9

Levels of processing during non-conscious perception: a critical review of visual masking

Sid Kouider and Stanislas Dehaene*

Understanding the extent and limits of non-conscious processing is an important step on the road to a thorough understanding of the cognitive and cerebral correlates of conscious perception. In this article, we present a critical review of research on subliminal perception during masking and other related experimental conditions. Although initially controversial, the possibility that a broad variety of processes can be activated by a non-reportable stimulus is now well established. Behavioural findings of subliminal priming indicate that a masked word or digit can have an influence on perceptual, lexical and semantic levels, while neuroimaging directly visualizes the brain activation that it evokes in several cortical areas. This activation is often attenuated under subliminal presentation conditions compared to consciously reportable conditions, but there are sufficiently many exceptions, in paradigms such as the attentional blink, to indicate that high activation, *per se*, is not a sufficient condition for conscious access to occur. We conclude by arguing that for a stimulus to reach consciousness, two factors are jointly needed: (i) the input stimulus must have enough strength (which can be prevented by masking) and (ii) it must receive top-down attention (which can be prevented by drawing attention to another stimulus or task). This view leads to a distinction between two types of non-conscious processes, which we call subliminal and preconscious. According to us, maintaining this distinction is essential in order to make sense of the growing neuroimaging data on the neural correlates of consciousness.

Keywords: consciousness; subliminal perception; priming; brain imaging; review

9.1 Introduction

To what extent can non-conscious perception affect our behaviours? This issue, one of the most controversial in psychology (e.g. Sidis 1898; Eriksen 1960; Dixon 1971; Holender 1986; Merikle & Daneman 1998), has been predominantly addressed through the use of subliminal stimulation methods, in which a stimulus is presented below the ‘limen’ or threshold for conscious perception. Subliminal perception is inferred when a stimulus is demonstrated to be invisible while still influencing thoughts, feelings, actions, learning or memory.

Construction of a convincing empirical demonstration of subliminal processing has constituted a challenging task. Indeed, this topic has faced some of the most complex problems of experimental psychology, not only technically (e.g. How to present stimuli that are invisible but still processed?), but also methodologically (e.g. How to measure non-conscious influences from a stimulus? How to demonstrate an absence of conscious perception?), theoretically (e.g. Should we trust introspective subjective measures or rather rely on objective measures?) and epistemologically (e.g. Why do so many subliminal perception experiments

*Author and Address for correspondence: Ecole Normale Supérieure, 46 rue d’Ulm, 75005 Paris, France (sid.kouider@ens.fr).

fail to be replicated?). Such difficulties, among others, are the reasons why the topic of perception without awareness has taken so long to achieve respectability.

Nowadays, while the existence of subliminal perception is no longer denied, the controversy has shifted to the depth of processing of invisible stimuli. While it is largely accepted that lower levels of processing (e.g. motor reflexes, sensory analysis) do not necessitate perceptual awareness, the existence of non-conscious computations at higher levels (e.g. semantic or inferential processing) remains debated. The claim of subliminal semantic activation has been cyclically acclaimed or rejected (Eriksen 1960; Dixon 1971; Holender 1986; Greenwald 1992).

In parallel, conflicting theoretical positions have been adopted regarding the differences between conscious and non-conscious processing. Some authors continue to argue in favour of the classical notion that mental representations and consciousness go hand in hand, thus leaving little room for the possibility of non-conscious levels of representation (Dulany 1997; Perruchet & Vinter 2002; Holender & Duscherer 2004). According to this 'mentalistic' perspective, non-conscious processes exist, but are non-representational and thus, by definition, cannot involve semantic representations. Conversely, several authors have argued that all information processing can proceed without conscious experience, at least in principle, and that consciousness may therefore be of an altogether different, perhaps non-computational nature (Chalmers 1996). This perspective meshes well with the hypothesis that non-conscious processes can attain the highest levels of representation, a position advocated for instance by Marcel (1983, p. 238): 'non-conscious perceptual processes automatically redescribe sensory data into every representational form and to the highest levels of description available to the organism'.

In between these two extreme positions, an intermediate and widely held view proposes that a stimulus first involves a non-conscious analysis associated with the lower levels of processing, and then a second conscious stage associated with higher levels of representations. According to this view, non-conscious processes exist but are limited in depth. To follow Greenwald's (1992) terminology, non-conscious processes should be considered as 'dumb' rather than 'smart' in comparison to conscious processes. The two-stage position suggests a rigid limit between non-conscious and conscious levels of processing, the former involving an automatic activation of information while the latter are associated with strategic processes under volitional control (Posner & Snyder 1975; Schneider & Shiffrin 1977). According to this position, it is strictly an empirical problem to determine whether semantic-level processes fall below or above the hypothetical limit of subliminal processing depth.

Nowadays, two-stage accounts have evolved into a more dynamical view, which considers the notion of 'conscious access' as a central concept. In the global neuronal workspace framework (Dehaene & Naccache 2001; Dehaene & Changeux 2004), which extends Baars' (1988) cognitive theory of consciousness, the human brain is viewed as a collection of specialized processors that mostly operate non-consciously, but whose content can be consciously accessed whenever they are linked to a global, metastable assembly involving distant prefrontal and parietal neurons with long-range axons. According to this view, there is no fixed limit between conscious and non-conscious processing but, rather, subjects at any given moment can attend to one of the several (though not necessarily all) levels of representation and bring the corresponding information into consciousness.

With these conflicting theories in mind, the present article provides an overview of past and current researches on non-conscious perception. We initially focus on subliminal masking paradigms, then extend our review to discuss other forms of non-conscious perception such as those induced by inattention. In §9, we outline a theoretical framework that may account for the differences between these two types of non-conscious perception.

9.2 A historical perspective on subliminal perception

It is primarily via the demonstration of semantic activation from invisible stimuli that researchers have tried to define the limits of non-conscious perception. This approach consists of testing the hypothesis that the meaning of a stimulus is extracted while the subject cannot consciously identify it or even detect its presence. Stimuli are usually made subliminal by the joint use of brief presentations and masking techniques. A direct measure such as identification, discrimination or detection is used to show null sensitivity on the masked stimulus. An indirect measure is used to show that, nevertheless, this stimulus influences behaviour. The most common indirect measure is masked priming, in which a highly visible target stimulus is processed more efficiently when preceded by a related and heavily masked prime than by an unrelated prime. Figure 9.1 provides examples of established subliminal priming methods in the domain of visual words, faces and speech perception.

As we review below, characterization of the processes involved in subliminal masked priming has remained controversial. The development of this field of research can be divided into five periods.

9.3 Period 1: On demonstrating perception without awareness

The study of non-conscious perception appeared simultaneously with the emergence of psychology and its separation from philosophy during the nineteenth century. Several scientists evoked the possibility that mental life extended beyond conscious processing. Johann Herbart (1776–1841) introduced the word 'subliminal' to describe ideas that compete below the limen for consciousness. According to Hermann Von Helmholtz (1821–1894), visual perception mostly resulted from the operation of non-conscious inferential processes. On the other hand, under the influence of Wilhelm Wundt during the second part of the nineteenth century, introspective reports were considered as a scientifically valid measure for studying mental states. Contrary to Herbart and Von Helmholtz's perspective, this position considered that all mental states are potentially accessible to conscious report. In spite of its limits, this played a helpful role in developing methods for measuring aspects of conscious experience.

The introspective approach was used in a landmark paper by Pierce & Jastrow (1884). In their study, subjects (Peirce and Jastrow themselves) received a first pressure on a finger and then a second slightly stronger or slightly weaker one. They judged which one seemed the more intense by rating their estimation on a 0–3 scale, where '0 denoted absence of any preference for one answer over its opposite, so that it seemed nonsensical to answer at all' (Pierce & Jastrow 1880, p. 78). They also performed a forced-choice discrimination task between the two possibilities. Peirce and Jastrow found that under subjective estimations of null awareness they could still discriminate the two alternatives well above the 50% criterion for chance performance, suggesting the existence of non-conscious influences on behaviour. Along the same lines, Sidis (1898) presented cards containing alphanumeric characters at a distance, such that subjects reported they barely saw a dim, blurred spot. Yet, subjects were better than chance not only at discriminating whether the stimulus was a digit or a letter in a forced-choice task, but also in guessing its identity. Stroh *et al*. (1908) extended these findings to the auditory modality, by showing that subjects were better than chance at guessing whispered letter names under conditions where they reported not hearing any sound.

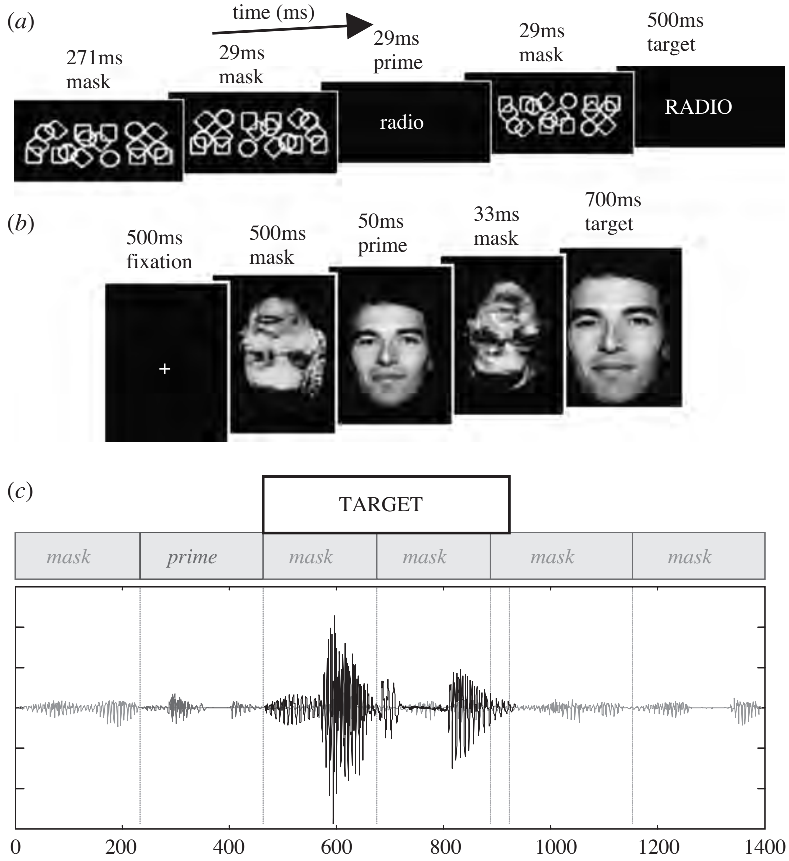

Fig. 9.1 Schematic description of three masked priming methods for which objective direct measures have demonstrated prime invisibility or inaudibility. (*a*) Visual word repetition priming across case (Dehaene *et al*. 2001). (*b*) Repetition priming for faces (Kouider *et al*. submitted). Masks are made of overlaid and reversed faces and the prime size is reduced by 80% when compared with the target. (*c*) Repetition priming for spoken words (Kouider & Dupoux 2005). Masks made from backward speech and the prime are attenuated (−15 dB) and time compressed to 35% of their original duration.

These pioneering studies were followed by a few other similar demonstrations during the first half of the twentieth century (see Adams 1957, for a review). Claims of subliminal influences on behaviour became especially popular during the mid-1950s, when a few advertising companies initiated the fallacious belief that it can have long-term effects on consumer's choice (see Pratkanis 1992, for a review).

The end of this first period can be attributed to Eriksen's (1960) criticism of the scientific literature on subliminal perception. Basically, he argued against the use of introspection as a valid measure of awareness. Subjective measures might reflect response bias rather than the genuine subjective experience of the observer owing to the so-called 'underconfidence phenomenon' (Bjorkman *et al*. 1993). Subjects may partially or even fully see the stimulus, yet claim that they have not seen it because they need a higher level of certainty. This confidence criterion depends on the expectations that the experimenter is imposing on the subject. Furthermore, experimenters might have a tendency to underestimate awareness as a function of the hypothesis at hand (S. Kouider 2002, unpublished doctoral thesis). Eriksen further argued that the objective threshold for consciousness should be defined as a situation where forced-choice discrimination is at chance. According to this new operational definition of awareness, the discrimination tasks previously used as indirect measures thought to prove non-conscious influences now became the direct measure thought to index awareness of the stimulus. Of course, such a new definition of awareness left researchers with the difficult problem of inventing new indirect measures of subliminal processing.

9.4 Period 2: On demonstrating subliminal semantic influences

The second phase of research started with the use of semantic influences as an indirect measure of perception, primarily with the seminal work of Marcel (1974, 1980, 1983). Marcel used the method of visual masking to render stimuli invisible and provided two types of experimental evidence for non-conscious semantic processing. First, he argued that under presentation conditions, where subjects could not detect the presence or absence of a masked word, this stimulus nevertheless produced semantic biases. Subsequently to a masked word (e.g. 'salt'), subjects were presented with two alternatives, one which was semantically related (e.g. 'pepper') and the other unrelated (e.g. 'lotus'). Subjects preferred to choose the former alternative, suggesting the presence of semantic influences from invisible words. Similarly, Allport (1977) found that when subjects failed to correctly recognize a masked word, many of their errors were semantically related to the masked word. Second, Marcel (1980, 1983) provided evidence that semantic priming—the facilitation of the processing of a target word by another semantically related 'prime' word—remained present under heavy masking conditions that render the primes subliminal.

