Review

Exploring the unconscious using faces

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Understanding the mechanisms of unconscious processing is one of the most substantial endeavors of cognitive science. While there are many different empirical ways to address this question, the use of faces in such research has proven exceptionally fruitful. We review here what has been learned about unconscious processing through the use of faces and face-selective neural correlates. A large number of cognitive systems can be explored with faces, including emotions, social cueing and evaluation, attention, multisensory integration, and various aspects of face processing.

Faces as a window to study unconscious processing

Do we process information unconsciously? If so, what are the mechanisms of unconscious processing? This question has puzzled researchers and laymen for centuries [1]. However, the real surge in scientific investigation in this field only started in the past two decades – largely due to the availability of modern neuroimaging methods that permit the exploration of the neural mechanisms of consciousness [2]. In the current review we synthesize the evidence regarding the unconscious processing of one particular visual category – faces. There are two key reasons for focusing specifically on faces. First, the amount and richness of information conveyed by a face stimulus extends beyond the visual image *per se*. Therefore, because different cognitive systems are engaged in various aspects of face processing, the use of faces provides an outstanding opportunity to explore the general mechanisms of unconscious processing. Second, consciously visible faces elicit a reliable and large brain response. Therefore, these face-selective neural correlates can serve as a powerful tool (i.e., biomarker) to explore mechanisms of unconscious processing.

In our review we first introduce the research methodology that is used to investigate mechanisms of unconscious processing in general, and the unconscious processing of faces in particular. In the first part of the discussion we demonstrate what the use of faces has revealed about unconscious processing by different cognitive systems. We make a distinction between cognitive systems involved in social cognition and affective processing, versus cognitive systems that do not include an affective component. In the second part we discuss mechanisms of the unconscious processing of faces that are face-specific, non-generic, and primarily visual.

Methodology of exploring unconscious processing

An essential part of experiments that explore unconscious processing is that the experimental manipulation should remain unconscious for participants (e.g., a picture of a face that is shown should be unnoticed by the participant). For the visual modality, several techniques are available to render a stimulus invisible to the observer [3]. For the sake of simplicity, the stimuli that were rendered invisible hereafter are referred to as 'invisible stimuli' (or 'invisible faces'). The two most frequently used techniques are (i) backward/forward masking [4] (see Glossary and Figure 1A), in which a mask shown after, and, in some case also before, a briefly presented stimulus prevents participants from consciously seeing the stimulus, and (ii) continuous flash suppression (CFS) [5] (Figure 1B), in which a constantly changing pattern of different shapes projected to one eye prevents participants from seeing a target image projected to the other eye. Additional techniques, listed in the Glossary and illustrated in Figure 1C–H, include binocular rivalry, binocular fusion, change detection (or change blindness), attentional blink, object substitution masking, and crowding.

The techniques mentioned above are used in experiments with healthy participants. In addition, in rare cases of brain damage, patients might not consciously see a visible-for-all stimulus; nevertheless, they might still be able to guess above chance some properties about the stimulus. The two phenomena with this characteristic behavior are blindsight ([6] for review) and spatial neglect ([7] for review), and they result from lesions in striate cortex and posterior parietal lobe, respectively.

Methodologically, how can we establish that invisible stimuli were indeed processed? Unconscious processing can be detected using behavioral measures, as, for example, in the case of subliminal priming, when an invisible stimulus (prime) might modulate perception of the visible stimulus (probe) that is shown after the prime. Another possible manifestation of unconscious processing is a change in autonomic body response, such as a change in skin conductance (e.g., [8]). Finally, invaluable sources of information regarding unconscious processing include neuroimaging [fMRI, electroencephalography (EEG), magnetoencephalography (MEG)] and electrophysiology [single-cell recording and electrocorticography (ECoG) methods] [2]. These methods make it possible to establish the type of stimuli or type of cognitive processing that can be processed unconsciously, and indicate which brain regions are

