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Affective Processing Requires Awareness

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Studies using backward masked emotional stimuli suggest that affective processing may occur outside visual awareness and imply primacy of affective over semantic processing, yet these experiments have not strictly controlled for the participants' awareness of the stimuli. Here we directly compared the primacy of affective versus semantic categorization of biologically relevant stimuli in 5 experiments (n = 178) using explicit (semantic and affective discrimination; Experiments 1–3) and implicit (semantic and affective priming; Experiments 4–5) measures. The same stimuli were used in semantic and affective tasks. Visual awareness was manipulated by varying exposure duration of the masked stimuli, and subjective level of stimulus awareness was measured after each trial using a 4-point perceptual awareness scale. When participants reported no awareness of the stimuli, semantic and affective categorization were at chance level and priming scores did not differ from zero. When participants were even partially aware of the stimuli, (a) both semantic and affective categorization could be performed above chance level with equal accuracy, (b) semantic categorization was faster than affective categorization, and (c) both semantic and affective priming were observed. Affective categorization speed was linearly dependent on semantic categorization speed, suggesting dependence of affective processing on semantic recognition. Manipulations of affective and semantic categorization tasks revealed a hierarchy of categorization operations beginning with basic-level semantic categorization and ending with superordinate level affective categorization. We conclude that both implicit and explicit affective and semantic categorization is dependent on visual awareness, and that affective recognition follows semantic categorization.

Keywords: visual awareness, affective recognition, affective priming

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Can emotional processing occur outside of visual awareness and thus precede other types of visual recognition processes? According to the *affective primacy* hypothesis (LeDoux, 1998; Murphy & Zajonc, 1993; Zajonc, 1980) emotional stimulus dimensions are evaluated prior to completing the early semantic object recognition stages. Most recent theories of emotional processing also posit that emotional stimuli that are not consciously perceived are nevertheless actively processed and may trigger emotional responses and corresponding behavior (see Tamietto & de Gelder, 2010, for a review). From an evolutionary perspective, this proposition seems viable at least on the surface level: It may take hundreds of milliseconds for conscious percept to emerge (Koch, 2004), thus engaging the emotion systems for promoting flight-or-fight behavior in a potentially harmful situation before awareness arises could make the difference between life and death.

However, recently evidence has been accumulating against both affective processing outside awareness and consequently also against affective primacy. This has led some researchers to propose that conscious semantic recognition would actually precede affective evaluation, thus implying *semantic primacy* over affective processing (Calvo & Nummenmaa, 2008; Nummenmaa, Hyönä, & Calvo, 2010; Storbeck, Robinson, & McCourt, 2006). Critically, although several studies (see below) have provided support for affective processing in the absence of consciousness, the factual evidence remains elusive because these studies have neither controlled for the participants' trial-wise awareness of the stimuli, nor contrasted affective with semantic processing to see whether other types of visual information processing could occur without awareness as well. Consequently, the visual processing limits of affective and semantic recognition remain unresolved.

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The temporal relationship between affect and cognition, as well as the limits that sensory awareness imposes on visual processing has been an enduring question in cognitive and affective sciences. These limits are critically relevant to the amount of visual processing resources required for object recognition along affective and semantic dimensions, as well as to whether emotional cues can really modulate information processing in the brain earlier than other types of sensory signals (see review in Pessoa, 2005). In the current study we contrasted affective and semantic processing of stimuli under different levels of awareness using explicit (two-alternative forced-choice [2AFC] recognition tasks; Experiments 1–3) and implicit (combined affective-semantic priming task; Experiments 4–5) indices of affective and semantic processing. We show that neither explicit nor implicit affective or semantic recognition can take place in the complete absence of visual awareness and that regardless of the level of awareness or the stimuli used, semantic categorization is faster and more or at least equally accurate as affective categorization.