At that time, mainly owing to Eriksen's (1960) critical review, the scientific community was extremely sceptical regarding the existence of subliminal perception, not to mention the existence of subliminal activation at the semantic level. Yet, by the early 1980s, several other authors started to report similar results. Semantic priming from masked stimuli was replicated not only with words (Fowler *et al*. 1981; Balota 1983) but also with pictures (McCauley *et al*. 1980; Carr *et al*. 1982). However, as we will see below, all these studies without exception suffered from serious methodological flaws.

9.5 Period 3: The hunt for artefacts

Holender (1986) published a detailed and intensively argued criticism of masked priming studies. The article stressed the need to carefully control the methods used to argue for the existence of subliminal semantic processing. He mainly argued that the issue of awareness was not properly addressed and was largely underestimated in past studies. After Holender's article, scepticism regarding the existence of subliminal semantic activation became the rule. It was also motivated by several other studies that pointed to serious methodological flaws in demonstrations of subliminal semantic influences. We summarize these different problems below.

(a) The need for methodological controls

First, the semantic biases in the choice of alternatives observed by Marcel (1983) could have been due to the absence of counterbalancing for the experimental and control word lists.

Subjects tend to report that the prime is pepper rather than lotus not only if the prime is salt but also when there is no prime at all (Fowler *et al*. 1981)! Along the same lines, although it is true that subjects can sometimes erroneously report a semantic associate of a masked word (Allport 1977), this need not happen more often than what would be expected from chance (Ellis & Marshall 1978; Williams & Parkin 1980; however, see Gaillard *et al*. 2006*a* for a clear case of semantic influence on verbal reports).

Second, Merikle (1982) used signal detection theory to show that the small sample of items frequently used to evaluate the threshold for conscious perception (not more than 20 trials) is not statistically reliable. Under statistically valid conditions, Marcel's experiments could no longer be replicated (Cheesman & Merikle 1984).

Third, prime visibility was largely underestimated. Indeed, the first studies of Marcel and others used tachistoscopic presentations for which the display parameters were fixed in a preliminary phase, before the proper indirect measure (e.g. priming) started. A method of descending threshold was used, consisting of decreasing the delay between the prime and a brief backward mask until subjects performed at a chance level on the direct measure. These parameters were then considered as subliminal during the subsequent indirect measure. However, subjects were differentially adapted to darkness during the two phases. During the threshold definition, only brief (e.g. 50 ms) primes and backward masks were presented, while subjects also received a long (e.g. 800 ms) and visible target during the indirect measure. This had the consequence of increasing dark adaptation, and thus increasing prime identification from 0 to 70% as shown by Purcell *et al*. (1983). Moreover, they found that when luminance is controlled carefully, semantic priming fully correlated with prime visibility. Similarly, Nolan & Caramazza (1982) asked subjects to perform the direct and indirect measures on the same trials and also found that semantic effects correlated with performance on the prime detection task. These studies suggest that stimulus visibility should not be established before but, rather, during or after the indirect measure and, furthermore, that the same display conditions should be used.

Fourth, Bernstein *et al*. (1989) found that the semantic context can modulate prime visibility. This finding is based on the fact that unmasked semantic priming reflects not only classical or proactive priming, i.e. semantic activation from the prime representation to the target representation, but also backward or retroactive priming, i.e. semantic activation from the target to the prime (see Neely 1991, for a review). Evidence for retroactive priming comes from studies showing that priming occurs for semantically related pairs for which an association exists from the target to the prime, but not from the prime to the target (Koriat 1981; Chwilla *et al*. 1998). Since semantically related target stimuli can increase, retrospectively, the identification of masked primes (Bernstein *et al*. 1989), the absence of any target stimuli during threshold definition procedures in the experiments of Marcel and others probably underestimated prime visibility. In fact, many other studies have found that semantic priming, prime reportability and retroactive priming are interdependent (Briand *et al*. 1988; Dark 1988; Dark & Benson 1991; Van Voorhis & Dark 1995). Semantic relatedness increases, retrospectively, the reportability of the prime, which in turns leads to semantic priming. Accordingly, in these studies, masked semantic priming occurred only when subjects were able to identify the masked primes: in the absence of retroactive priming, prime reportability decreased and masked semantic priming vanished. It is of note, however, that Durante & Hirshman (1994) found the reverse correlation: proactive semantic priming decreased when retroactive priming increased. It remains unclear why the results of this study are discordant with others.

(b) On the status of qualitative dissociations

According to some authors (e.g. Dixon 1971, 1981), another way of demonstrating subliminal influences is to show that subliminal and conscious perception afford qualitatively different processes. Marcel (1980) used this process-dissociation logic and reported that context effects on semantic priming for homographs depend on prime awareness. He presented subject with word triplets corresponding to the context/prime/target presentation sequence and for which the first and last words were either congruent (hand/palm/wrist) or incongruent (tree/palm/wrist). If the prime was clearly visible, he found facilitation for congruent trials and interference for incongruent trials. By contrast, Marcel reported that no context bias occurs when the prime is not visible, leading to facilitation for both congruent and incongruent trials. These results were considered as evidence for a dissociation between non-conscious and conscious processes.

A similar dissociation logic was used by Merikle *et al*. with the goal of avoiding exceeding reliance on objective measures of consciousness. While all the above studies used objective measures of awareness, in accord with Eriksen's (1960) criticism, Cheesman & Merikle (1986) privileged subjective measures, as in the earliest research on subliminal perception. Their main argument against the use of objective measures was that they can lead to above-chance performance due to non-conscious influences, thus making the definition of an objective threshold an extremely conservative measure of conscious access. To address this problem, Cheesman & Merikle (1986), using a process-dissociation logic, argued that the definition of a subjective limit between conscious and subliminal perception would be validated if they gave rise to qualitatively different forms of processing. They used a priming version of the Stroop task in which, compared with a neutral condition, subjects are slower to respond to a target colour patch if it is preceded by a prime word denoting a different colour (e.g. the word 'blue' preceding a red patch) and faster if the prime and target denote the same colour. In accord with past studies (Taylor 1977), they found that if the proportion of congruent trials increased (for instance, from 25 to 75%), then facilitation and interference increased. Indeed, in this case, the prime is the same as the target in most cases, and subjects can use this information to anticipate the identity of the target during the appearance of the prime. However, when prime duration was decreased from 250 ms to a shorter duration at which subjects denied perceiving the primes, priming was still found and, importantly, it ceased to be affected by predictive strategies. According to Cheesman & Merikle, this dissociation demonstrates that subjects are genuinely unaware of the primes with brief prime durations. In later work, Merikle and colleagues (Merikle *et al*. 1995; Merikle & Joordens 1997) showed that under some conditions, predictive strategies could even reverse the Stroop effect, leading to faster reaction times for incongruent primes. Here too, this was the case only for rather long prime duration (e.g. 150 ms), but not for shorter durations (e.g. 50 ms).

However, as outlined by Holender (1986), the problem with this logic is that qualitative dissociations need not reflect a dissociation between conscious and subliminal processing. One must ensure that they do not occur merely owing to other confounded differences, for instance because the SOA is much shorter in the subliminal case, as was the case in the studies of both Marcel (1980) and Cheesman & Merikle (1986). As argued by S. Kouider (2002, unpublished doctoral thesis), it is well known from the unmasked priming literature that even clearly visible primes produce qualitative differences as a function of the prime-target delay. For instance, Swinney (1979) has shown that context effects on semantic priming of homographs depend on the time course of prime processing, not prime visibility *per se*. Thus, rather than being due to visibility, these qualitative dissociations could be due to differences in the time or resources needed to strategically process the prime. In the case of Merikle and colleagues' studies, in which subjects are explicitly asked to try to identify the primes before responding to the target, primes that are difficult to identify would require attentional resources that otherwise could be used for predictive strategies. As recently shown by Kouider & Dupoux (2004), predictive strategies can no longer be used with short prime duration owing to the difficulty in identifying the primes, not because the primes are rendered subliminal. In fact, when the primes are not just difficult to perceive but genuinely invisible, then Stroop priming disappears as well (Tzelgov *et al*. 1997; Kouider & Dupoux 2004).

The process-dissociation method was later extended through the use of inclusion–exclusion tasks (Debner & Jacoby 1994; Merikle *et al*. 1995; Merikle & Joordens 1997). In a typical exclusion task, subjects have to complete a target fragment (e.g. 'YE____') with any word that comes to mind, except the prime (e.g. 'yellow'). Debner & Jacoby (1994) have shown that exclusion is no longer possible when primes are masked and presented for a brief duration (50 ms). Instead, subjects frequently complete the fragment with the prime word itself. This failure to exclude masked primes while being influenced by them suggests a process-dissociation between conscious and subliminal perception (Debner & Jacoby 1994; Merikle *et al*. 2001). Yet, one should be cautious before making this conclusion because the results may be imputed to partial conscious perception. Indeed, it is possible that subjects were only aware of some letters of the prime such as 'llow' and then completed the fragment 'YE___' onto 'yellow' while faithfully complying with the instruction to avoid reporting a seen word. In fact, recent investigations have shown that when an orthographic baseline (e.g. 'billow') is used, then there is a similar probability to complete 'YE___' onto 'yellow' (Hutchison *et al*. 2004). Although the authors used this result to argue that non-conscious influences occur at the orthographic level with this task, it may as well mean that it results from partial conscious perception of the primes. Further studies will be needed to demonstrate that perceptual influences on the exclusion task are of a genuinely subliminal nature.

9.6 Period 4: Methodological improvements and recovery from scepticism

In the late 1980s, subliminal perception was no longer an isolated domain in the study of non-conscious processing, given the emergence of great interest in implicit memory and implicit learning at that time (e.g. Kihlstrom 1987; Schacter 1987). While these topics also suffered from similar difficulties, especially regarding the assessment of awareness (Shanks & St. John 1994), they largely contributed to reinstate the study of non-conscious processing from a cognitive rather than a psychoanalytic perspective (Greenwald 1992). Furthermore, despite Holender's massive criticism, or perhaps under its admonition, new and stronger paradigms of subliminal priming emerged.

(a) Insights from psycholinguistics

In the hands of Forster and Humphreys, masked priming became a powerful method to study visual word recognition (Evett & Humphreys 1981; Forster & Davis 1984). These authors did not focus on semantic activation, but rather on lexical processing. They used masked priming with the assumption that a minimal perceptual awareness of the word stimulus allows study of its automatic, strategy-free processing (e.g. Posner & Snyder 1975). They primarily relied on orthographic and repetition priming, not semantic priming, to address several issues that are more directly relevant to psycholinguistics than to subliminal perception (e.g. Is masked repetition priming affected by word frequency? Is priming lexical or sub-lexical? Can it occur at a phonological level? Do orthographic neighbours inhibit or facilitate word recognition? And so forth). We first describe the paradigm introduced by Humphreys and colleagues, as well as its implications, and then turn to the one introduced by Forster and colleagues.

(i) Humphreys' masked priming method

The masked priming method of Humphreys and colleagues (Evett & Humphreys 1981; Humphreys *et al*. 1982, 1988) comprised the presentation of four events: a forward mask (i.e. random letter fragments), the prime in lower case, the target in upper case and then a backward mask. All these events were presented for a very short duration (e.g. 25–50 ms) such that the prime could not be identified, while the target could be correctly identified on about half of the trials. The measure here was whether perceptual identification of the target improved when preceded by a related prime. Yet, since the presentation parameters were estimated for each subject during a preceding threshold definition session, this methodology did not fully escape Holender's criticism (see above).

The research mostly investigated whether masked written words can contact the phonological level of representations. Although the first answer provided by Evett & Humphreys (1981) was negative, later studies found that, under some conditions, phonological effects can be found in addition to orthographic priming (e.g. Humphreys *et al*. 1982). Perfetti and colleagues (Perfetti *et al*. 1988; Perfetti & Bell 1991; Berent & Perfetti 1995) later developed a backward priming variant, in which the prime follows, rather than precedes, the target and in which robust phonological priming effect can be found.

Nonetheless, this methodology has been less popular than the one introduced by Forster and colleagues (described below) for two main reasons. First, given that not only the prime but also the target is presented very briefly in this paradigm, subjects sometimes report the prime instead of the target and tend to mix their letters during identification, suggesting conscious access to at least partial information regarding the primes (Brysbaert & Praet 1992; Perry & Ziegler 2002). As shown by Perry & Ziegler (2002), phonological effects in this paradigm can result from partial awareness rather than subliminal processing. Second, as shown by Davis & Forster (1994), priming in this paradigm might be entirely due to differences in terms of target legibility, which results from a physical fusion between the prime and target stimuli and is higher for orthographically related words. Importantly, when the target duration is relatively long, as in the Forster and Davis method, low-level physical integration disappears (Davis & Forster 1994).

(ii) Forster and Davis' masked priming method

The masked priming method by Forster and colleagues (Forster & Davis 1984, 1991) is simpler because it has no backward mask, the target being itself considered a very strong mask. The display typically consists of a 500 ms forward mask (e.g. ######), a lower-case prime for a brief duration (60 ms or below) and an upper-case target for another 700 ms. Priming with this method has been found not only at the orthographic level (Forster *et al*. 1987), but also at the level of morphology (easier processing of cars-CAR compared with card-CAR; Forster *et al*. 1987; Rastle *et al*. 2000), phonology (easier processing of klip-CLIP compared with plip-CLIP; Ferrand & Grainger 1992, 1993; Lukatela *et al*. 1998), cross-modal repetitions (visual-to-auditory priming; Kouider & Dupoux 2001) and, importantly, for semantically related words (Sereno 1991; Perea & Gotor 1997; Rastle *et al*. 2000) and translations (Gollan *et al*. 1997; Grainger & Frenck-Mestre 1998).