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Glossary

Attentional blink paradigm: a rapid sequence of images containing a T1 distractor target is followed after several hundred ms by a T2 main target (Figure 1F). The participant must make a judgment about both targets. The main target (T2) is frequently missed because of attentional focus on the processing distractor target (T1).
Backward and forward masking paradigm: a briefly presented stimulus (tens of ms) is followed and might also be preceded by a mask image (Figure 1A). As a result of manipulation, the stimulus becomes consciously invisible. The experimental task is usually subliminal priming (see below).
Binocular rivalry paradigm: two different stimuli (e.g., face and house) are projected dichoptically to different eyes – a manipulation that results in a spontaneously fluctuating percept of each monocular stimulus (Figure 1C).
Binocular fusion paradigm: the same image with contrast-reversed colors is projected to each eye ('opposite stimulation' in Figure 1D) – a procedure that renders the image perceptually invisible.
Blindsight: some patients (usually after stroke or head injury) lose the conscious ability to see (in part of the visual field or completely) but can nevertheless correctly guess properties of an invisible stimulus. Blindsight occurs as a result of brain damage in the early visual cortex (cortical blindness) ([6] for review).
Capgras delusion: people who suffer from this disorder are able to visually recognize a face, but they deny that this person is familiar to them (e.g., they might claim that someone 'looks like my husband' or 'pretends to be him'). This disorder is usually a result of psychiatric illness or brain injury [48].
Change detection: (change blindness) paradigm: two sets of stimuli (or two complex pictures) are presented one after another, separated by an intervening screen (Figure 1E). There is a slight difference between two sets of stimuli that cannot be easily detected because the spatial location of the change is not known in advance.
Charles Bonnet Syndrome: a condition in which fully or partially blind patients experience complex hallucinations (e.g., faces).
Continuous flash suppression (CFS) paradigm: the target stimulus (e.g., a face) is projected to one eye while a constantly changing pattern of different shapes (Mondrian pattern) is projected to the other (Figure 1B). In one variation of the paradigm, usually used in imaging experiments (e.g., [67]), at the end of the trial the participant has to guess the type or some properties of the invisible stimulus (e.g., was it face or not). Another variation, named 'breaking continuous flash suppression' (b-CFS) ([89] for recent review), is used mostly in behavioral experiments. During the trial the contrast of an invisible stimulus is gradually ramped up such that at some stage the stimulus becomes visible. The dependant variable is the time until the 'emergence to consciousness' and this is compared between conditions (e.g., upright versus inverted faces [80]).
Crowding paradigm: the participant in the experiment fixates on some location while the target face is shown at the periphery of the visual field; the target stimulus (e.g., face) is surrounded by distractor stimuli (Figure 1H). As a result, some parameters about the face (e.g., type of facial emotion) might be not identified. For the stimulation be classified as 'unconscious', it is crucial to ensure that the fixation is maintained during the whole trial (i.e., the target stimulus is always at the periphery of the visual field). An elegant solution to this problem is a gaze-contingent crowding procedure [90], where the gaze direction of the participants is eye-tracked in real time. Once the program detects that the fixation has been broken, the target stimulus is replaced with a meaningless image.
Disorders of consciousness: a range of clinical conditions such as coma, vegetative state, and a minimally consciousness state in which a patient fully or partially loses self-awareness.
Inattentional blindness paradigm: a failure to notice a clearly visible stimulus owing to diverted focus of attention. In the experimental paradigm, the participant performs a very difficult secondary task while a small target is unexpectedly and briefly shown (e.g., [51]).
Object substitution masking (OSM) paradigm: a set of images consisting of the target face and several distractors is shown briefly; the target is surrounded by a frame or dots – the surrounding frame remains on the screen after the set of images disappears (Figure 1G). The surrounding frame after offset of the stimuli creates an illusory effect that there was no target stimulus. The benefit of this paradigm compared to backward/forward masking is that the spatial location of the frame in the OSM does not overlap with the stimulus.
Spatial neglect: this phenomenon is similar to blindsight (absence of conscious vision) but occurs as a result of brain damage to the posterior parietal lobe, which controls the mechanisms of attention (for differences between blindsight and spatial neglect see [7]).
Subliminal priming paradigm: the experimental task is to make a speed judgment about a visible 'probe' stimulus that is preceded by an invisible 'prime' (Figure 1A). To render the 'prime' invisible, most experiments use backward/forward masking. A subtype of the subliminal priming paradigm is 'subliminal affective priming', in which an invisible prime picture contains emotional content (e.g., an emotional face).
Prosopagnosia: a disorder characterized by the inability to recognize faces, either as a result of brain damage of the visual areas in the occipital or posterior temporal lobe (acquired prosopagnosia) or due to an innate brain malfunction (congenital prosopagnosia). The lesion in case of acquired prosopagnosia is usually right lateralized [91].

involved in this unconscious processing. Crucially, the major advantage of using faces in exploring mechanisms of unconscious processing is that the brain contains well-established and reliably localized face-selective neural correlates. In particular, in the fMRI domain, the largest face-selective regions are the fusiform face area (FFA), occipital face area (OFA), posterior superior temporal sulcus (pSTS), and prefrontal face area [9–11] (Figure IA); in the EEG/MEG domain, the most face-selective components are N170/M170 (Figure IB) [12,13]. These face-selective correlates can serve as biomarkers of unconscious processing. Advantages of using face-selective neural correlates are discussed in Box 1.

What can faces teach us about unconscious processing in general?

Cognitive systems involved in social cognition

Emotions. Unconscious emotional processing has been the focus of many studies in recent decades ([14–16] for review), most of which have used invisible facial emotions as a stimulus of choice. Although the neural mechanisms of unconscious emotional processing are highly debated ([14,16] for reviews), all seem to agree that unconscious emotions can be processed outside of awareness.

In behavioral studies, researchers have repeatedly shown that unconscious emotional faces can be detected above chance level in healthy and brain-damaged patients (e.g., [17,18]). In the subliminal affective priming paradigm [19], primed invisible emotional faces modulate the judgment of a subsequent visible probe stimulus (e.g., [20]) and change consumption behaviors (e.g., [21]). The effects of affective priming are usually short-lived (ms or seconds); but, in some cases, they can extend to as long as 24 h [22]. Indirect autonomic body responses have also been shown to be sensitive to unconscious emotion processing. For example, participants could synchronize their own facial expression to unconsciously presented facial images [23].

A large body of evidence regarding unconscious facial emotion processing has also accumulated in the neuroimaging domain ([16] for review). For example, with healthy participants, in one of the most remarkable studies participants were exposed to the white parts of the eyes that were rendered invisible; the researchers showed that the invisible eyes with fearful, as opposed to happy, expressions elicited higher responses in the amygdala [24] (Figure 2A). More recent studies have gone further by demonstrating that different sub-parts of the amygdala are sensitive to fearful faces depending on participant awareness of a face [25]. Although the amygdala is the most frequent locus of activation elicited by unconscious emotional stimuli in general and emotional faces in particular [15,16], a recent meta-analysis [26] suggests that the insula, fusiform gyrus, anterior cingulate, and hippocampus are also involved in unconscious emotional processing. Interestingly, a recent ERP study found that infants aged 7 months are already able to discriminate invisible fearful from non-fearful eyes [27].