Neurocognitive Mechanisms of Visual Recognition Outside Awareness

Models of emotional processing assume that affective processing is quick, effortless and automatic (Bargh, 1997), may occur prior to semantic recognition (Murphy & Zajonc, 1993; Zajonc, 1980) and possibly even outside of visual awareness (Öhman & Soares, 1998; Morris et al., 1998). All of these models share the assumption that affective processing does not require detailed perceptual processing or semantic identification of the stimulus. Several prominent neurobiological theories of emotion also assume independence of affective processing and awareness. These claims rest on the assumption that the automated or nonconscious processing of affect involves specific neural systems that act independently of the mechanisms associated with conscious perception. For example, a popular "two-pathway" model (LeDoux, 1998; Tamietto & DeGelder, 2010; Vuilleumier, 2005) differentiates between a cortical "high road" of detailed visual information processing that gives rise to conscious perception, and a nonconscious subcortical "low road" involved in less detailed but faster emotional processing of stimuli. According to this model, low spatial frequency information conveyed to the amygdala by a subcortical pathway through the superior colliculus and the pulvinar can be used to crudely appraise the emotional significance of events before these events are consciously perceived and categorized along semantic dimensions. Conscious perception, on the other hand, is thought to rely on the slower cortical processing of high spatial frequency information along the ventral visual stream. The stream starts at the primary visual cortex (V1) and projects through V2 and V4 to the inferotemporal cortex, which in turn provides connections to amygdala (Milner, Goodale, & Vingrys, 2006). However, recently this model has been challenged on the grounds that there is no evidence for a functionally independent subcortical route in primates (Pessoa & Adolphs, 2010). More precisely, visual input from the superior colliculus terminates in the inferior nucleus in the visual subregion of the pulvinar, whereas connections to the amygdala originate from medial nucleus in the associational region of the pulvinar. The inferior pulvinar is heavily interconnected with the early visual cortex and receives its primary input from striate and extrastriate visual areas, whereas the medial pulvinar receives input primarily from fronto-parietal and higher visual cortical areas. Critically, connections between these two pulvinar regions have not been described (Pessoa, 2005). This pattern of connectivity suggests that the pulvinar does not process visual information independently from the cortex, and should instead be viewed as part of the cortical visual circuits. The revised model also fits better with computational models of visual perception, as the computational properties required to perform object categorization have not been found in the proposed direct subcortical pathway (for a review see Cauchoix & Crouzet, 2013).

Instead of distinct neuroanatomical pathways, recent theories of visual awareness propose a radically different explanation for the neurobiology of nonconscious visual processing (Dehaene et al., 2006; Lamme, 2006a). These models have shifted from attributing consciousness to specific structures on a purely anatomical basis, and instead link conscious and nonconscious processing to two separate types of coordinated activity between brain regions. These models differentiate between an initial fast *feedforward sweep,* in which sensory information cascades through the visual system, and a later stage of *recurrent processing* where higher visual areas send signals back to lower areas via feedback connections (Lamme & Roelfsema, 2000). The feedforward sweep is assumed to be involved in rapid nonconscious visuomotor responses, whereas visual awareness arises from recurrent processing between higher and lower cortices. Indeed, several studies (e.g., Serre, Oliva, & Poggio, 2007; Thorpe et al., 1996) have suggested that pure feedforward activity in the ventral stream may be sufficient for crude object categorization. Moreover, the above models predict that momentary feedforward activation in sensory cortices in response to spatially attended but physically weak stimuli would be sufficient for priming effects, yet insufficient for conscious perception (Dehaene et al., 2006). Thus, these models imply that affective processing outside of awareness—if it occurs in the first place—would in fact have a cortical basis and would in this respect not be different from other types of nonconscious processing of visual information. Importantly, these kinds of models can account for both affective and nonaffective, nonconscious processing without the need for a redundant affect-specific subcortical pathway.

Is There Evidence for Emotional Processing Outside Awareness?

Key evidence for the existence of nonconscious processing of affect comes from studies using backward masked emotional stimuli. In these studies, short (typically 33 ms or below) stimulus display duration together with postmasking is assumed to render the stimuli outside of visual awareness. Under such conditions, masked emotional stimuli have been shown to elicit affective priming effects (Hermans et al., 2003; Murphy & Zajonc, 1993; Sweeny et al., 2009), cause spontaneous reactions in facial muscles involved in generating facial expressions (Dimberg, Thunberg, & Elmehed, 2000), induce skin conductance responses indicative of a change in arousal state (Öhman & Soares, 1998), modulate the face-sensitive N170 and the N2 event-related potentials (Kiss & Eimer, 2008; Liddell et al., 2004; Pegna et al., 2008; Smith, 2011; Williams et al., 2004) and trigger activation of the amygdala, which is considered the key region in the brain's emotion circuit (Juruena et al., 2010; Killgore & Yurgelun-Todd, 2004; Liddell et al., 2005; Morris et al., 1998; Morris, Buchel, & Dolan, 2001; Whalen et al., 1998, 2004; Williams et al., 2006;).