Nevertheless, the problem with all these studies is that most of them do not provide an index of prime awareness, making it difficult to assess whether the primes were visible or not. Kouider & Dupoux (2001) assessed prime awareness in this method across several prime durations and showed that a prime can be considered as genuinely invisible only if its duration is below 50 ms. Although orthographic and morphological priming are found at such durations, priming usually vanishes below 50 ms for semantic (Perea & Gotor 1997; Rastle *et al*. 2000) and phonological relations (Ferrand & Grainger 1992, 1993). In a recent auditory version of this masked priming procedure (figure 9.1*c*), Kouider & Dupoux (2005) found word repetition priming in the absence of prime audibility, while semantic priming was found only for audible primes. The results seem stronger for translation priming (Gollan *et al*. 1997; Grainger & Frenck-Mestre 1998; especially when the prime is in the first language and the target in the second language; Jiang 1999), possibly because translation equivalents are more strongly associated at the semantic level. Yet, a clear demonstration that primes were genuinely subliminal has not been provided.

Whether phonological priming occurs in masked priming remains a debated issue in psycholinguistics (Rastle & Bryasbert 2006), and it is unfortunate that the possibility that prime awareness might account for some of the conflicting results is not taken seriously. Of course, it might also be that phonological priming requires a longer prime duration because it requires longer processing regardless of conscious perception (Ferrand & Grainger 1992).

In a recent functional magnetic resonance imaging (fMRI) study, we studied the behavioural and neural distinction between priming from visible and priming from invisible stimuli (Kouider *et al*. in press). Moreover, we compared orthographic and phonological priming in a semantic decision task while the prime duration was kept constant (i.e. 43 ms). We found orthographic priming for both visible and invisible primes. By contrast, we found phonological priming only for visible primes. At the neural level, only for visible primes we observed phonological repetition enhancement in the left inferior frontal cortex and anterior insula, two regions usually associated with phonological and articulatory processing. This study thus adds to the evidence that visibility may be needed for the emergence of phonological priming. Yet, it does not mean that subliminal phonological effects cannot occur under conditions that emphasize phonological processing of the prime. Rather, we prefer to argue that these effects are very fragile and that they increase drastically during conscious perception. It is possible that subliminal phonological priming is more reliable when the task explicitly requires phonological recoding from orthographic inputs, such as in the naming task (Shen & Forster 1999), under special masking conditions that allow for longer prime durations while keeping the prime invisible (Grainger *et al*. 2003), or when using an orthography with a high degree of transparency, such as the Kana Japanese syllabary (Nakamura *et al*. 2006).

In summary, from the psycholinguistic literature on masked priming, one can infer that some forms of orthographic and lexical processing clearly occur under subliminal conditions. By contrast, phonological and semantic masked priming effects appear rather fragile and sometimes difficult to replicate, especially when using short prime durations to prevent conscious perception.

(b) Semantic congruity evoked by subliminal primes

By the mid-1990s, a renewal of interest for subliminal semantic activation became apparent in the scientific community. Two articles claiming that genuinely invisible primes could influence processing at the semantic level appeared in *Science* and *Nature* (Greenwald *et al*. 1996; Dehaene *et al*. 1998).

Greenwald *et al*. (1996; see also Draine & Greenwald 1998) proposed two methodological improvements in order to obtain robust subliminal priming. The first one was to use a response-window procedure that forced subjects to respond extremely quickly to the target stimulus. This response-window procedure was thought to improve the sensitivity of the indirect measure because priming is short-lived under subliminal conditions. The second improvement was statistical. Instead of demonstrating chance performance on objective measures of awareness for all subjects, they proposed to use a regression method that uses the visibility measure as a predictor of the priming effect. The intercept of the regression was then used to evaluate the amount of priming for null performance on prime visibility (Greenwald *et al*. 1995). The main advantage of this method is that subliminal priming can be evaluated even when some of the subjects show better-than-chance performance in the visibility test. In a typical experiment performed by Greenwald and colleagues, subjects classified target words as pleasant (e.g. 'happy') or unpleasant (e.g. 'vomit') and these words were preceded by a congruent prime (i.e. a word from the same category, such as 'love' preceding the target happy) or an incongruent prime (vomit preceding happy). Subjects were faster for congruent trials when compared with incongruent trials, even under conditions where they could not perform the affective evaluation on the prime.

As discovered later by Klinger *et al*. (2000), the priming effect found by Greenwald and colleagues depends on whether the prime and target are congruent or incongruent, not on whether they are semantically (or affectively) related or unrelated. It means that subliminal priming results from a competition between the prime and target categories and thus reflects categorical congruity rather than semantic priming in the classical sense of spreading activation theories (Collins & Loftus 1975; McNamara 1992, 1994).

A similar demonstration of a subliminal congruity effect was made by Dehaene *et al*. (1998) who further proposed that subliminal processing depends on strategic rather than automatic processing. According to them, subliminal semantic processing can be found under conditions where the task performed on the target stimuli is strategically applied to the prime. In order to provide evidence for this possibility, they asked subjects to classify numbers, presented in spelled-out or Arabic form, as smaller or larger than the reference number 5. These numbers were preceded by subliminal number primes that were also smaller or larger than 5. Subjects were faster when both the prime and the target belonged to the same category than when they belonged to opposite categories. Moreover, this study was the first one to use brain imaging (fMRI and event-related potentials (ERPs)) to show that subliminal stimuli can elicit not only a behavioural influence, but also a detectable neural activity in the motor cortex due to response competition (we return to this aspect below).

In summary, all these studies suggested, by the end of the 1990s, that priming from genuinely subliminal stimuli is a real phenomenon that can be studied without suffering from all the methodological criticisms made earlier on the underestimation of prime visibility. However, as we will see in §7, which covers contemporary research, although the existence of subliminal perception is largely acknowledged today, some researchers still debate the semantic interpretation of these experiments.

9.7 Period 5: Outline and status of contemporary research

(a) Semantic versus alternative interpretations of congruity effects

Although the evidence for subliminal semantic priming by Greenwald *et al*. (1996) and Dehaene *et al*. (1998) renewed the interest in non-conscious perception, it also did not take long before non-semantic interpretations were proposed (Abrams & Greenwald 2000; Damian 2001). Basically, it was argued that congruity effects reflect conflicting stimulus–response associations rather than competition between semantic categories. This assumption is based on the direct motor specification hypothesis according to which an adequate response is unconsciously associated with a stimulus without having to be mediated by the semantic level (Neumann & Klotz 1994). Research on sensorimotor processing has shown that subliminal primes (e.g. ») can elicit competition with an opposite target (e.g. «; Neumann & Klotz 1994; Eimer & Schlaghecken 1998). In this case, motor congruity effects from a subliminal prime result from a learned stimulus–response mapping because the prime stimulus was previously presented as a target. In both the studies of Greenwald *et al*. (1996) and Dehaene *et al*. (1998), owing to the use of a restricted set of items, the masked primes were also used as target stimuli. For instance, Dehaene *et al*. (1998) used only the numbers 1, 4, 6 and 9 that appeared repeatedly both as primes and targets during the experiment. Thus, it could be argued that the observed subliminal congruity effects did not imply semantic mediation.

Damian (2001) claimed that subliminal priming occurred only for practised primes. Novel primes (i.e. primes that had not received a prior response) did not give rise to any effect. At the same time and independently, Abrams & Greenwald (2000) also showed that their own past work (e.g. Greenwald *et al*. 1996) should be totally reinterpreted as implying no semantic mediation. They showed that subliminal priming not only did not generalize to novel words, but in fact resulted from a learned association between fragments of the word primes and the response. For instance, in an affective evaluation task where the target words 'smut' and 'bile' were repeatedly classified as unpleasant, subliminal presentation of the prime word 'smile' (made of smut and bile) initiated an unpleasant response. These results suggested that in Greenwald's original paradigm, subliminal words were analysed only in terms of their orthographic constituents, not as a whole and thus probably not up to the semantic level. Nevertheless, Abrams *et al*. (2002) also disconfirmed the motor specification hypothesis. They found that subliminal priming for words results from the learned mapping between stimulus fragments and a semantic category rather than to a motor response. Abrams *et al*. (2002) showed that the valence (i.e. pleasant versus non-pleasant) activated by the primes followed a reversal of key assignment. For instance, if subjects had to categorize a pleasant word such as smile with the left hand, and were then told to use the right hand for pleasant words, the subliminal prime smile would now facilitate right-hand responses. This result suggests that subliminal priming for words goes beyond the level of motor processing *per se*. Yet, priming for words was still restricted to practised items and, thus, provides little support for semantic interpretations.

Dehaene *et al*.'s (1998) claim of subliminal semantic priming for numbers turned out to resist better under scrutiny. Naccache & Dehaene (2001*a*) found that subliminal priming extended to novel number stimuli. As in their previous work, they found priming for practised primes (the numbers 1, 4, 6 and 9), but they also found priming for unpractised primes (2, 3, 7 and 8), although the former led to a stronger effect. These results suggested that subliminal priming for numbers was mediated, at least in part, by semantic representations. Several studies using numbers have since found that subliminal priming can extend to novel stimuli, suggesting that it can be mediated by semantic codes (Greenwald *et al*. 2003; Reynvoet *et al*. 2005).

However, Kunde *et al*. (2003) proposed an intermediate interpretation to account for the restriction to number stimuli. According to Kunde *et al*. (2003), subjects prepare action triggers in order to quickly associate each possible experimental stimulus with its appropriate response in minimal time. The setting of action triggers happens during the instructions or practice phase and depends on the stimulus set size, as it is efficient only for narrow categories (e.g. Arabic numbers from 1 to 9). According to this account, even novel primes (e.g. 2 and 3) may prime the appropriate response not because the meaning of these primes has been extracted, but rather because the adequate response to these stimuli was consciously prepared in advance (see Forster 2004, for a similar account). Kunde *et al*. (2003) provided evidence for this account by showing in several experiments that priming in numerical judgment paradigms (Dehaene *et al*. 1998) does not extend to novel primes that fall outside the expected numerical target range, or when primes occur in an unexpected format (Arabic instead of verbal or vice versa). Thus, priming was found only for the set of stimuli that subjects expected to see as targets, suggesting that the subliminal primes did not receive a semantic analysis.

As of today, the issue of whether subliminal priming reflects action-triggers or genuine semantic activation from subliminal primes remains intensely debated (Van Opstal *et al*. 2005*a*,*b*; Kunde *et al*. 2005). Van Opstal and colleagues argue that considerable evidence cannot be accounted for by the action-trigger model and suggests that, at least with certain types of masking procedures, genuine subliminal semantic priming occurs (e.g. Reynvoet *et al*. 2002, 2005; Reynvoet & Brysbaert 2004). Kunde and colleagues argue that such effects result from inefficient masking of the primes, leading to the conditions of conscious rather than subliminal perception.

It is important, however, to note that at least one study on congruity effects induced by subliminal primes does not appear to suffer from these criticisms and provides strong evidence for subliminal semantic processing. In this study, Dell'Acqua & Grainger (1999) asked subjects to categorize pictures of objects as referring to living things or artefacts and found a prime-target congruity effect even under conditions where the primes never appeared as targets during the experiment (ruling out stimulus–response interpretations) and were part of a large set of 252 objects (ruling out action-triggers interpretations). Although it is rather isolated, this study represents a clear-cut demonstration of congruity effects at the semantic level. One possibility is that pictures have a more direct access to meaning representations and thus lead to stronger semantic effects under subliminal conditions.

(b) Brain imaging and levels of representation for invisible stimuli

Another approach to the study of subliminal perception is to use brain activity rather than behavioural influences as an indirect measure of subliminal influences. This logic consists in finding whether cerebral regions or electrophysiological components associated with a given level of representations (i.e. motor, orthographic, semantic, etc.) are activated by subliminal stimuli. We first describe studies using ERPs, then turn to research using fMRI and intracranial recordings (see figure 9.2 for illustrations).

(i) Evidence from event-related potentials

Several studies have used ERPs in conjunction with priming paradigms induced by congruity effects. ERP correlates of priming are revealed through the use of the 'lateralized readiness potential' (LRP), an index of left-and right-hand movement preparation, which is computed by comparing the differential activity between the right and left hemispheres (Coles *et al*. 1988).

Congruent trials induce a greater LRP because both the prime and the target favour the same response side. By contrast, incongruent trials induce a decrease in the LRP, and the difference between the two types of LRP can be used as an electrophysiological index of priming. Dehaene *et al*. (1998) and Eimer & Schlaghecken (1998), using numbers and arrows, respectively, have shown that the LRP index can be modulated by priming from invisible stimuli. Moreover, the temporal resolution of the ERPs allowed to see that the subliminal prime first induced a LRP, then modulated the LRP induced by the target depending on whether it was congruent or incongruent (see also Leuthold & Kopp 1998; Jaskowski *et al*. 2002).