Unconscious processing of emotions was also shown with brain-damaged patients. For example, the patient T.N., who suffered from bilateral lesions to the early visual cortex [28], was able to discriminate between facial emotions beyond

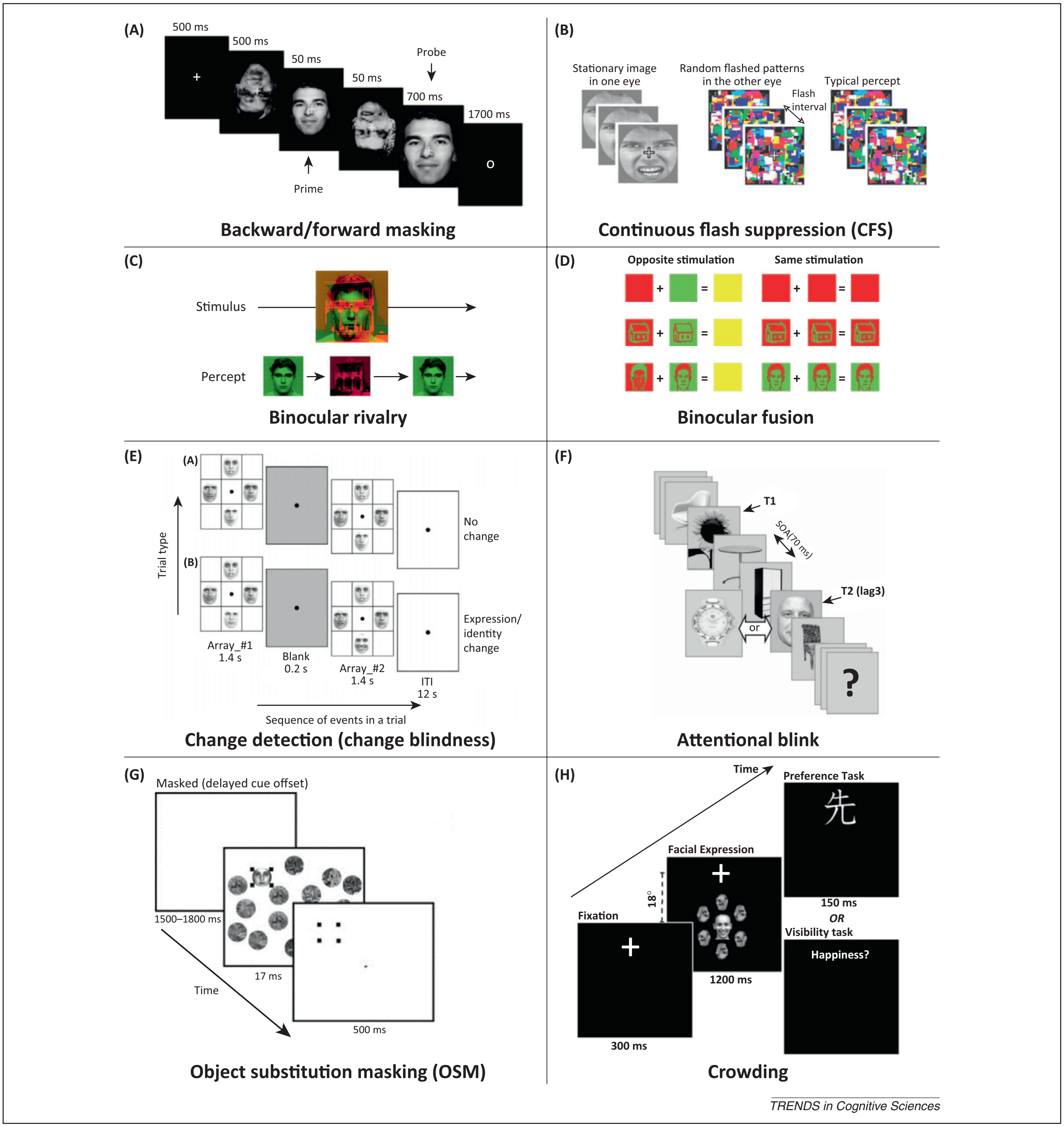

Figure 1. Invisibility manipulations used to render faces invisible. **(A)** Backward and forward masking paradigm, reproduced, with permission, from [41]. **(B)** Continuous flash suppression (CFS) paradigm, reproduced, with permission, from [5]. **(C)** Binocular rivalry paradigm, reproduced, with permission, from [92]. **(D)** Binocular fusion paradigm, reproduced from [68]. **(E)** Change detection paradigm, reproduced, with permission, from [93]. **(F)** Attentional blink paradigm, reproduced, with permission, from [53]. **(G)** Object substitution masking (OSM) paradigm, reproduced from [75]. **(H)** Crowding paradigm, reproduced from [90].

chance level despite not consciously being able to report their presence, a phenomenon known as blindsight; in addition, the response in his amygdala was higher to emotional than to neutral faces [28] (Figure 2B).

Social evaluation. In a pioneering series of studies conducted almost half a century ago, it was shown that face images of the opposite sex with larger pupils are judged as more attractive than those with smaller pupils [29]. Crucially, the participants did not consciously notice that the pupils differed in size. More recently, using the breaking continuous flash suppression paradigm (b-CFS), it was shown that images of dominant and untrustworthy faces, compared to neutral faces, took a longer time to emerge to awareness [30]. In a follow-up study using voxel-based morphometric (VBM) analysis, the authors correlated

Box 1. On the advantages of using face-selective neural correlates for exploring unconscious processing

The face-selective neural correlates (fMRI regions and ERP component) are localized by contrasting the brain activity elicited by visible faces versus non-face stimuli (Figure IA,B). These correlates are extensively explored in studies that aim to understand general mechanisms of face processing (e.g., [9–13,94,95]). Remarkably, face-selective correlates have also become a convenient biomarker to study unconscious processing. There are three main reasons to use face-selective correlates to explore unconscious mechanisms.

