Learn. Mem. Cogn.* **20**, 304–317 (1994).
39. Visser, T. A. W. & Merikle, P. M. Conscious and unconscious processes: the effects of motivation. *Conscious. Cogn.* **8**, 94–113 (1999).
40. Baars, B. J. *A Cognitive Theory of Consciousness* (Cambridge Univ. Press, Cambridge, 1988).
41. Baars, B. J. The conscious access hypothesis: origins and recent evidence. *Trends Cogn. Sci.* **6**, 47–52 (2002).
42. Dehaene, S., Kerszberg, M. & Changeux, J. P. A neuronal model of a global workspace in effortful cognitive tasks. *Proc. Natl Acad. Sci. USA* **95**, 14529–14534 (1998).
43. Dehaene, S. & Naccache, L. Towards a cognitive neuroscience of consciousness: basic evidence and workspace framework. *Cognition* **79**, 1–37 (2001).
44. Dehaene, S. *et al.* Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neurosci.* **4**, 752–758 (2001).
45. Coles, M. G., Gratton, G. & Donchin, E. Detecting early communication: using measures of movement-related potentials to illuminate human information processing. *Biol. Psychol.* **26**, 69–89 (1988).
46. Dehaene, S. *et al.* Imaging unconscious semantic priming. *Nature* **395**, 597–600 (1998).
47. Eimer, M. & Schlaghecken, F. Response facilitation and inhibition in subliminal priming. *Biol. Psychol.* **64**, 7–26 (2003).