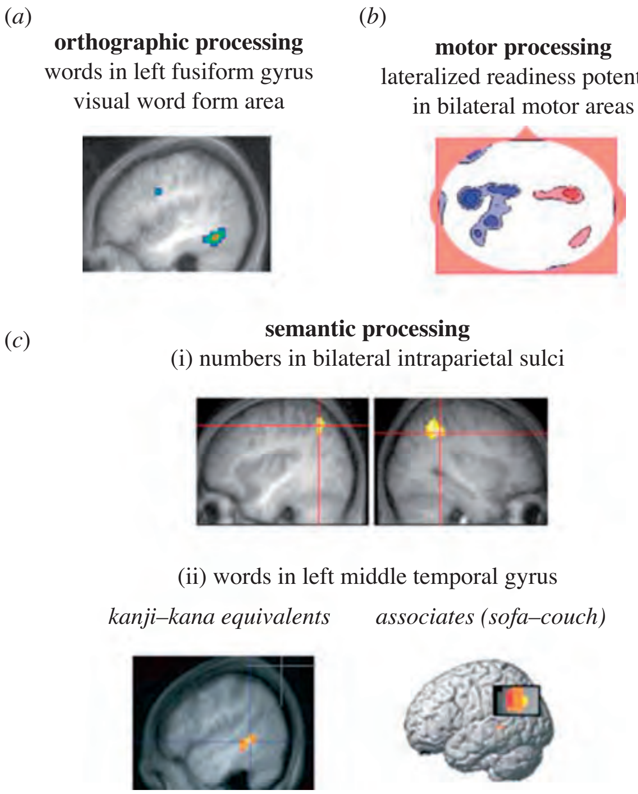

Fig. 9.2 Examples of brain imaging studies showing subliminal processing at orthographic, motor and semantic levels of processing for words and numbers. (*a*) The left occipitotemporal region is sensitive to repetition priming from masked words, independently of the case in which words are presented, and with a sensitivity to orthographic similarity (Dehaene *et al*. 2001; Devlin *et al*. 2004). (*b*) Subliminal digits can prime a motor response during a number comparison task, as revealed by the LRP measured with ERPs (Dehaene *et al*. 1998). (*c*, i) The bilateral intraparietal sulcus is sensitive to subliminal repetition priming of numbers, independently of whether they are presented as words or as digits (Naccache & Dehaene 2001*b*); other experiments indicate a dependency on numerical distance, suggesting that this region may encode the semantic dimension of numerical magnitude. (*c*, ii) The left middle temporal gyrus (with blown-up inset shown) is sensitive to priming by synonym words (Devlin *et al*. 2004) as well as priming by repetition of words presented in the Kanji and Kana Japanese writing systems (Nakamura *et al*. 2005), suggesting that this region encodes words at a semantic level.

Surprisingly, Eimer & Schlaghecken (1998) also discovered that this congruity effect can be totally reversed, resulting in a 'negative compatibility effect'. At the behavioural levels, it leads to longer reaction times for congruent trials and faster reaction times for incongruent trials. At the level of ERPs, they found that at around 300 ms the LRP activated by the prime was massively reversed. According to them, such a paradoxical effect would be the result of a supplementary inhibition mechanism applied on invisible primes. As of today, whether this negative compatibility effect, observed solely with arrow primes, really reflects central inhibition of the primes or, rather, a confound due to the resemblance of masks with prime stimuli remains a controversial issue (Lleras & Enns 2004; Verleger *et al*. 2004; Schlaghecken & Eimer 2006). In any case, all these studies consensually show that invisible stimuli can elicit motor responses.

Regarding word processing, Brown & Hagoort (1993) were the first to compare semantic priming for visible and invisible primes using ERPs. Semantic priming produced an attenuation of the N400, an ERP component thought to reflect either lexical or semantic integration of information (Kutas & Hillyard 1980; Holcomb 1993). However, this N400 attenuation was obtained only for visible primes. Brown & Hagoort (1993) concluded that the N400 reflects conscious post-lexical processing rather than automatic processing. Schnyer *et al*. (1997) found an N400 modulation for masked repetition rather than semantic priming. Although, some of the subjects reported conscious perception of the primes in this study, this finding was replicated in later studies controlling more carefully for the absence of visibility (Misra & Holcomb 2003; Holcomb *et al*. 2005). Moreover, Holcomb *et al*. (2005) recently compared masked repetition and semantic priming as a function of prime visibility. They found that, by contrast to repetition priming, the N400 modulation induced by semantic priming totally correlates with prime awareness.

By contrast, several other studies have reported that the N400 is modulated by semantic priming even for invisible primes (Deacon *et al*. 2000; Kiefer & Spitzer 2000; Kiefer 2002; Kiefer & Brendel 2006). Some of these studies might have underestimated conscious perception because they used a preliminary threshold definition procedure (Deacon *et al*. 2000) or because too few trials were used for the objective measure (Deacon *et al*. 2000; Kiefer 2002). Yet even when prime awareness was controlled carefully, subliminal semantic priming was reflected in both the reaction times and the N400 component, as shown recently by Kiefer & Brendel (2006).

In summary, the literature on the ERP correlates of subliminal priming strongly suggests that subliminal stimuli can reach motor and lexical levels of processing. Some studies show that it can reach the semantic level, whereas others find that the semantic level is involved only during conscious perception. The reason for this discrepancy remains an open question for future research.

(ii) Evidence from fMRI and intracranial recordings

Dehaene *et al*. (1998) used subliminal priming in the numerical judgment task presented above in conjunction with fMRI. They used an equivalent of the LRP component labelled the 'lateralized BOLD response'. This index, which reflects the differential BOLD activity between the left and right motor cortices, allowed them to show that subliminal congruity effects occur in motor cortex.

Again with fMRI, Dehaene *et al*. (2001) showed that subliminal repetition priming induces repetition suppression (a decrease in neural activity; Naccache & Dehaene 2001*b*; Henson 2003) in the occipital extrastriate cortex and in a region of the posterior fusiform gyrus corresponding to the visual word form area (VWFA). Occipital regions responded only to physical repetition (e.g. for 'radio–radio', but not for 'radio–RADIO'), whereas the VWFA, which is thought to encode abstract orthographic knowledge (Cohen *et al*. 2000), was insensitive to case change (e.g. repetition suppression was equivalent for radio–radio and radio–RADIO). This brain imaging study provided evidence that invisible stimuli are processed at least to the level of abstract orthographic representations. Dehaene *et al*. (2004) used anagram words to distinguish whether this repetition priming effect in the VWFA reflects processing at the single-letter level or at the level of larger orthographic units. In their study, for instance, the French target word 'REFLET' was preceded by the prime word 'trefle', such that almost all of the middle letters (r, e, f, l, e) could be repeated. Moreover, a shift in letter position allowed to present these middle letters at the same spatial position (e.g. 'trefle_'–'_REFLET'). Dehaene *et al*. (2004) found that the posterior part of the VWFA responded specifically to the repetition of letters at the same location, whereas the anterior part of the VWFA was more invariant and responsive to larger letter-sequence units. Kouider *et al*. (in press) used orthographically related primes and targets (garape-GARAGE) and found also priming in the posterior part of the VWFA. Along the same lines, Gaillard *et al*. (2006*b*) used intracranial recording to show that several areas in the ventral stream, including the VWFA, are activated by invisible word stimuli.

All these fMRI (or intracranial) studies provided evidence that invisible stimuli can reach orthographic, lexical and motor levels of representation. Three studies further indicate that subliminal priming can also tap semantic regions. For numbers, Naccache & Dehaene (2001*b*) observed a notation-independent repetition suppression effect in bilateral intraparietal cortices, at a site thought to encode numerical magnitudes. For other types of words, Devlin *et al*. (2004) used priming of semantic associates and we used, in Nakamura *et al*. (2005), cross-script priming of Japanese Kanji and Kana equivalents. Both studies led to repetition suppression in the left middle temporal gyrus, a region thought to be involved in semantic processing or words and objects (e.g. Tyler *et al*. 2003). Thus, these studies provide convergent evidence that subliminal perception can reach the semantic level of processing.

fMRI was also used to demonstrate emotional processing of masked stimuli (Morris *et al*. 1998; Whalen *et al*. 1998). In these experiments, subjects saw brief (e.g. 33 ms) fearful or fear-associated faces followed by a clearly visible neutral face that also served as a backward mask. Both studies found that the processing of these emotional faces was associated with an increased activity in the amygdala relative to neutral stimuli (see also Vuilleumier & Driver 2007), while subjects reported no subjective experience of these faces after the experiment. Since then, these studies have been replicated with faces as well as other types of stimuli (e.g. fearful animals; see Ohman 2002 for a review).

However, most studies in this field do not provide stringent demonstrations that the masked faces were genuinely subliminal. The assumption that the stimuli were not visible depended rather on the argument that their duration was short enough (e.g. 33 ms; Pessoa 2005). As shown recently by Pessoa *et al*. (2005), about 60% of subjects are able to report whether the masked stimulus is fearful or not under presentation conditions that were previously argued to reflect perception without awareness. More recently, Pessoa *et al*. (2006) showed that, when stimulus visibility is controlled carefully, the amygdala does not always seem to be activated under conditions of subliminal face processing. Should we thus conclude that emotional processing in the amygdala cannot be activated from subliminal stimuli? Before making such a strong assumption, one would need to check that in the study by Pessoa *et al*. (2006), masking was not too strong to prevent any form of processing, even at the lowest levels of visual processing.

Recently, Kouider *et al*. (submitted) developed a new method that allows for efficient masking of faces conjoined with subliminal repetition priming effects (figure 9.1*b*). They found repetition suppression in several occipitotemporal areas, including the fusiform face area. It would be interesting to use the same procedure to test whether invisible fearful faces can activate the amygdala. Robust evidence for genuinely subliminal emotional processing has been found in a recent study using word stimuli and intracranial recordings of the amygdala. Naccache *et al*. (2005) found that masked words that are threatening (e.g. 'danger') increase the activity in the amygdala compared with neutral words (e.g. 'cousin'). Crucially, in this case, subjects were totally at chance in categorizing these masked words as threatening or neutral. Unexpectedly, in this study, the latency of activation of the amygdala was relatively late (around 800 ms after stimulus presentation). According to Naccache *et al*. (2005), before reaching the amygdala, words have to pass through several levels of processing, including visual, lexical and, crucially, semantic levels of processing. In summary, this study provides evidence that areas coding for an emotional semantic dimension can indeed be activated by subliminal words.

(c) Subliminal perception is modulated by attention

Until recently, attention was considered the main 'gatekeeping' mechanism of consciousness (Posner 1994). Subliminal priming was assumed to involve automatic processes and thus to be unaffected by conscious controlled processes (Posner & Snyder 1975). Recently, however, several studies have shown that even subliminal processing may be modulated by spatial and temporal attention.

For temporal attention, Naccache *et al*. (2002) used an extension of the numerical decision paradigm (Dehaene *et al*. 1998) and found that subliminal congruity effects vanished if the prime did not appear at temporally predictable moments, and therefore did not fall into the temporal window of attention. Kiefer & Brendel (2006) used the same experimental logic (predictable versus unpredictable targets) with masked priming of semantic associates and found that the N400 modulation induced by semantic priming is reduced for unattended primes.

For spatial attention, Dupoux *et al*. (2003) used masked auditory priming under dichotic conditions. Subjects were asked to pay attention to words in the attended ear (e.g. the right ear) in order to perform a lexical decision task and to ignore the unattended ear (e.g. the left ear), which contained prime stimuli. Except under conditions where the prime stimuli could pop out from the auditory signal and attract subjects' attention, auditory repetition priming disappeared under dichotic conditions, suggesting that masked priming requires spatial attention. Lachter *et al*. (2004) reached a similar conclusion for the visual domain. In a series of word repetition priming experiments, they used presentation condition where the prime and target could appear either at the same location or one below the other. Here also, repetition priming was found only at attended locations. Along the same lines, Sumner *et al*. (2006) used a precueing procedure to manipulate attention to a subliminal prime and found that it substantially increased priming effects.

In summary, all these studies suggest that attention increases the processing of invisible stimuli at both perceptual and semantic levels. This conclusion contrasts largely with the classical view of automatic processing, by which all levels of non-conscious representations are mandatorily and passively involved during perception (Posner & Snyder 1975; Schneider & Shiffrin 1977). Nonetheless, it remains an open question for further research whether attention modulates subliminal priming even at the lowest levels of sensory processing.

9.8 Comparison with non-conscious perception during inattention

While this review focuses on subliminal masking paradigms, where the evidence for semantic processing is limited to specific experimental conditions, it is also interesting to consider other paradigms where non-conscious perception is induced by inattention. Indeed, there is a large consensus that in such cases, semantic processing can occur in the absence of conscious perception. In these paradigms, stimuli fail to be seen because the subject's attention is occupied on a different task and/or with another stimulus. It is important to note that it constitutes a drastically different situation compared with subliminal masking paradigms, because in this case it involves supraliminal stimuli that can be reported when they are attended. To make stimuli invisible in masking paradigms, where the subject's attention is focused on the stimuli, the experimenter must drastically reduce the amount of sensory input, for instance, by using short stimulus durations. Under conditions of inattention, however, the stimulus can be presented for a long duration, with only late masking (attentional blink) or no masking at all (inattentional blindness), and yet remain unreportable. As a result, much stronger non-conscious effects are observed.

In the attentional blink paradigm, focused attention to a first item (T1) hinders the subsequent identification of a second item (T2) presented a few hundred milliseconds later (Raymond *et al*. 1992). Yet, failure to consciously perceive T2 does not prevent its semantic processing. Shapiro *et al*. (1997) used a semantic priming version of the attentional blink by having a third word T3 that was either semantically related or unrelated to T2. They found that semantic priming increased the identification of T3 not only when T2 was reported, but also when it was missed, although priming was smaller for missed items (see also Martens *et al*. 2002).

In an ERP study by Luck *et al*. (1996), T1 and T2 were preceded by a context word that was either semantically related or unrelated to T2. The N400 was modulated by the semantic relation between T1 and T2, not only when T2 was reported, but also when it was missed. Surprisingly, the N400 induced by reported and missed targets was identical in amplitude, suggesting that, even under non-conscious conditions, semantic processing can remain entirely unaffected. Rolke *et al*. (2001) replicated this N400 semantic modulation for missed stimuli, although, in this study, it was smaller than for reported stimuli. Sergent *et al*. (2005) recorded the entire sequence of ERP components evoked by unseen T2s, and found unaffected P1 and N1 components as well as a preserved but reduced N400. In summary, studies using semantic priming in conjunction with the attentional blink have provided strong evidence for the existence of semantic activation during non-conscious perception. Mack & Rock (1998) report similar, though scarcer, evidence from the inattentional blindness paradigm, where a single, totally unexpected task-unrelated target is presented foveally without any masking. Under such conditions, a word can remain undetected, yet subsequently cause priming, for instance, in a stem completion task.