(i) Faces have corresponding neural correlates for both fMRI and EEG/MEG modalities. Thus, they allow testing of the same experimental phenomenon using both fMRI and EEG/MEG (e.g., [73,96]).

(ii) fMRI face-selective regions span large portions of the brain (Figure IA), permitting unconscious processing to be explored at different levels of the hierarchy. An excellent demonstration of this approach was provided by a study that used a change detection paradigm to examine whether fMRI face-selective regions can be sensitive to a change of face identity or emotion [93]. The authors showed that the lower-level OFA was sensitive to a physical change of face image without the participant's conscious percept (Figure IC, red arrow); remarkably, the higher-level FFA and pSTS regions were also sensitive to physical change, but only when participants were consciously aware of the change (Figure IC, blue arrows).

(iii) Face-selective brain correlates can be used in both humans and monkeys [97]. This is in contrast, for example, to fMRI word-selective areas [98], which exist only in humans.

In addition to exploring unconscious processing, face-selective brain correlates can be used to explore different conscious states such as dreams, hallucinations, or disorders of consciousness; no behavioral reports can be typically obtained in these states. Using fMRI and based on the activity in the visual cortex and the face-selective regions, researchers were able to decode the contents of healthy participants' dreams [99], as well hallucination content experienced by patients with Charles Bonnet syndrome [100] and schizophrenia [101]. Finally, testing the fMRI activation of brain-selective regions was shown to be helpful in the clinical diagnosis and prognosis of patients suffering from disorders of consciousness. In particular, a recent study [102] demonstrated spared face-selective activity in the FFA (Figure ID) and the amygdala in four patients in a vegetative state ([103] for similar findings). Remarkably, two patients with the strongest connectivity between these two regions later regained full consciousness.