48. Naccache, L. & Dehaene, S. The priming method: imaging unconscious repetition priming reveals an abstract representation of number in the parietal lobes. *Cereb. Cortex* **11**, 966–974 (2001).
49. Dehaene, S. *et al.* Letter binding and invariant recognition of masked words. *Psychol. Sci.* **15**, 307–313 (2004).
50. Deacon, D., Hewitt, S., Yang, C. & Nagata, M. Event-related potential indices of semantic priming using masked and unmasked words: evidence that the N400 does not reflect a post-lexical process. *Cogn. Brain Res.* **9**, 137–146 (2000).
51. Stenberg, G., Lindgren, M., Johansson, M., Olsson, A. & Rosen, I. Semantic processing without conscious identification: evidence from event-related potentials. *J. Exp. Psychol. Learn. Mem. Cogn.* **25**, 973–1004 (2000).
52. Kiefer, M. & Spitzer, M. Time course of conscious and unconscious semantic brain activation. *Neuroreport* **11**, 2401–2407 (2000).
53. Kiefer, M. The N400 is modulated by unconsciously perceived masked words: further evidence for an automatic spreading activation account of N400 priming effects. *Cogn. Brain Res.* **13**, 27–39 (2002).
54. Kutas, M. & Hillyard, S. A. Reading senseless sentences: brain potentials reflect semantic incongruity. *Science* **207**, 203–205 (1980).
55. Brown, C. & Hagoort, P. The processing nature of the N400: evidence from masked priming. *J. Cogn. Neurosci.* **5**, 34–44 (1993).
56. Ruz, M., Madrid, E., Lupianez, J. & Tudela, P. High density ERP indices of conscious and unconscious semantic priming. *Cogn. Brain Res.* **17**, 719–731 (2003).
57. LeDoux, J. *The Emotional Brain: The Mysterious Underpinnings of Emotional Life* (Simon & Schuster, New York, 1996).
58. Linke, R., De Lima, A. D., Schwegler, H. & Pape, H. C. Direct synaptic connections of axons from superior colliculus with identified thalamo-amygdaloid projection neurons in the rat: possible substrates of a subcortical visual pathway to the amygdala. *J. Comp. Neurol.* **403**, 158–170 (1999).
59. Whalen, P. J. *et al.* Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. *J. Neurosci.* **18**, 411–418 (1998).
60. Morris, J. S., Ohman, A. & Dolan, R. J. Conscious and unconscious emotional learning in the human amygdala. *Nature* **393**, 467–470 (1998).
61. Nomura, M. *et al.* Functional association of the amygdala and ventral prefrontal cortex during cognitive evaluation of facial expressions primed by masked angry faces: an event-related fMRI study. *Neuroimage* **21**, 352–363 (2004).
62. Phillips, M. L. *et al.* Differential neural responses to overt and covert presentations of facial expressions of fear and disgust. *Neuroimage* **21**, 1484–1496 (2004).
63. Morris, J. S., Ohman, A. & Dolan, R. J. A subcortical pathway to the right amygdala mediating ‘unseen’ fear. *Proc. Natl Acad. Sci. USA* **96**, 1680–1685 (1999).
64. Morris, J. S., DeGelder, B., Weiskrantz, L. & Dolan, R. J. Differential extrageniculostriate and amygdala responses to presentation of emotional faces in a cortically blind field. *Brain* **124**, 1241–1252 (2001).
65. Vuilleumier, P. *et al.* Neural response to emotional faces with and without awareness: event-related fMRI in a parietal patient with visual extinction and spatial neglect. *Neuropsychologia* **40**, 2156–2166 (2002).
66. Driver, J. & Vuilleumier, P. Perceptual awareness and its loss in unilateral neglect and extinction. *Cognition* **79**, 39–88 (2001).
67. Pasley, B. N., Mayes, L. C. & Schultz, R. T. Subcortical discrimination of unperceived objects during binocular rivalry. *Neuron* **42**, 163–172 (2004).
68. Williams, L. M. *et al.* Mapping the time course of nonconscious and conscious perception of fear: an integration of central and peripheral measures. *Hum. Brain Mapp.* **21**, 64–74 (2004).
69. Liddell, B. J., Williams, L. M., Rathjen, J., Shevrin, H. & Gordon, E. A temporal dissociation of subliminal versus supraliminal fear perception: an event-related potential study. *J. Cogn. Neurosci.* **16**, 480–486 (2004).
70. Krolak-Salmon, P., Henaff, M. A., Vighetto, A., Bertrand, O. & Mauguiere, F. Early amygdala reaction to fear spreading in occipital, temporal, and frontal cortex: a depth electrode ERP study in human. *Neuron* **42**, 665–676 (2004).
71. Vuilleumier, P., Armony, J. L., Driver, J. & Dolan, R. J. Distinct spatial frequency sensitivities for processing faces and emotional expressions. *Nature Neurosci*. **6**, 624–631 (2003).
72. Pessoa, L., McKenna, M., Gutierrez, E. & Ungerleider, L. G. Neural processing of emotional faces requires attention. *Proc. Natl Acad. Sci. USA* **99**, 11458–11463 (2002).
73. Esteves, F. & Ohman, A. Masking the face: recognition of emotional facial expressions as a function of the parameters of backward masking. *Scand. J. Psychol.* **34**, 1–18 (1993).
74. Broadbent, D. E. *Perception and Communication* (Oxford Univ. Press, London, 1987.
75. Deutsch, J. A. & Deutsch, D. Attention: some theoretical considerations. *Psychol. Rev.* **70**, 51–61 (1963).
76. Treisman, A. M. Strategies and models of selective attention. *Psychol. Rev.* **76**, 282–299 (1969).
77. Dulany, D. E. in *Scientific Approaches to Consciousness* (eds Cohen, J. D. & Schooler, J. W.) 179–212 (Carnegie Mellon Symposia on Cognition, Hillsdale, New Jersey 1997).
78. Di Lollo, V., Enns, J. T. & Rensink, R. A. Competition for consciousness among visual events: the psychophysics of reentrant visual processes. *J. Exp. Psychol. Gen.* **129**, 481–507 (2000).
79. Lamme, V. A. F., Zipser, K. & Spekreijse, H. Masking interrupts figure-ground signals in V1. *J. Cogn. Neurosci.* **14**, 1044–1053 (2002).
80. Rolls, E. T., Tovee, M. J. & Panzeri, S. The neurophysiology of backward visual masking: information analysis. *J. Cogn. Neurosci.* **11**, 300–311 (1999).
81. Macknik, S. L. & Livingstone, M. S. Neuronal correlates of visibility and invisibility in the primate visual system. *Nature Neurosci.* **1**, 144–149 (1998).
82. Marcel, A. J. Conscious and unconscious perception: an approach to the relations between phenomenal experience and perceptual processes. *Cogn. Psychol.* **15**, 283–300 (1983).
83. Marcel, A. J. in *Attention and Performance VIII* (ed. Nickerson, R. S.) 435–457 (Erlbaum, Hillsdale, New Jersey, 1980).
84. Marcel, A. J. Conscious and unconscious perception: experiments on visual masking and word recognition. *Cogn. Psychol.* **15**, 197–237 (1983).
85. Merikle, P. M. & Reingold, E. M. in *Perception Without Awareness: Cognitive, Clinical, and Social Perspectives* (eds Bornstein, R. F. & Pittman, T. S.) 55–80 (Guilford, New York, 1992).
86. Stoerig, P. & Cowey, A. Blindsight in man and monkey. *Brain* **120**, 535–559 (1997).
87. Weiskrantz, L. Roots of blindsight. *Prog. Brain Res.* **144**, 229–241 (2004).
88. Wiens, S. *et al.* Keeping it short: a comparison of methods for brief picture presentation. *Psychol. Sci.* **15**, 282–285 (2004).
89. Abrams, R. L. & Greenwald, A. G. Parts outweigh the whole (word) in unconscious analysis of meaning. *Psychol. Sci.* **11**, 118–124 (2000).
90. Gazaniga, M. S., Ivry, R. B. & Mangun, G. R. *Cognitive Neuroscience: the Biology of the Mind* 2nd Edn (W. W. Norton & Company, New York, 2002).

Competing interests statement

The authors declare no competing financial interests.

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