Neuropsychological deficits such as unilateral neglect also offer the possibility to study perception under conditions of inattention (Driver & Vuilleumier 2001). Neglect patients may fail to report stimuli on the side of space contralateral to their damaged hemisphere, when this stimulus competes with another ipsilateral stimulus (extinction). Since the stimulus can be reported if attention is cued towards it, neglect is considered as a loss of awareness resulting from a lack of attention, not a lack of sensory processing (Posner *et al*. 1984; Driver & Vuilleumier 2001). In a pioneering study on non-conscious processing during extinction, Volpe *et al*. (1979) showed that although neglect patients could not report the identity of a stimulus (i.e. a word or an object) in the contralateral field, they were still able to guess whether it had the same or a different name as the stimulus in the ipsilateral field. Above-chance guessing in the absence of subjective report of the contralateral stimuli was taken as evidence for non-conscious perception. Berti *et al*. (1992) extended this finding to higher levels of processing. They showed that patients could guess that the objects presented on the two sides had the same name even when different views were displayed. In addition, they argued that guessing could involve choosing between exemplars from the same or a different semantic category. These results were taken as evidence that the stimulus in the neglected field primed the category of the stimulus in the intact field. Nevertheless, two major points of caution should be raised. First, stimuli from the same semantic category tended to be much more similar physically than exemplars from different categories. Second, the approach suffers from the same criticisms raised against the early studies of subliminal perception (Eriksen 1960). Above-chance performance on discrimination could reflect partial or even full conscious perception in the presence of the under-confidence phenomenon during the subjective measure of conscious perception. Along these lines, Farah *et al*. (1991) matched the difficulty of the direct and indirect measure by having subjects performing a two-alternative forced-choice task on the neglected stimuli, rather than identification. Under conditions where discrimination performance on the neglected stimuli was at chance, patients were no longer able to match it to the stimulus in the intact field.

A more promising approach has been to use priming as the indirect measure of non-conscious influences. Audet *et al*. (1991) used a priming task in which neglect patients had to identify one of the two target stimuli presented at central fixation (the letter 'T' or 'K') preceded by peripheral stimuli that were either identical (T preceded by T), incongruent (T preceded by K) or neutral (T preceded by O). As shown by Taylor (1977), normal subjects in this task show facilitation on repeated trials and interference on incongruent trials relative to the neutral condition. In the study by Audet *et al*. (1991), the prime could be presented on the left (i.e. in the neglected field) or above the target (i.e. reportable at central fixation). As with normal subjects, they found both facilitation and interference, but only as long as the prime appeared in the intact field. When the prime was presented in the neglected side, the general pattern of results was facilitation in the absence of interference. Nevertheless, interference was found in one of the four experiments reported, when the subject was told to explicitly use the prime to predict the target. Following the same logic, Cohen *et al*. (1995) asked patients to judge the colour of a central target (e.g. green), surrounded by a repeated (e.g. green), incongruent (e.g. red) or neutral (e.g. blue) prime presented either in the ipsi- or in the contralateral side. In this study, Cohen and colleagues not only found interference from the neglected field, but also that it was just as large as interference from the intact field.

Unfortunately, a problem with these two studies is that awareness was not fully controlled. Audet and colleagues relied only on subjective reports, which can be criticized for the above-mentioned reasons. Cohen and colleagues used a colour decision on the peripheral rather than on the central stimulus and found that patients had much more difficulty in identifying the contralateral than the ipsilateral stimulus, which allowed them to demonstrate that patients indeed suffered from extinction. However, patients remained much better than chance for contralateral stimuli, and thus it remains possible that the effects were due to conscious perception.

Fuentes & Humphreys (1996) relied on the negative priming phenomenon and controlled more rigorously for potential influences from conscious perception. Subjects received on each trial a first display with a central letter to identify (e.g. 'T') and a distractor (e.g. 'M') to ignore on the right side of fixation (e.g. '+T M') or on the left side (e.g. 'MT+'). Then they received a second display in which, compared to the distractor on the first display, the central letter was identical (e.g. '+M L') or different (e.g. '+B L'). Contrary to the classical facilitatory priming effect, repetition leads here to lower accuracy and longer reaction times (i.e. negative priming) because the distractor in the first display receives active suppression (Tipper 1985). Fuentes & Humphreys (1996) replicated this negative priming with distractors in the intact field of a neglect patient. However, priming from the contralateral field was positive rather than negative. Moreover, Fuentes & Humphreys showed that this repetition effect occurred across a case change, suggesting the involvement of abstract letter representations. In addition, they used an objective measure to assess the awareness of distractors. Subjects were asked to either report the central stimulus that was presented alone, or the number of displayed letters when a distractor was added. Importantly, the task was provided only after the display, such that subjects were primarily paying attention to the central stimulus, as in the priming experiment. Patients easily reported the presence of two letters when the distractor was on the right side (e.g. '+TM'), but failed when the distractor was on the left side. Fuentes & Humphreys (1996) concluded that perception occurs without awareness in neglect patients and involves levels of representation above simple visual sensory processing. By contrast, according to them, inhibitory processes require conscious perception.

Recently, Rusconi *et al*. (2006) extended the results of Fuentes & Humphreys by providing evidence for the extraction of arithmetic information from neglected number stimuli. Their subjects were instructed to perform a parity judgment task with a target number that was preceded by two prime numbers. When the product of the two primes was equal to the target (e.g. 2###7 followed by 14), then normal subjects were slower to perform the parity judgment task. Rusconi and colleagues replicated this result in a neglect patient. However, when the primes appeared in the neglected field, then interference turned into facilitation. Rusconi and colleagues used an identification task to show that none of the stimuli in the neglect field could be identified. These results suggest that associations between numbers can be activated without conscious perception and that, as in the study by Fuentes & Humphreys (1996), inhibitory processes require, by contrast, conscious processing.

Other studies concentrated on the semantic level of processing. Berti & Rizzolatti (1992) asked patients to categorize drawings as referring to animals or vegetables. Patients were presented with two drawings, one on the neglected side followed by another on the intact field, that either referred to the same category or was incongruent. Berti & Rizzolati found a congruence effect even when restricting the analysis to patients reporting having seen only one stimulus on each trial, not two. At first glance, this result suggests a non-conscious semantic influence. Yet, given that the stimulus set was very narrow (i.e. 14 in total) and that the prime stimuli could appear as target stimuli, this experiment does not unequivocally provide evidence for non-conscious semantic processing, but could reflect motor congruity effects (Damian 2001; see above). Moreover, here subjective reports can also be largely criticized due to the potential confound with confidence criteria.

Two other studies used priming with semantic associates and controlled more carefully for the absence of conscious perception. Ladavas *et al*. (1993) used word stimuli, whereas McGlinchey-Berroth *et al*. (1993) relied on picture primes and word targets. In both cases, semantic priming was obtained from primes in the neglected field. Moreover, McGlinchey-Berroth and colleagues compared the amount of priming from the neglected and intact field and found no difference, suggesting that semantic processing can remain entirely unaffected during non-conscious perception by inattention. Importantly, both studies showed that under similar presentation conditions, patients were at chance in several objective measures of conscious perception of the primes, such as lexical decision, semantic categorization, detection (Ladavas *et al*. 1993) and two-alternative forced-choice (McGlinchey-Berroth *et al*. 1993). It is of note, however, that the presentation conditions were not identical in the direct and indirect measures, because the target was omitted during the measure of conscious prime perception. Thus, it might be argued that conscious perceptibility was higher during the priming experiment owing to retroactive semantic priming (Briand *et al*. 1988; Dark 1988; Bernstein *et al*. 1989; see above for details). Nevertheless, those experiments, together with those on the attentional blink, constitute some of the best evidence to date for semantic-level processing without conscious perception.

9.9 Theoretical conclusions

We have reviewed evidence for the depth of non-conscious processing in two categories of experimental conditions: masked priming paradigms and inattention paradigms. The depth of processing seems to differ in those two conditions. In masked priming, while orthographic and lexical levels are easily contacted, evidence for phonological and semantic processing, although real, is much more restricted. Subliminal semantic priming effects can be very small, indeed much smaller than under conscious conditions. However, in inattention paradigms, while effect sizes vary according to experimental conditions, strong semantic effects can be observed. Under the most favourable conditions of the attentional blink, where spatial attention is focused onto the stimulus location, but central executive attention is occupied by a secondary task, there may be little or no difference between semantic-level processing under conditions of conscious versus blinked (Luck *et al*. 1996) or extinguished (McGlinchey-Berroth *et al*. 1993) stimulus processing.

In this concluding section, we would like to argue that those results fit with the tripartite distinction of subliminal, preconscious and conscious processing that one of us has recently proposed (Dehaene *et al*. 2006). According to the global neuronal workspace theory, sensory information is consciously accessed whenever a bidirectional, self-sustained activation loop is established between the relevant posterior sensory processors and an assembly of workspace neurons with long-distance axons, distributed through the brain, but particularly dense in associative cortical areas, most notably prefrontal cortex (Dehaene *et al*. 1998, 2001, 2003). Thus, for a stimulus to reach consciousness, two factors are jointly needed: first, the input stimulus must have enough strength to cross a dynamic threshold for global reverberation (which can be prevented by stimulus degradation or competition with other stimuli, i.e. masking); and second, it must receive top-down amplification by distant neurons (which can be prevented by drawing these neurons into another stimulus or task). Accordingly, conscious access may fail for two quite distinct reasons, leading to a distinction between two types of non-conscious processes, which we call subliminal and preconscious, respectively (figure 9.3).

According to the theory, subliminal processing is a condition of information inaccessibility where the bottom-up, stimulus-induced activation itself is insufficient to trigger large-scale reverberation. Thus, subliminal information is information that cannot be brought into consciousness, in spite of all efforts of focused attention. This does not mean, of course, that subliminal processing is independent of the subject's attention and strategies. As we have seen, whichever task and attentional sets are prepared consciously can orient and amplify the processing of a subliminal stimulus, even if its bottom-up strength remains insufficient for global conscious access.

On the other hand, preconscious processing occurs when processing is limited by top-down access rather than bottom-up strength. According to the theory, preconscious processes potentially carry enough activation for conscious access, but are temporarily buffered in a non-conscious store owing to a lack of top-down attentional amplification (for instance, owing to transient occupancy of the central workspace system). As shown by the attentional blink and inattentional blindness paradigms, even strong visual stimuli can remain temporarily preconscious. They are potentially visible (contrary to subliminal stimuli, they could quickly gain access to conscious report if they were attended), but they are not consciously seen at the moment. However, they are clearly maintained in a sensory buffer for a few hundreds of milliseconds, since they may ultimately achieve conscious access once the central workspace is freed (as exemplified by the psychological refractory period paradigm, in which one task is put

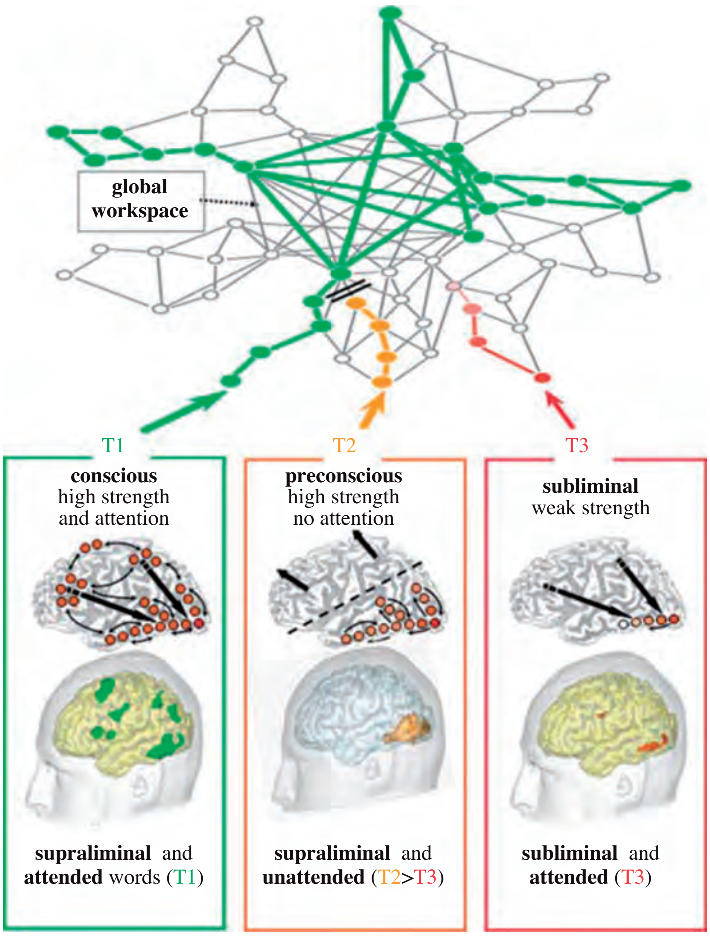

Fig. 9.3 Taxonomy between conscious, preconscious and subliminal processing, based on the theoretical proposal by Dehaene *et al*. (2006). This distinction stipulates the existence of three types of brain states associated with conscious report, non-conscious perception due to inattention (preconscious state; Kouider *et al*. in press) and non-conscious perception due to masking (subliminal perception; Dehaene *et al*. 2001, 2006).

on hold while another task is being processed). This sensory buffer can be erased by other competing stimuli, however, in which case a preconscious stimulus may never gain access to conscious processing (as achieved by late masking in the attentional blink paradigm).