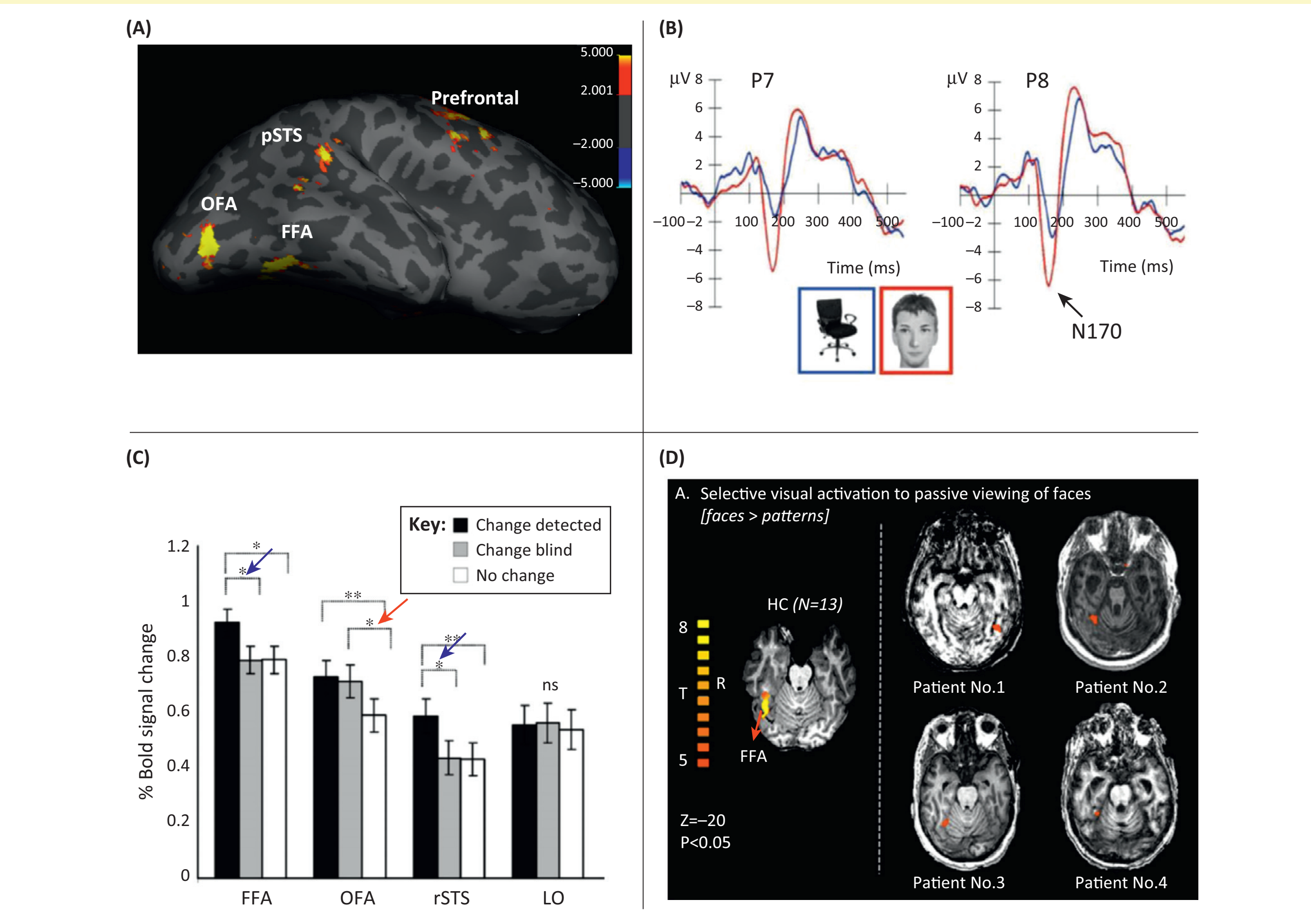

Figure I. Using face-selective neural correlates to explore unconscious processing. **(A)** fMRI face-selective regions in the occipital-posterior cortex (fusiform face area [FFA], occipital face area [OFA], posterior superior temporal sulcus [pSTS]), and in the frontal lobe. Data are from a representative participant [11] overlaid on an inflated anatomical surface of the right hemisphere ($P < 0.001$, contrast: face > objects). **(B)** Face-selective ERP N170 component in the right (P8) and left (P7) hemispheres reproduced, with permission, from [95]. **(C)** Unconscious processing of change detection (for the paradigm, see Figure 1E): the physical change was detected only in the OFA (significant difference between 'change blind' and 'no change'; red arrow). A change in the conscious percept was detected only in the FFA and STS (significant difference between 'change detected' and 'change blind'; blue arrows). Reproduced, with permission, from [93]. **(D)** Brain activations in the fusiform face area (FFA) of four patients in the vegetative state and 13 control participants (faces versus pattern contrast); the highest activations elicited by contrasting faces versus patterns are indicated by yellow. Reproduced from [102].

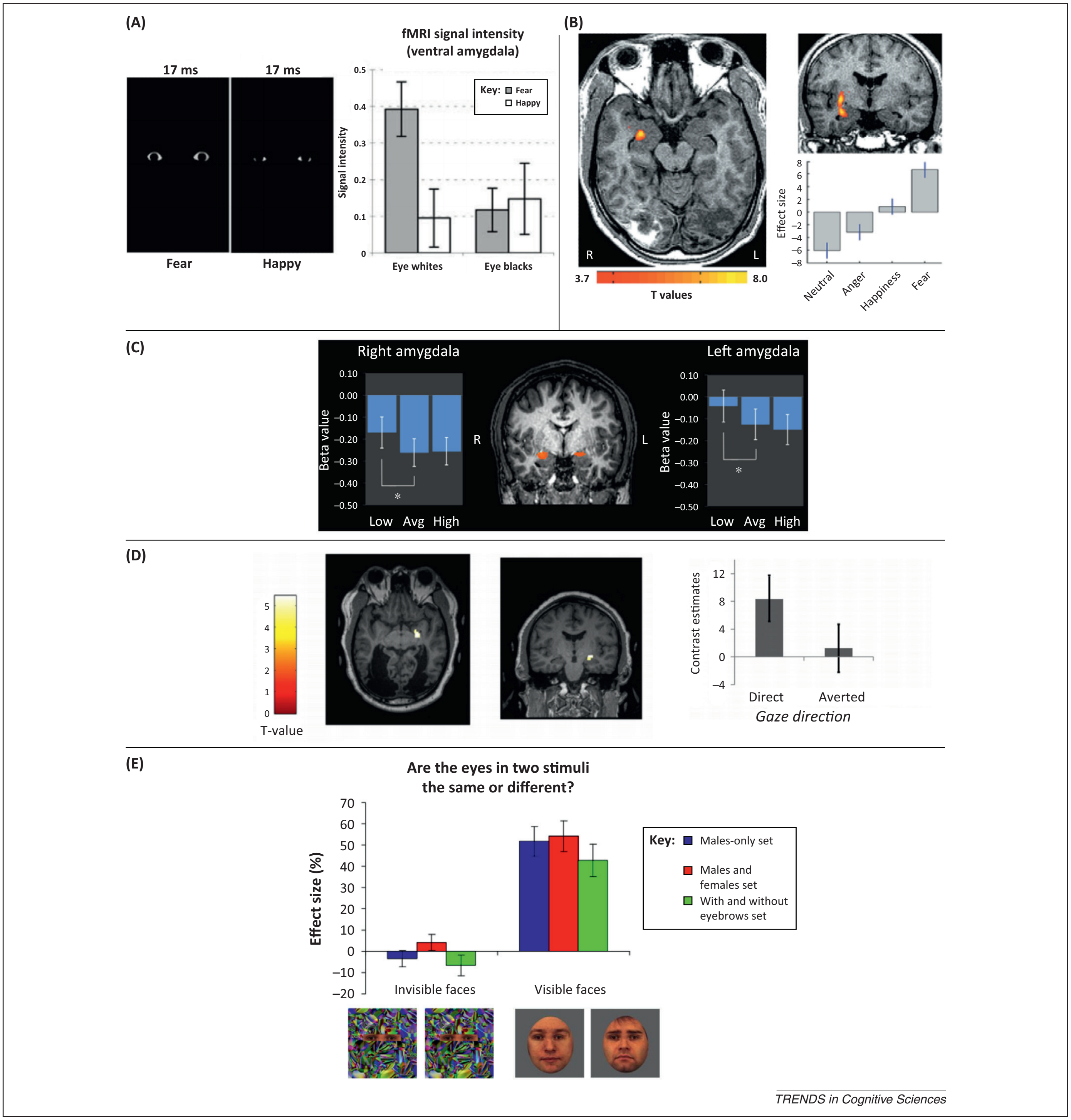

Figure 2. Exploring different cognitive systems using invisible faces. **(A)** fMRI study with healthy participants. Left, examples of stimuli (fearful and happy eye-whites); right, significantly higher response in the ventral amygdala for invisible fearful eye-whites compared to happy eye-whites. Reproduced, with permission, from [24]. **(B)** Brain-damaged patient T.N. (lesion in the striate cortex). Unconscious emotional faces (fear, anger, happiness) elicited higher activation of the right amygdala than did a neutral face. Functional activations are projected on the axial and coronal T1-weighted image. Radiological convention: the right side of the brain is shown on the left side. Reproduced, with permission, from [28]. **(C)** Study with healthy participants. Group-level activations of the amygdala in response to invisible faces independently rated as having different levels of trustworthiness. Note stronger bilateral amygdala activation for low-trustworthy faces. Error bars indicate standard error of the mean. Reproduced, with permission, from [32]. **(D)** The same T.N. patient as in (B): an unconsciously presented directed gaze elicited higher activations in the right amygdala compared to an averted gaze. The bar chart shows contrast estimates for directed and averted gaze. Functional activations are projected on the axial and coronal T1-weighted image. Neurological convention: the right side of the brain is shown on the right side. Note the lesion in the striate cortex. Reproduced, with permission, from [39]. **(E)** Healthy participants were asked to discriminate between the visible eyes of two consecutively presented stimuli; the faces were either visible or invisible. Visible, but not invisible, faces influenced judgment of the eyes. Reproduced from [87].