Even though the canonical interpretation of these findings is that they show affective processing outside of awareness, the results of these studies are inconclusive for four reasons. First and foremost, many backward masking studies arguing for unconscious affective processing have relied solely on manipulation of stimulus onset asynchronies (SOAs) to control awareness of the stimuli. The general assumption is that stimuli presented for certain duration - typically determined in a previous study or in a separate threshold estimation experiment - remain consistently below the detection threshold on all trials and across all participants (Liddell et al., 2004; Nomura et al., 2004; Phillips et al., 2004; Williams et al., 2004, 2006). The problem with this approach is that it does not take into account between-subjects variance in detection threshold, nor within-subject variance resulting from momentary changes in arousal and attentiveness between trials (Macmillan & Creelman, 2004; Pessoa, Japee, & Ungerleider, 2005). Importantly, discrimination thresholds may vary for different recognition operations (Grill-Spector & Kanwisher, 2005; Nummenmaa et al., 2010). Thus, a fixed SOA may not result in a subthreshold signal for all participants, trials or recognition tasks.

Second, several studies (e.g., Eimer et al., 2008; Kiss & Eimer, 2008; Morris et al., 1998; Morris et al., 2001; Pegna et al., 2008; Smith, 2011;) have focused on the *discrimination threshold*, using chance performance in discriminating between emotional and neutral stimuli as the criterion for lack of awareness. This approach assumes that emergence of visual awareness can be derived from above chance performance in a discrimination task. However, this reasoning is flawed in the sense that performance in forced-choice tasks only measures the observer's capability for classifying between different stimulus categories without regard to whether this categorization is accompanied by conscious percept or not. As awareness is a purely subjective phenomenon, it can only be measured through introspective methods; thus, classification of the subjective experience through self reports or similar measures should be considered mandatory. Consequently, as previous experiments have not indexed the subjective percept, they do not account for the possibility that the participants may have detected the presence of the stimulus, that is, "seen something," but been unable to successfully classify the percept (Overgaard et al., 2006). Alternatively, some studies could have observed above chance classification that actually occurred in the absence of awareness, but failed to appreciate their findings since proper quantification of subjective experience was not conducted.

Third, some studies (Juruena et al., 2010; Killgore & Yurgelun-Todd, 2004; Whalen et al., 1998, 2004) have relied on subjective reports from postexperimental interviews for assessing whether the participants were aware of the stimuli or not. However, as this method relies solely on the subject's memory of the experiment, it's suitability for reliably establishing lack of awareness is questionable (Heijden, 1981; Posner & Konick, 1966). Finally, in the studies employing trial-wise measurement of awareness collected from all participants (Gläscher & Adolphs, 2003; Smith, 2011), forced-choice judgments of "absent" or "present" are typically used for indexing awareness. But as widely acknowledged in studies on visual awareness, the critical limitation of these binary judgments is that, unless confidence ratings or signal detection measures are also applied, they cannot determine the participants' criterion for "absent" responses (Macmillan & Creelman, 2004; Pessoa, Japee, & Ungerleider, 2005; Rodríguez et al., 2012). Consequently, if the participants respond using a conservative criterion, partially aware stimuli may be classified as absent. Thus, any observed effects from trials rated as nonconscious could reflect conditions of partial stimulus awareness.

In sum, the majority of studies arguing for the existence of nonconscious processing of affect have not properly controlled for the participants' actual awareness of the stimuli. Trial-wise measurement of awareness with confidence ratings from all participants has only been employed in two backward masking studies with affective stimuli (Pessoa, 2005; Pessoa et al., 2006), and neither of these studies actually found any indication of affective processing in the absence of awareness. Moreover, studies that have argued for affective processing outside of awareness, in general make the assumption that conscious perception is dichotomous, an all-or-none process. However, recent studies on visual awareness (Overgaard et al., 2006; Sandberg, Timmermans, Overgaard, & Cleeremans, 2010) have shown that conscious perception is in fact a gradual phenomenon, with perceptual states of "fringe consciousness" and partial awareness between the states of no awareness and complete awareness represented by the ends of the continuum. Therefore, to properly determine the extent to which processing of affective information can take place outside of awareness, measures of awareness which distinguish between states of partial awareness and complete absence of awareness need to be used. In sum, even though independence from awareness is generally assumed in theories of emotional processing, to our knowledge there exist no studies where emotional processing outside of awareness has been established while properly verifying the participants' lack of awareness of the masked stimuli.