We have argued that maintaining this distinction is essential in order to make sense of the growing neuro-imaging data on the neural correlates of consciousness (Dehaene *et al*. 2006; Kouider *et al*. in press). Here, we add that consideration of the neural bases of subliminal and preconscious states may then help in understanding why they differ in the depth of non-conscious processing. During subliminal processing, brain imaging and neurophysiological data indicate that masking prevents the efficient propagation of bottom-up stimulus activation in successive perceptual areas, leaving only a short pulse of activity whose amplitude decreases at each synaptic step (Kovacs *et al*. 1995; Thompson & Schall 1999; Dehaene *et al*. 2001; Lamme 2003). Thus, although behavioural priming effects can be detected at a distance from sensory systems, they are expected to decrease with synaptic distance and become very small and frequently undetectable in distant phonological and semantic areas. On the other hand, during preconscious processing (defined as suprathreshold stimulation under conditions of inattention), neuroimaging data shows a much increased and durable activation in posterior occipitotemporal cortices, probably corresponding to the activation of local reverberatory loops forming a sensory buffer, yet without extension into a global brain-scale parietofrontal ignition (Tse *et al*. 2005; Kouider *et al*. in press). It is therefore not surprising that such a durable and extended activity state should be capable of causing greater priming at multiple processing levels. Indeed at the cerebral level, repetition suppression and repetition enhancement effects can be seen in a much wider cortical network that includes areas known to be involved in phonology and semantics (Kouider *et al*. in press), owing to preconscious processing.

As increasingly reliable paradigms are being designed to create such preconscious states and to collect the subject's own assessment of their degree of consciousness (Sergent *et al*. 2005), we suspect that researchers will discover increasingly reliable evidence for non-conscious activation of broad perceptual, lexical, phonological and semantic networks. Accordingly, research should progressively shift to another crucial issue, that of understanding which cognitive processes, if any, are the exclusive privilege of conscious processing. The global neuronal workspace model makes the clear prediction that they should bear the characteristics of a 'central executive' parietofrontal system: long-lasting maintenance of information; flexible recombination and exchange of intermediate results across processors; and intentional effortful control should be deployed only during conscious processing (Dehaene & Naccache 2001). While highly suggestive evidence already exists (e.g. Kunde 2003), the testing of this prediction remains a key issue for further research.

References

Abrams, R. L. & Greenwald, A. G. 2000 Parts outweigh the whole (word) in unconscious analysis of meaning. *Psychol. Sci*. **11**, 118–124. (doi:10.1111/1467-9280.00226)

Abrams, R. L., Klinger, M. R. & Greenwald, A. G. 2002 Subliminal words activate semantic categories (not automated motor responses). *Psychon. Bull. Rev*. **9**, 100–106.

Adams, J. K. 1957 Laboratory studies of behavior without awareness. *Psychol. Bull*. **54**, 383–405. (doi:10.1037/ h0043350)

Allport, A. 1977 On knowing the meaning of words we are unable to report: the effects of visual masking. In *Attention and performance*, vol. 6 (ed. D. S. Dornic), pp. 505–534. London, UK: Academic Press.

Audet, T., Bub, D. & Lecours, A. R. 1991 Visual neglect and left-sided context effects. *Brain Cogn*. **16**, 11–28. (doi:10. 1016/0278-2626(91)90082-J)

Baars, B. J. 1988 *A cognitive theory of consciousness*. New York, NY: Cambridge University Press.

Balota, D. A. 1983 Automatic semantic activation and episodic memory encoding. *J. Verb. Learn. Verb. Behav*. **22**, 88–104. (doi:10.1016/S0022-5371(83)80008-5)

Berent, I. & Perfetti, C. A. 1995 A rose is a REEZ: the two-cycles model of phonology assembly in reading English. *Psychol. Rev*. **102**, 146–184. (doi:10.1037/0033-295X. 102.1.146)

Bernstein, I. H., Bissonnette, V., Vyas, A. & Barclay, P. 1989 Semantic priming: subliminal perception or context? *Percept. Psychophys*. **45**, 153–161.

Berti, A. & Rizzolatti, G. 1992 Visual processing without awareness: evidence from unilateral neglect. *J. Cogn. Neurosci*. **4**, 345–351.

Berti, A., Allport, A., Driver, J., Dienes, Z., Oxbury, J. & Oxbury, S. 1992 Level of processing for stimuli in an "extinguished" visual field. *Neuropsychologia* **30**, 403–415. (doi:10.1016/0028-3932(92)90088-4)

Bjorkman, M., Juslin, P. & Winman, A. 1993 Realism of confidence in sensory discrimination: the underconfidence phenomenon. *Percept. Psychophys*. **54**, 75–81.

Briand, K., den Heyer, K. & Dannenbring, G. L. 1988 Retroactive semantic priming in a leixcal decision task. *Q. J. Exp. Psychol. A* **40**, 341–359.

Brown, C. & Hagoort, P. 1993 The processing nature of the N400: evidence from masked priming. *J. Cogn. Neurosci*. **5**, 34–44.

Brysbaert, M. & Praet, C. 1992 Reading isolated words: no evidence for automatic incorporation of the phonetic code. *Psychol. Res*. **54**, 91–102. (doi:10.1007/BF00937137)

Carr, T. H., McCauley, C., Sperber, R. D. & Parmalee, C. M. 1982 Words, pictures, and priming: on semantic activation, conscious identification, and the automaticity of information processing. *J. Exp. Psychol. Hum. Percept. Perform*. **8**, 757–777. (doi:10.1037/0096-1523.8.6.757)

Chalmers, D. 1996 *The conscious mind: in search of a fundamental theory*. Oxford, UK: Oxford University Press.

Cheesman, J. & Merikle, P. M. 1984 Priming with and without awareness. *Percept. Psychophys*. **36**, 387–395.

Cheesman, J. & Merikle, P. M. 1986 Distinguishing conscious from unconscious perceptual processes. *Can. J. Psychol*. **40**, 343–367.

Chwilla, D. J., Hagoort, P. & Brown, C. M. 1998 The mechanism underlying backward priming in a lexical decision task: spreading activation versus semantic matching. *Q. J. Exp. Psychol. A* **51**, 531–560. (doi:10.1080/ 027249898391521)

Cohen, A., Ivry, R., Rafal, R. & Kohn, C. 1995 Response code activation by stimuli in the neglected visual field. *Neuropsychology* **9**, 165–173. (doi:10.1037/0894-4105.9. 2.165)

Cohen, L., Dehaene, S., Naccache, L., Lehericy, S., Dehaene-Lambertz, G., Henaff, M.-A. & Michel, F. 2000 The visual word form area: spatial and temporal characterization of an initial stage of reading in normal subjects and posterior split-brain patients. *Brain* **123**, 291–307. (doi:10.1093/ brain/123.2.291)

Coles, M. G. H., Gratton, G. & Donchin, E. 1988 Detecting early communication: using measures of movement-related potentials to illuminate human information processing. *In Event-related potential investigations of cognition* (eds B. Renault, M. Kutas, M. G. H. Coles & A. W. K. Gaillard), pp. 69–89. Amsterdam, The Netherlands: North-Holland. (Published as Volume 26, Nos. 1–3 of Biological Psychology.)

Collins, A. M. & Loftus, E. F. 1975 A spreading-activation theory of semantic processing. *Psychol. Rev*. **82**, 407–428. (doi:10.1037/0033-295X.82.6.407)

Damian, M. 2001 Congruity effects evoked by subliminally presented primes: automaticity rather than semantic processing. *J. Exp. Psychol. Hum. Percept. Perform*. **27**, 154–165. (doi:10.1037/0096-1523.27.1.154)

Dark, V. J. 1988 Semantic priming, prime reportability, and retroactive priming are interdependent. *Mem. Cogn*. **16**, 299–308.

Dark, V. J. & Benson, K. 1991 Semantic priming and identification of near threshold primes in a lexical decision task. *Q. J. Exp. Psychol. A* **43**, 53–78.

Davis, C. & Forster, K. I. 1994 Masked orthographic priming: the effect of prime-target legibility. *Q. J. Exp. Psychol. A* **47**, 673–697.
Deacon, D., Hewitt, S., Yang, C.-M. & Nagata, M. 2000 Event-related potential indices of semantic priming using masked and unmasked words: evidence that the N400 does not reflect a postlexical process. *Cogn. Brain Res*. **9**, 137–146. (doi:10.1016/S0926-6410(99)00050-6)
Debner, J. A. & Jacoby, L. L. 1994 Unconscious perception: attention, awareness, and control. *J. Exp. Psychol. Learn. Mem. Cogn*. **20**, 304–317. (doi:10.1037/0278-7393.20. 2.304)
Dehaene, S. & Changeux, J.-P. 2004 Neural mechanisms for access to consciousness. In *The cognitive neurosciences* (ed. M. Gazzaniga), 3rd edn. Cambridge, MA: MIT Press.
Dehaene, S. & Naccache, L. 2001 Towards a cognitive neuroscience of consciousness: basic evidence and a workspace framework. *Cognition* **79**, 1–37. (doi:10.1016/ S0010-0277(00)00123-2)
Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., van de Moortele, P. F. & Le Bihan, D. 1998 Imaging unconscious semantic priming. *Nature* **395**, 597–600. (doi:10.1038/26967)
Dehaene, S., Naccache, L., Cohen, L., Le Bihan, D., Mangin, J.-F., Poline, J.-B. & Rivière, D. 2001 Cerebral mechanisms of word masking and unconscious repetition priming. *Nat. Neurosci*. **4**, 752–758. (doi:10. 1038/89551)
Dehaene, S., Sergent, C. & Changeux, J.-P. 2003 A neuronal network model linking subjective reports and objective physiological data during conscious perception. *Proc. Natl Acad. Sci. USA* **1001**, 8520–8525. (doi:10.1073/pnas. 1332574100)
Dehaene, S., Jobert, A., Naccache, L., Ciuciu, P., Poline, J. B., Le Bihan, D. & Cohen, L. 2004 Letter binding and invariant recognition of masked words. *Psychol. Sci*. **15**, 307–313. (doi:10.1111/j.0956-7976.2004.00674.x)
Dehaene, S., Changeux, J.-P., Naccache, L., Sackur, J. & Sergent, C. 2006 Conscious, preconscious, and subliminal processing: a testable taxonomy. *Trends Cogn. Sci*. **10**, 204–211. (doi:10.1016/ j.tics.2006.03.007)
Dell'Acqua, R. & Grainger, J. 1999 Unconscious semantic priming to pictures. *Cognition* **73**, B1–B15. (doi:10.1016/ S0010-0277(99)00049-9)
Devlin, J. T., Jamison, H. L., Matthews, P. M. & Gonnerman, L. M. 2004 Morphology and the internal structure of words. *Proc. Natl Acad. Sci. USA* **101**, 14 984–14 988. (doi:10.1073/pnas.0403766101)
Dixon, N. F. 1971 *Subliminal perception: the nature of a controversy*. London, UK: McGraw-Hill.
Dixon, N. F. 1981 *Preconscious processing*. New York, NY: Wiley.
Draine, S. C. & Greenwald, A. G. 1998 Replicable unconscious semantic priming. *J. Exp. Psychol. Gen*. **127**, 286–303. (doi:10.1037/0096-3445.127.3.286)
Driver, J. & Vuilleumier, P. 2001 Perceptual awareness and its loss in unilateral neglect and extinction. *Cognition* **79**, 39–88. (doi:10.1016/S0010-0277(00)00124-4)
Dulany, D. E. 1997 Consciousness in the explicit (deliberative) and implicit (evocative). In *Scientific approaches to consciousness* (eds J. Cohen & J. Schooler), pp. 179–211. Mahwah, NJ: Lawrence Erlbaum Associates.
Dupoux, E., Kouider, S. & Mehler, J. 2003 Lexical access without attention? Exploration using dichotic priming. *J. Exp. Psychol. Hum. Percept. Perform*. **29**, 172–183. (doi:10.1037/ 0096-1523.29.1.172)
Durante, R. & Hirshman, E. 1994 Retrospective priming and masked semantic priming: the interfering effects of prime activation. *J. Mem. Lang*. **33**, 112–127. (doi:10.1006/jmla. 1994.1006)
Eimer, M. & Schlaghecken, F. 1998 Effects of masked stimuli on motor activation: behavioral and electrophysiological evidence. *J. Exp. Psychol. Hum. Percept. Perform*. **24**, 1737–1747. (doi:10.1037/0096-1523.24.6.1737)
Ellis, A. W. & Marshall, J. C. 1978 Semantic errors or statistical flukes? A note on Allport's "Onknowing the meanings of words we are unable to report". *Q. J. Exp. Psychol*. **30**, 569–575.
Eriksen, C. W. 1960 Discrimination and learning without awareness: a methodological survey and evaluation. *Psychol. Rev*. **67**, 279–300. (doi:10.1037/h0041622)
Evett, L. J. & Humphreys, G. W. 1981 The use of abstract graphemic information in lexical access. *Q. J. Exp. Psychol*. **33**, 325–350.

Farah, M. J., Monheit, M. A., Brunn, J. L. & Wallace, M. A. 1991 Unconscious perception of "extinguished" visual stimuli: reassessing the evidence. *Neuropsychologia* **29**, 949–958. (doi:10.1016/0028-3932(91)90059-H)

Ferrand, L. & Grainger, J. 1992 Phonology and orthography in visual word recognition: evidence from masked non-word priming. *Q. J. Exp. Psychol. A* **45**, 353–372.