individual differences in time to emerge to awareness with volume of grey matter in different brain regions [31]. For dominant faces, the authors found significant correlations in the right insula; for untrustworthy faces, the significant correlation was found in the medial prefrontal cortex, right temporoparietal junction, and bilateral fusiform face area. Finally, a recent fMRI study found that the activation level of the amygdala reflected trustworthiness of the face images that were not consciously seen (Figure 2C) [32].

Social cuing. Social cuing is the attraction of someone's attention by means of a gaze, head-view, or body gesture. While most research has focused on gaze processing when participants are consciously aware of the stimulus, a growing body of evidence suggests that the gaze can be also processed unconsciously. For instance, using a backward masking paradigm, it was found [33] that gaze direction in a rendered invisible face can trigger attentional shift (for comparable results using the CFS paradigm, see [34]). To this extent, attentional shift triggered by rendered invisible gaze is qualitatively similar to the effect elicited by unconscious endogenous cues such as an arrow ([35] for review). Using the b-CFS paradigm, it was also shown that invisible faces with directed gaze reach awareness faster than faces with averted gaze (e.g., [36]). Similar results were obtained in a study testing the effect of face-view for invisible faces [37] – using b-CFS, the researchers reported that faces directed toward the observer broke through suppression faster than did averted faces.

At the neural level, in an event-related potentials (ERP) experiment with healthy participants, researchers have shown that an invisible directed gaze compared to a diverted gaze elicited larger negative deflections at 200–350 ms over the parietofrontal electrodes [38]. In addition, interesting findings were recently obtained in an fMRI experiment with the cortically blind patient T.N. [39] (referred to previously in the context of emotional processing [28]). In particular, the response in T.N.'s amygdala was higher when he was exposed to a face with a directed gaze as compared to a diverted gaze, even though his condition prevented him from being consciously aware of either face (Figure 2D).

Familiarity and covert recognition. Familiarity with a stimulus is a feeling that the stimulus had been encountered previously (e.g., we have already seen it). It is plausible that the processing of familiarity is not limited to the memory system, but also includes an affective component – such as when one encounters the odor of a perfume that was once used by a girlfriend from high school. The question is whether the processing of familiarity can be invoked and can operate without conscious awareness. To this extent, faces are a convenient test stimulus because various aspects of familiarity can be ecologically manipulated with faces (e.g., image of a self, personal familiar faces, faces of celebrities, faces that were studied in the course of the experiment).

Unconscious mechanisms of familiarity have been tested with healthy participants using invisible faces, and the evidence clearly supports the unconscious familiarity processing hypothesis. In particular, using b-CFS, it was shown that personally familiar faces reach awareness faster than unfamiliar faces [40]. In addition, studies using both masking (e.g., [41,42]) and crowding [43] paradigms showed that only famous, and not unfamiliar, face identities could be processed unconsciously.

An outstanding opportunity to explore unconscious familiarity processing is provided by prosopagnosia, an unfortunate condition characterized by the inability to consciously recognize faces. Strikingly, some prosopagnosic patients, despite their inability to overtly recognize a face, demonstrate differential responses to the faces that they had previously seen versus new faces (covert face recognition) [44]. Covert face recognition can be observed in the form of elevated skin conductance and enhanced P300 ERP component (e.g., [45]) as well as fMRI activations in the occipitotemporal lobe (e.g., [46]). Covert face recognition has been reported for both acquired and congenital prosopagnosia ([44,47] for review).

Interestingly, while the impaired face recognition mechanism in prosopagnosia is accompanied by intact familiarity processing, people who suffer from Capgras delusion have intact visual face recognition but impaired familiarity ([48] for review). In particular, these patients can visually recognize the face they see (e.g., a patient may say that a person looks like his or her spouse), but still deny that he or she is familiar with this person (e.g., by claiming that this is an identical-looking impostor). Thus, an example of Capgras delusion illustrates that familiarity processing is an integral part of the face recognition system.

Non-affective types of cognitive processing

Attention. The relationship between attention and consciousness is complex ([49] for review). A particularly interesting question is whether unconscious processing can be carried out independently of attention. Faces constitute a strong test-case because faces are extremely salient and appear to be processed automatically [15,50]. In particular, faces are easily noticed and detected in inattentional blindness [51], change detection [52], attentional blink (Figure 1F) [53], and visual search paradigms (e.g., [54]; for similar findings with brain-damaged patients, see [55]). Thus, if it were found that the allocation of attention can modulate unconscious processing of automatically processed stimuli such as faces, then this would provide strong support for the dissociative nature of attention and consciousness [49].

Two studies with invisible faces that used dichotic stimulation with an after-effect probe indeed found that spatial attention significantly modulated unconscious processing of faces [56,57]. By contrast, two other studies [58,59] that used priming paradigms with backward masking failed to find an effect of spatial attention modulation. While the discrepancy in the results can be attributed to a difference in paradigms and invisibility manipulations (Box 2), it is also possible that the attentional task was not demanding enough, at least in one of the latter studies [58]. To resolve this discrepancy, additional research is needed.