Ferrand, L. & Grainger, J. 1993 The time course of orthographic and phonological code activation in the early phases of visual word recognition. *Bull. Psychonom. Soc*. **31**, 119–122.

Forster, K. I. 2004 Category size revisited: frequency and masked priming effects in semantic categorization. *Brain Lang*. **90**, 276–286. (doi:10.1016/S0093-934X(03) 00440-1)

Forster, K. I. & Davis, C. 1984 Repetition priming and frequency attenuation in lexical access. *J. Exp. Psychol. Learn. Mem. Cogn*. **10**, 680–698. (doi:10.1037/0278-7393.10.4.680)

Forster, K. I. & Davis, C. 1991 The density constraint on form-priming in the naming task: interference from a masked prime. *J. Mem. Lang*. **30**, 1–25. (doi:10.1016/0749-596X(91)90008-8)

Forster, K. I., Davis, C., Schoknecht, C. & Carter, R. 1987 Masked priming with graphemically related forms: repetition or partial activation? *Q. J. Exp. Psychol*. **39**, 211–251.

Fowler, C. A., Wolford, G., Slade, R. & Tassinary, L. 1981 Lexical access with and without awareness. *J. Exp. Psychol. Gen*. **110**, 341–362. (doi:10.1037/0096-3445.110.3.341)

Fuentes, L. J. & Humphreys, G. W. 1996 On the processing of "extinguished" stimuli in unilateral visual neglect: an approach using negative priming. *Cogn. Neuropsychol*. **13**, 111–136. (doi:10.1080/026432996382088)

Gaillard, R., Del Cul, A., Naccache, L., Vinckier, F., Cohen, L. & Dehaene, S. 2006*a* Nonconscious semantic processing of emotional words modulates conscious access. *Proc. Natl Acad. Sci. USA* **103**, 7524–7529. (doi:10.1073/pnas. 0600584103)

Gaillard, R. *et al*. 2006*b* Direct intracranial, fMRI and lesion evidence for the causal role of left inferotemporal cortex in reading. *Neuron* **50**, 191–204. (doi:10.1016/j.neuron. 2006.03.031)

Gollan, T. H., Forster, K. I. & Frost, R. 1997 Translation priming with different scripts: masked priming with cognates and non-cognates in Hebrew-English bilinguals. *J. Exp. Psychol. Learn. Mem. Cogn*. **23**, 1122–1139. (doi:10.1037/0278-7393.23.5.1122)

Grainger, J. & Frenck-Mestre, C. 1998 Masked translation priming in bilinguals. *Lang. Cogn. Process*. **13**, 601–623. (doi:10.1080/016909698386393)

Grainger, J., Diependaele, K., Spinelli, E., Ferrand, L. & Farioli, F. 2003 Masked repetition and phonological priming within and across modalities. *J. Exp. Psychol. Learn. Mem. Cogn*. **29**, 1256–1269. (doi:10.1037/0278-7393.29.6.1256)

Greenwald, A. G. 1992 New Look 3: reclaiming unconscious cognition. *Am. Psychol*. **47**, 766–779. (doi:10.1037/0003-066X.47.6.766)

Greenwald, A. G., Klinger, M. R. & Schuh, E. S. 1995 Activation by marginally perceptible ("subliminal") stimuli: dissociation of unconscious from conscious cognition. *J. Exp. Psychol. Gen*. **124**, 22–42. (doi:10. 1037/0096-3445.124.1.22)

Greenwald, A. G., Draine, S. C. & Abrams, R. L. 1996 Three cognitive markers of unconscious semantic activation. *Science* **273**, 1699–1702. (doi:10.1126/science.273.5282. 1699)

Greenwald, A. G., Abrams, R. L., Naccache, L. & Dehaene, S. 2003 Long-term semantic memory versus contextual memory in unconscious number processing. *J. Exp. Psychol. Learn. Mem. Cogn*. **29**, 235–247. (doi:10.1037/ 0278-7393.29.2.235)

Henson, R. N. A. 2003 Neuroimaging studies of priming. *Prog. Neurobiol*. **70**, 53–81. (doi:10.1016/S0301-0082(03) 00086-8)

Holcomb, P. J. 1993 Semantic priming and stimulus degradation: implications for the role of the N400 in language processing. *Psychophysiology* **30**, 47–61.

Holcomb, P. H., Reder, L., Misra, M. & Grainger, J. 2005 The effects of prime visibility on ERP measures of masked priming. *Cogn. Brain Res*. **24**, 155–172. (doi:10.1016/ j.cogbrainres.2005.01.003)

Holender, D. 1986 Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: a survey and appraisal. *Behav. Brain Sci*. **9**, 1–23.

Holender, D. & Duscherer, K. 2004 Unconscious perception: the need for a paradigm shift. *Percept. Psychophys*. **66**, 872–881.
Humphreys, G. W., Evett, L. J. & Taylor, D. E. 1982 Automatic phonological priming in visual word recognition. *Mem. Cogn*. **10**, 576–590.
Humphreys, G. W., Besner, D. & Quinlan, P. T. 1988 Event perception and the word repetition effect. *J. Exp. Psychol. Gen*. **117**, 51–67. (doi:10.1037/0096-3445.117.1.51)
Hutchison, K. A., Neely, J. H., Neill, W. T. & Walker, P. 2004 Lexical and sub-lexical contributions to unconscious identity priming. *Conscious. Cogn*. **13**, 512–538. (doi:10. 1016/j.concog.2004.05.001)
Jaskowski, P., van der Lubbe, R. H., Schlotterbeck, E. & Verleger, R. 2002 Traces left on visual selective attention by stimuli that are not consciously identified. *Psychol. Sci*. **13**, 48–54. (doi:10.1111/1467-9280.00408)
Jiang, N. 1999 Testing explanations for asymmetry in cross-language priming. *Bilingual. Lang. Cogn*. **2**, 59–75. (doi:10.1017/S1366728999000152)
Kiefer, M. 2002 The N400 is modulated by unconsciously perceived masked words: further evidence for a spreading activation account of N400 priming effects. *Cogn. Brain Res*. **13**, 27–39. (doi:10.1016/S0926-6410(01)00085-4)
Kiefer, M. & Spitzer, M. 2000 Time course of conscious and unconscious semantic brain activation. *Neuroreport* **11**, 2401–2407. (doi:10.1097/00001756-200008030-00013)
Kiefer, M. & Brendel, D. 2006 Attentional modulation of unconscious 'automatic' processes: evidence from event-related potentials in a masked priming paradigm. *J. Cogn. Neurosci*. **18**, 184–198. (doi:10.1162/jocn.2006.18.2.184)
Kihlstrom, J. F. 1987 The cognitive unconscious. *Science* **237**, 1445–1452. (doi:10.1126/science.3629249)
Klinger, M. R., Burton, P. C. & Pitts, G. S. 2000 Mechanisms of unconscious priming I: response competition not spreading activation. *J. Exp. Psychol. Learn. Mem. Cogn*. **26**, 441–455. (doi:10.1037/0278-7393.26.2. 441)
Koriat, A. 1981 Semantic facilitation in lexical decision as a function of prime-target association. *Mem. Cogn*. **9**, 587–598.
Kouider, S. & Dupoux, E. 2001 A functional disconnection between spoken and visual word recognition: evidence from unconscious priming. *Cognition* **82**, B35–B49. (doi:10.1016/S0010-0277(01)00152-4)
Kouider, S. & Dupoux, E. 2004 Partial awareness creates the "Illusion" of subliminal semantic priming. *Psychol. Sci*. **15**, 75–81. (doi:10.1111/j.0963-7214.2004.01502001.x)
Kouider, S. & Dupoux, E. 2005 Subliminal speech priming. *Psychol. Sci*. **16**, 617–625. (doi:10.1111/j.1467-9280. 2005.01584.x)
Kouider, S., Dehaene, S., Jobert, A. & Le Bihan, D. In press. Cerebral bases of subliminal and supraliminal priming during reading. *Cereb. Cortex*.
Kouider, S., Eger, E., Dolan, R. & Henson, R. Submitted. Non-conscious face processing in the ventral stream.
Kovacs, G., Vogels, R. & Orban, G. A. 1995 Cortical correlate of pattern backward masking. *Proc. Natl Acad. Sci. USA* **92**, 5587–5591. (doi:10.1073/pnas.92.12.5587)
Kunde, W. 2003 Sequential modulations of stimulus-response correspondence effects depend on awareness of response conflict. *Psychon. Bull. Rev*. **10**, 198–205.
Kunde, W., Kiesel, A. & Hoffmann, J. 2003 Conscious control over the content of unconscious cognition. *Cognition* **88**, 223–242. (doi:10.1016/S0010-0277(03) 00023-4)
Kunde, W., Kiesel, A. & Hoffmann, J. 2005 On the masking and disclosure of unconscious elaborate processing. A reply to van Opstal, Reynvoet & Verguts. *Cognition* **97**, 99–105. (doi:10.1016/j.cognition.2005.03.005)
Kutas, M. & Hillyard, S. A. 1980 Event-related brain potentials to semantically inappropriate and surprisingly large words. *Biol. Psychol*. **11**, 99–116. (doi:10.1016/0301-0511(80)90046-0)
Lachter, J., Forster, K. I. & Ruthruff, E. 2004 Forty years after Broadbent: still no identification without attention. *Psychol. Rev*. **111**, 880–913. (doi:10.1037/0033-295X. 111.4.880)

Ladavas, E., Paladini, R. & Cubelli, R. 1993 Implicit associative priming in a patient with left visual neglect. *Neuropsychologia* **31**, 1307–1320. (doi:10.1016/0028-3932 (93)90100-E)

Lamme, V. A. 2003 Why visual attention and awareness are different. *Trends Cogn. Sci*. **7**, 12–18. (doi:10.1016/S1364-6613(02)00013-X)

Leuthold, H. & Kopp, B. 1998 Mechanisms of priming by masked stimuli: inferences from event-related brain potentials. *Psychol. Sci*. **9**, 263–269. (doi:10.1111/1467-9280.00053)

Lleras, A. & Enns, J. T. 2004 Negative compatibility or object updating? A cautionary tale of mask-dependent priming. *J. Exp. Psychol. Gen*. **133**, 475–493. (doi:10.1037/0096-3445.133.4.475)

Luck, S. J., Vogel, E. K. & Shapiro, K. L. 1996 Word meanings can be accessed but not reported during the attentional blink. *Nature* **383**, 616–618. (doi:10.1038/ 383616a0)

Lukatela, G., Frost, S. J. & Turvey, M. T. 1998 Phonological priming by masked nonword primes in the lexical decision task. *J. Mem. Lang*. **39**, 666–683. (doi:10.1006/jmla.1998. 2599)

Mack, A. & Rock, I. 1998 *Inattentional blindness*. Cambridge, MA: MIT press.

Marcel, A. J. 1974 *Perception with and without awareness*. Paper presented at the meeting of the Experimental Psychology Society, Stirling, Scotland.

Marcel, A. J. 1980 Conscious and preconscious recognition of polysemous words: locating the selective effects of prior verbal context. In *Attention and performance, VIII* (ed. R. S. Nickerson). Hillsdale, NJ: Erlbaum.

Marcel, A. J. 1983 Conscious and unconscious perception: experiments on visual masking and word recognition. *Cogn. Psychol*. **15**, 197–237. (doi:10.1016/0010-0285(83) 90009-9)

Martens, S., Wolters, G. & van Raamsdonk, M. 2002 Blinks of the mind: memory effects of attentional processes. *J. Exp. Psychol. Hum. Percept. Perform*. **28**, 1275–1287. (doi:10.1037/0096-1523.28.6.1275)

McCauley, C., Parmelee, C. M., Sperber, R. D. & Carr, T. H. 1980 Early extraction of meaning from pictures and its relation to conscious identification. *J. Exp. Psychol. Hum. Percept. Perform*. **6**, 265–276. (doi:10.1037/0096-1523.6. 2.265)

McGlinchey-Berroth, R., Milberg, W. P., Verfaellie, M., Alexander, M. & Kilduff, P. T. 1993 Semantic processing in the neglected visual field: evidence from a lexical decision task. *Cogn. Neuropsychol*. **10**, 79–108.

McNamara, T. P. 1992 Theories of priming I: associative distance and lag. *J. Exp. Psychol. Learn. Mem. Cogn*. **18**, 1173–1190. (doi:10.1037/0278-7393.18.6.1173)

McNamara, T. P. 1994 Theories of priming II: types of primes. *J. Exp. Psychol. Learn. Mem. Cogn*. **20**, 507–520. (doi:10.1037/0278-7393.20.3.507)

Merikle, P. M. 1982 Unconscious perception revisited. *Percept. Psychophys*. **31**, 298–301.

Merikle, P. M. & Daneman, M. 1998 Psychological investigations of unconscious perception. *J. Conscious. Stud*. **5**, 5–18.