Multisensory integration. Multisensory integration is the process of neural integration of different sensory modalities. To what extent multisensory integration can be achieved unconsciously is a subject of active investigation ([60] for review). Crucially, one of the most-used tools to study multisensory integration is the McGurk illusion [61], which arises when identically vocalized syllables are perceived as different when accompanied by the image of a person making different lip movements. To study unconscious multisensory integration, one or even both of the modalities can be rendered unconscious.

Box 2. On the differences of invisibility manipulations

In many studies there is no practical difference between invisibility manipulations because they are merely used as a 'black-box' tool to 'hide' a stimulus from awareness. Even so, one should keep in mind that underlying cognitive and neural mechanisms might vary substantially between the manipulations. The invisibility paradigms can be roughly classified according to two principles.

(i) Does the paradigm include manipulation of attention?

In paradigms such as backward and forward masking (see Figure 1A in main text), or binocular paradigms (see Figure 1B–D in main text), only one target stimulus needs to be processed, and the spatial location of this stimulus is usually fixed and predefined. Therefore, the invisible target stimulus is fully attended. By contrast, in paradigms that manipulate attention, such as change detection (see Figure 1E in main text), attentional blink (see Figure 1F in main text), and inattentional blindness, the attention of the observer is artificially reduced or diverted from processing the target stimulus. That is, had the stimulus been attended to, the observer would have been consciously aware of a stimulus. A similar distinction is also made with regard to brain-damaged patients, specifically blindsight (visual cortical blindness, but spared mechanisms of attention) versus spatial neglect (damage to attentional system of the posterior parietal lobe, but spared visual processing) [7].

(ii) Monocular versus binocular visual manipulations

In the binocular class of paradigms (CFS, Figure 1B in main text; binocular rivalry, Figure 1C in main text; binocular fusion, Figure 1D in main text; [104] for recent review), the stimuli are presented dichoptically (i.e., different stimuli to different eyes). Binocular paradigms capitalize on the fact that the visual system is unable to cope with completely incompatible input to the two eyes. As a result, conscious awareness reflects visual input to one of the eyes, while the stimulus projected to the other eye remains invisible. By contrast, in variations of the masking paradigm (backward and forward masking, Figure 1A in main text; object substitution masking, Figure 1G in main text), the stimulation is monocular (i.e., the same input to both eyes). The function of the mask, and especially of the backward mask that comes immediately after the target, is to prevent a deep (re-entrant) processing of the target stimulus – the type of processing that is thought to be associated with, and to be crucial for, conscious awareness [105].

It is noteworthy that not all paradigms are suitable for all types of experiments. In particular, CFS and crowding are the only paradigms that permit us to achieve sustained invisibility for a prolonged period of time (e.g., dozens of seconds) [5,106,107].

To date, three behavioral studies using CFS [62,63] and b-CFS [64] to render faces invisible explored multisensory integration with variations of the McGurk illusion. Remarkably, all three studies found that invisible faces with lip movements congruent with the pronounced syllables were processed faster (congruency effect) than stimuli with lip movements incongruent with the pronounced syllables. In a separate experiment of one of these studies [62], the researchers asked participants to make a direct judgment regarding pronounced (sounded) syllables that were accompanied by invisible faces. This time, no evidence of unconscious multisensory integration was found. Thus, it is possible that an indirect test (congruency effect) was more sensitive than a direct judgment of syllables (see also Ref. [60] for an alternative explanation). Finally, at the neural level, an ERP study found that activity of the occipitotemporal and frontocentral electrodes was modulated in early (~100–200 ms) and late (~300–700 ms) latencies through the interactive processing of invisible emotional faces and voices (sounded) [65]. Thus, results of studies using variations of a McGurk illusion suggest that multisensory integration, at least to some level, can be accomplished unconsciously (see also discussion in [60]).

Exploring unconscious processing of visual stream using faces

The processing of faces is special. On the one hand, as we have shown, the processing of faces engages different general cognitive systems, the processing that is not face-specific (e.g., emotional processing). On the other hand, the visual aspects of face-stimulus analysis involve face-specific processing (e.g., activation of the fMRI face-selective regions in the visual occipitotemporal cortex). In this section we discuss face-specific mechanisms of the unconscious processing of faces. This type of processing is executed only (or at least mostly) in the visual cortex (occipital and ventral temporal lobe). To minimize the influence of other cognitive systems, the face stimuli discussed in this section are unfamiliar and have a neutral facial expression. Notably, one should bear in mind that the exploration of specialized mechanisms has both pros and cons. That is, on the positive side, the insight that we can gain using faces is unique and cannot be achieved using other types of stimuli; however, it should not be taken for granted that the obtained results using faces would generalize to other stimuli.

Discriminating between face and non-face

The most basic question with regard to unconscious processing of faces is whether an invisible face can be discriminated from an invisible non-face (e.g., house). Face-selective neural correlates are optimal tools to address this question, and indeed the studies using CFS (e.g., [66,67]) and binocular fusion (e.g., [68]) paradigms have shown that an invisible face could be discriminated from an invisible non-face in face-selective regions of the visual cortex. Comparable results have also been obtained in EEG/MEG studies using the CFS paradigm, where the N170/M170 component was found for invisible faces ([69–71]; see also a case-study of blindsight patient [72]). It is noteworthy that several studies, especially using EEG, failed to find an unconscious processing effect {e.g., [73–76]; see also the ECoG study [77]}. The notable difference between studies with positive and negative findings is that the former employed variations of dichotic stimulation (i.e., CFS, binocular fusion), whereas the latter used variations of the masking paradigm. Thus, it is possible that differences between the invisibility manipulations contribute to this discrepancy (Box 2).

Discriminating between upright and inverted faces

Inverting an image of a visible face, compared to inverting any other object or visual scene, disproportionally impairs the ability to recognize it (the so-called 'inversion effect' [78]). Accordingly, it is believed that inverted faces are processed differently from upright faces [79]. Several studies have found that invisible inverted faces, compared to invisible upright faces, are also processed differently. In particular, in behavioral studies using a b-CFS paradigm, researchers have found that upright faces reach awareness faster than inverted faces [80–82]. At the neural level, an ERP study found [71] that whether for visible faces the visual component amplitude (N1170) was larger for upright than to inverted faces, for invisible faces the effect was reversed. Thus, different neural

Table 1. Summary of the results of unconscious processing of faces

Cognitive system	Cognitive subsystem	Type of face processing	Can it be processed unconsciously?
Social cognition	Emotions	Invisible facial emotions	Yes
	Social evaluation	Impression from a person based on invisible face (e.g., pleasantness, trustworthiness)	Yes
	Social cuing	Gaze and face view processing	Yes
	Familiarity and covert recognition	Familiarity processing of unconsciously presented faces (healthy participants) Covert face recognition in prosopagnosia	Yes Yes
Non-affective processing	Attention	Modulation of attention by invisible faces	mixed results, more studies are needed
	Multisensory integration	Integration of the invisible face and intact voice (variations of the McGurk illusion)	Yes
Face-specific processing	N/A[a]	Discriminating between face and non-face	Yes (dichotic paradigms) No (monocular paradigms)
	N/A	Discriminating between upright and inverted faces	Yes
	N/A	Processing unfamiliar face identity	No

[a]N/A, not applicable.

mechanisms might be responsible for conscious and unconscious inversion effect.

Processing unfamiliar face identity

Unconscious processing of face identity is a more complex type of processing than those discussed previously because it requires within-category discrimination (subordinate-level face processing). Studies that tested identity processing of invisible unfamilar faces with behavioral measures using CFS [83–85] and masking [41,42,85] found no evidence of unconscious processing. In addition, the gender and race of faces could not be processed without awareness [86]. Finally, a recent study examined whether holistic face processing, an essential component of face recognition [79], can be processed without awareness [87]. The stimulus used in the study contained visible eyes and a face that was rendered invisible using CFS (Figure 2E). The experimental task was to judge whether the eyes of two consecutive stimuli were the same or different. Importantly, the invisible faces in two consecutive stimuli were either the same or different; thus, the changing faces could potentially be interpreted as though the eyes had changed. Using three different sets of images, the authors showed that the change of invisible faces did not influence perception of the eyes (Figure 2E, left bars). Crucially, when faces were fully visible, a significant faces-to-eyes modulation effect was found (Figure 2E, right bars). Taken together, these findings indicate that unfamiliar face identities are not processed unconsciously. This conclusion is in line with the traditional view that the ventral stream of the visual cortex is associated with the conscious processing [88].

Box 3. Outstanding questions

- Is it possible that, using invisible faces (unconscious processing), we can reveal social phenomena that cannot be revealed using visible faces (conscious processing)? For example, can racist biases be revealed reliably by using invisible faces [108]? Can invisible faces be used in the future as a lie detector?
- Are different types of invisible emotional stimuli, such as emotional faces (e.g., expression of horror) and emotional scenes (e.g., scenes of horror), processed similarly? One previous case study with a blindsight patient suggested that invisible emotional faces are processed better (more profoundly) than scenes [28], but no study has directly compared these stimuli types with healthy participants.
- Several studies have reported that invisible emotional faces can be used for diagnosis and for measuring the effectiveness of intervention with patients suffering from depression (e.g., [109]). Would this or similar methods be effective for other psychiatric disorders, such as post-traumatic stress disorder (PTSD)?
- When people look at faces, they focus on characteristic features (e.g., on eyes for Western Caucasian observers [110]). Can similar eye-looking patterns be found for invisible faces? In the clinical domain, will autistic patients, who do not fixate on eyes (or fixate less compared to healthy participants) in visible faces [111], also not fixate on eyes in invisible faces?
- It has been shown that the position of the observer's own hand modulated the way in which he or she perceived an invisible hand [112]. Will one's own facial emotion also modulate the way in which one perceives invisible emotional faces?
- Can a multisensory McGurk illusion be processed unconsciously when both visual and auditory streams are rendered unconscious (see also [60])? Will unconscious multisensory integration processing using the McGurk illusion be enhanced if faces of celebrities are used?
- Will the use of sound in video clips of faces enhance face-selective activation in patients with disorders of consciousness? If so, would this mean that the mechanisms of multisensory integration in these patients have been spared?
- What is the reason for the large saliency of faces? Are there specific facial features that make faces so salient? For example, would the faces with covered (hidden) eyes be less salient in paradigms such as attentional blink [53]?
- Does the depth of unconscious processing in general, and for faces in particular, differ between invisibility paradigms? The results from several recent studies that compared the paradigms using faces have so far been largely inconsistent [85,90,105,113].

Concluding remarks

Faces provide an exceptional opportunity to study the generic mechanisms of unconscious processing. This review has focused on the many insights that science has gained from research on unconscious face processing (Table 1). Cognitive functions related to social cognition and multisensory integration can clearly be processed unconsciously. By contrast, the functioning of visual face-specific mechanisms outside conscious awareness is more limited, and there is already strong evidence against the unconscious processing of unfamiliar face identity. Invisible faces constitute a convenient platform for researchers to address new questions (Box 3), and represent a promising tool in both academic and clinical domains.

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