Merikle, P. M. & Joordens, S. 1997 Parallels between perception without attention and perception without awareness. *Conscious. Cogn*. **6**, 219–236. (doi:10.1006/ ccog.1997.0310)

Merikle, P. M., Joordens, S. & Stolz, J. 1995 Measuring the relative magnitude of unconscious influences. *Conscious. Cogn*. **4**, 422–439. (doi:10.1006/ccog.1995.1049)

Merikle, P. M., Smilek, D. & Eastwood, J. D. 2001 Perception without awareness: perspectives from cognitive pychology. *Cognition* **79**, 115–134. (doi:10.1016/S0010-0277(00) 00126-8)

Misra, M. & Holcomb, P. J. 2003 Event-related potential indices of masked repetition priming. *Psychophysiology* **40**, 115–130. (doi:10.1111/1469-8986.00012)

Morris, J. S., Öhman, A. & Dolan, R. J. 1998 Conscious and unconscious emotional learning in the amygdala. *Nature* **393**, 467–470. (doi:10.1038/30976)

Naccache, L. & Dehaene, S. 2001*a* Unconscious semantic priming extends to novel unseen stimuli. *Cognition* **80**, 215–229. (doi:10.1016/S0010-0277(00)00139-6)

Naccache, L. & Dehaene, S. 2001*b* The priming method: imaging unconscious repetition priming reveals an abstract representation of number in the parietal lobes. *Cereb. Cortex* **11**, 966–974. (doi:10.1093/ cercor/11.10. 966)

Naccache, L., Blandin, E. & Dehaene, S. 2002 Unconscious masked priming depends on temporal attention. *Psychol. Sci*. **13**, 416–424. (doi:10.1111/1467-9280.00474)

Naccache, L., Gaillard, R., Adam, C., Hasboun, D., Clemenceau, S., Baulac, M., Dehaene, S. & Cohen, L. 2005 A direct intracranial record of emotions evoked by subliminal words. *Proc. Natl Acad. Sci. USA* **102**, 7713–7720. (doi:10.1073/pnas.0500542102)

Nakamura, K., Dehaene, S., Jorbert, A., Le Bihan, D. & Kouider, S. 2005 Subliminal convergence of Kanji and Kana words: further evidence for functional parcellation of the posterior temporal cortex in visual word perception. *J. Cogn. Neurosci*. **17**, 954–968. (doi:10.1162/0898 929054021166)

Nakamura, K., Hara, N., Kouider, S., Takayama, Y., Hanajima, R., Sakai, K. & Ugawa, Y. 2006 Task-guided selection of the dual neural pathways for reading. *Neuron* **52**, 1–8. (doi:10.1016/j.neuron.2006.09.030)

Neely, J. H. 1991 Semantic priming effects in visual word recognition: a selective review of current findings and theories. In Basic *processes in reading; Visual word recognition* (eds D. Besner & G. Humphreys), pp. 264–337. Hillsdale, NJ: Erlbaum.

Neumann, O. & Klotz, W. 1994 Motor responses to nonreportable, masked stimuli: where is the limit of direct parameter specification? In *Conscious and nonconscious information processing: attention and performance*, vol. 15 (eds C. Umiltá & M. Moscovitch), pp. 123–150. Cambridge, MA: MIT Press.

Nolan, K. A. & Caramazza, A. 1982 Unconscious perception of meaning: a failure to replicate. *Bull. Psychon. Soc*. **20**, 23–26.

Ohman, A. 2002 Automaticity and the amygdala: noncon-scious responses to emotional faces. *Curr. Dir. Psychol. Sci*. **11**, 62–66. (doi:10.1111/1467-8721.00169)

Pierce, C. S. & Jastrow, J. 1884 On small differences in sensation. *Mem. Natl Acad. Sci*. **3**, 75–83.

Perea, M. & Gotor, A. 1997 Associative and semantic priming effects occur at very short stimulus-onset asynchronies in lexical decision and naming. *Cognition* **62**, 223–240. (doi:10.1016/S0010-0277(96)00782-2)

Perfetti, C. A. & Bell, L. 1991 Phonemic activation during the first 40 ms of word identification: evidence from backward masking and masked priming. *J. Mem. Lang*. **30**, 473–485. (doi:10.1016/0749-596X(91)90017-E)

Perfetti, C. A., Bell, L. & Delaney, S. 1988 Automatic phonetic activation in silent word reading: evidence from backward masking. *J. Mem. Lang*. **27**, 59–70. (doi:10. 1016/0749-596X(88)90048-4)

Perruchet, P. & Vinter, A. 2002 The self-organizing consciousness. *Behav. Brain Sci*. **25**, 297–330.

Perry, C. & Ziegler, J. C. 2002 On the nature of phonological assembly: evidence from backward masking. *Lang. Cogn. Process*. **17**, 31–59. (doi:10.1080/01690960042000157)

Pessoa, L. 2005 To what extent are emotional stimuli processed without attention and awareness? *Curr. Opin. Neurobiol*. **15**, 188–196. (doi:10.1016/j.conb.2005.03. 002)

Pessoa, L., Japee, S. & Ungerleider, L. G. 2005 Visual awareness and the detection of fearful faces. *Emotion* **5**, 243–247. (doi:10.1037/1528-3542.5.2.243)

Pessoa, L., Japee, S., Sturman, D. & Ungerleider, L. G. 2006 Target visibility and visual awareness modulate amygdala responses to fearful faces. *Cereb. Cortex* **16**, 366–375. (doi:10.1093/cercor/bhi115)

Posner, M. I. 1994 Attention: the mechanism of consciousness. *Proc. Natl Acad. Sci. USA* **91**, 7398–7402. (doi:10. 1073/pnas.91.16.7398)

Posner, M. I. & Snyder, C. R. R. 1975 Attention and cognitive control. In *Information processing and cognition: the Loyola symposion* (ed. R. L. Solso). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Posner, M. I., Walker, J. A., Friedrich, F. J. & Rafal, R. 1984 Effects of parietal injury on covert orienting of visual attention. *J. Neurosci*. **4**, 1863–1874.

Pratkanis, A. R. 1992 The cargo-cult science of subliminal persuasion. *Skept. Inq*. **16**, 260–272.

Purcell, D. G., Stewart, A. L. & Stanovich, K. E. 1983 Another look at semantic priming without awareness. *Percept. Psychophys*. **34**, 65–71.

Rastle, K. & Bryasbert, M. 2006 Masked phonological priming effects in English: are they real? Do they matter? *Cogn. Psychol*. **53**, 97–145. (doi:10.1016/j.cogpsych.2006. 01.002)

Rastle, K., Davis, M. H., Marslen-Wilson, W. D. & Tyler, L. K. 2000 Morphological and semantic effects in visual word recognition: a time-course study. *Lang. Cogn. Process*. **15**, 507–537. (doi:10.1080/01690960050119689)

Raymond, J. E., Shapiro, K. L. & Arnell, K. M. 1992 Temporary suppression of visual processing in an RSVP task: an attentional blink? *J. Exp. Psychol. Hum. Percept. Perform*. **18**, 849–860. (doi:10.1037/0096-1523.18.3.849)

Reynvoet, B. & Brysbaert, M. 2004 Cross-notation number priming investigated at different stimulus onset asynchronies in parity and naming tasks. *Exp. Psychol*. **51**, 81–90.

Reynvoet, B., Caessens, B. & Brysbaert, M. 2002 Automatic stimulus-response associations may be semantically mediated. *Psychon. Bull. Rev*. **9**, 107–112.

Reynvoet, B., Gevers, W. & Caessens, B. 2005 Unconscious primes activate motor codes through semantics. *J. Exp. Psychol. Learn. Mem. Cogn*. **31**, 991–1000. (doi:10.1037/ 0278-7393.31.5.991)

Rolke, B., Heil, M., Streb, J. & Henninghausen, E. 2001 Missed prime words within the attentional blink evoke an N400 semantic priming effect. *Psychophysiology* **38**, 165–174. (doi:10.1017/ S0048577201991504)

Rusconi, E., Priftis, K., Rusconi, M. L. & Umilta, C. 2006 Arithmetic priming from neglected numbers. *Cogn. Psychol*. **23**, 227–239.

Schacter, D. L. 1987 Implicit memory: history and current status. *J. Exp. Psychol. Learn. Mem. Cogn*. **13**, 501–518. (doi:10.1037/0278-7393.13.3.501)

Schlaghecken, F. & Eimer, M. 2006 Active masks and active inhibition: a comment on Lleras and Enns 2004 and on Verleger, Jaskowski, Aydemir, van der Lubbe, and Groen 2004. *J. Exp. Psychol. Gen*. **135**, 484–494. (doi:10.1037/ 0096-3445.135.3.484)

Schneider, W. & Shiffrin, R. W. 1977 Controlled and automatic human information processing, vol. I. Detection, search, and attention. *Psychol. Rev*. **84**, 1–66. (doi:10. 1037/0033-295X.84.1.1)

Schnyer, D. M., Allen, J. J. & Forster, K. I. 1997 Event-related brain potential examination of implicit memory processes: masked and unmasked repetition priming. *Neuropsychology* **11**, 243–260. (doi:10.1037/0894-4105. 11.2.243)

Sereno, J. A. 1991 Graphemic, associative, and syntactic priming effects at brief stimulus onset asynchrony in lexical decision and naming. *J. Exp. Psychol. Learn. Mem. Cogn*. **17**, 459–477. (doi:10.1037/0278-7393.17.3.459)

Sergent, C., Baillet, S. & Dehaene, S. 2005 Timing of the brain events underlying access to consciousness during the attentional blink. *Nat. Neurosci*. **8**, 1391–1400. (doi:10. 1038/nn1549)

Shanks, D. R. & St John, M. F. 1994 Characteristics of dissociable human systems. *Behav. Brain Sci*. **17**, 367–447.

Shapiro, K. L., Driver, J., Ward, R. & Sorensen, R. E. 1997 Priming from the attentional blink: a failure to extract visual tokens but not visual types. *Psychol. Sci*. **8**, 95–100. (doi:10.1111/j.1467-9280.1997. tb00689.x)

Shen, D. & Forster, K. I. 1999 Masked phonological priming in reading Chinese words depends on the task. *Lang. Cogn. Process*. **14**, 429–459. (doi:10.1080/016909699386149)

Sidis, B. 1898 *The psychology of suggestion*. New York, NY: Appleton.

Stroh, M. A., Shaw, M. & Washburn, M. F. 1908 A study of guessing. *Am. J. Psychol*. **19**, 243–245. (doi:10.2307/ 1412764)

Sumner, P., Tsai, P. C., Yu, K. & Nachev, P. 2006 Attentional modulation of sensorimotor processes in the absence of perceptual awareness. *Proc. Natl Acad. Sci. USA* **103**, 10 520–10 525. (doi:10.1073/pnas.0601974103)

Swinney, D. 1979 Lexical access during sentence comprehension: (Re)consideration of context effects. *J. Verb. Learn. Verb. Behav*. **18**, 645–660. (doi:10.1016/S0022-5371(79)90355-4)

Taylor, D. A. 1977 Time course of context effects. *J. Exp. Psychol. Gen*. **106**, 404–426. (doi:10.1037/0096-3445. 106.4.404)

Thompson, K. G. & Schall, J. D. 1999 The detection of visual signals by macaque frontal eye field during masking. *Nat. Neurosci*. **2**, 283–288. (doi:10.1038/6398)

Tipper, S. P. 1985 The negative priming effect: inhibitory priming by ignored objects. *Q. J. Exp. Psychol. A* **37**, 571–590.

Tse, P. U., Martinez-Conde, S., Schlegel, A. A. & Macknik, S. L. 2005 Visibility, visual awareness, and visual masking of simple unattended targets are confined to areas in the occipital cortex beyond human V1/ V2. *Proc. Natl Acad. Sci. USA* **102**, 17 178–17 183. (doi:10.1073/pnas.05080 10102)

Tyler, L. K., Bright, P., Dick, E., Tavares, P., Pilgrim, L., Fletcher, P., Greer, M. & Moss, H. 2003 Do semantic categories activate distinct cortical regions? Evidence for a distributed neural semantic system. *Cogn. Neuropsychol*. **20**, 541–559. (doi:10.1080/02643290244000211)

Tzelgov, J., Henik, A. & Porat, Z. 1997 Automaticity and consciousness: is perceiving the word necessary for reading it? *Am. J. Psychol*. **3**, 429–448. (doi:10.2307/ 1423567)

Van Opstal, F., Reynvoet, B. & Verguts, T. 2005*a* How to trigger elaborate processing? A comment on Kunde, Kiesel, & Hoffmann 2003. *Cognition* **97**, 89–97. (doi:10. 1016/j.cognition.2004.12.011)

Van Opstal, F., Reynvoet, B. & Verguts, T. 2005*b* Unconscious semantic categorization and mask interactions: an elaborate response to Kunde *et al*. 2005. *Cognition* **97**, 107–113. (doi:10.1016/ j.cognition.2005.04.005)

Van Voorhis, B. A. & Dark, V. J. 1995 Semantic matching, response mode, and response mapping as contributors to retroactive and proactive priming. *J. Exp. Psychol. Learn. Mem. Cogn*. **21**, 913–932. (doi:10.1037/0278-7393.21.4. 913)

Verleger, R., Jaśkowski, P., Aydemir, A., van der Lubbe, R. & Groen, M. 2004 Qualitative differences between conscious and nonconscious processing? On inverse priming induced by masked arrows. *J. Exp. Psychol. Gen*. **133**, 494–515. (doi:10.1037/0096-3445.133.4.494)

Volpe, B. T., Ledoux, J. E. & Gazzaniga, M. S. 1979 Information processing in an "extinguished" visual field. *Nature* **282**, 722–724. (doi:10.1038/282722a0)

Vuilleumier, P. & Driver, J. 2007 Modulation of visual processing by attention and emotion: windows on causal interactions between human brain regions. *Phil. Trans. R. Soc. B* **362**, 837–855. (doi:10.1098/rstb.2007.2092)

Whalen, P. J., Rauch, S. L., Etcoff, N. L., McInerney, S. C., Lee, M. & Jenike, M. A. 1998 Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. *J. Neurosci*. **18**, 411–418.

Williams, P. & Parkin, A. 1980 On knowing the meaning of words we are unable to report: a confirmation of a guessing explanation. *Q. J. Exp. Psychol*. **32**, 101–107.