Can Affective Processing Precede Semantic Recognition?

A second, related and yet unresolved issue is the relative temporal order of affective and semantic recognition operations, and their relative dependency on visual awareness. Models suggesting affective primacy (Murphy & Zajonc, 1993; Tamietto & DeGelder, 2010) typically assume that processing of affective stimulus dimensions such as 'goodness' and 'badness' is faster than semantic object recognition, and that such fast processing of affect is implemented in a subcortical pathway, the "low road." Faster processing in the subcortical pathway is assumed on an anatomical basis, as it takes fewer steps for visual information to reach the amygdala via the low road than through the cortical high road (LeDoux, 1998). Yet, both recent behavioral and electrophysiological evidence strongly contradicts such an affective primacy hypothesis. First, a comparison of semantic and affective categorization speeds for the same stimuli shows that affective discrimination is in fact slower than semantic categorization (Nummenmaa, Hyönä, & Calvo, 2010). Second, the earliest event-related potentials (ERPs) that are consistently modulated by affective stimulus content occur around 170 ms for emotional facial expressions (e.g., Ashley, Vuilleumier, & Swick, 2004; Batty & Taylor, 2003; Blau et al., 2007; Campanella et al., 2002; Eger et al., 2003; Krombholz, Schaefer, & Boucsein, 2007), and around 200–300 for arousal for complex emotional scenes (see review in Olofsson, Nordin, Sequeira, & Polich, 2008). In contrast, object-selective modulation of the N1 component indicates that the processing required for semantic categorization of visual scenes (animals vs. objects) can be carried out within 150 ms (Proverbio, Del Zotto, & Zani, 2007; Rousselet, Fabre-Thorpe, & Thorpe, 2002; Thorpe, Fize, & Marlot, 1996). Third, intracranial recordings of visual responses in the macaque brain show that visual cortical activation precedes amygdala responses, as the first responses in the amygdala occur around 100–200 ms (Kuraoka & Nakamura, 2007; Leonard et al., 1985; Nakamura, Mikami, & Kubota, 1992), while the first cortical responses are observed at 35–65 ms in early and intermediate visual areas (V1: 35 ms, MT: 39 ms, V2: 54 ms, V3: 50 ms; V4: 61 ms), and around 60–85 in the inferotemporal cortex (see meta-analysis in Lamme & Roelfsema, 2000). In line with the monkey data, intracranial recordings from humans have shown object-selective responses in occipito-temporal cortex 100 ms after stimulus presentation (Liu, Agam, Madsen, & Kreiman, 2009), whereas amygdala responses to visual emotional stimuli occur substantially later around 200 ms (Mormann et al., 2008; Oya et al., 2002).

Finally and critically to the aims of the present study, no studies exist that would have directly contrasted the relative temporal primacy of affective and semantic recognition operations and their dependence on visual awareness. Even if affective processing would occur when visual awareness is blocked, this would not yet confirm that affective processing is somehow 'special,' because it is currently not known whether semantic recognition would have occurred under corresponding constraints of visual awareness. Thus, existing behavioral and electrophysiological data cannot tell whether affective processing truly occurs prior to semantic processing.

The Current Study

Taken together, current experimental evidence for affective processing outside visual awareness is elusive, even though this notion has reached almost a canonical status in the literature. Moreover, we are not aware of any studies that would have directly contrasted affective and semantic recognition at different levels of awareness to test whether visual processing limits differ for these two types of recognition operations. Here we aim to shed light on these issues by directly contrasting i) affective and semantic categorization of ii) consciously versus nonconsciously perceived biologically relevant stimuli in a series of five experiments using explicit and implicit categorization as indices of affective and semantic processing.

The current study involved four methodological developments. First, unlike practically all prior studies, we measured each subject's subjective level of awareness after each trial using a four-point scale routinely used in studies of visual awareness (Ramsøy & Overgaard, 2004). This allowed us to strictly compare processing of below-detection threshold and below-discrimination threshold stimuli, rather than stimuli presented with fixed SOAs, which would sometimes reach awareness and sometimes not. Second, we directly compared affective and semantic categorization of the *same* stimuli above and below the subjective detection and discrimination thresholds for conscious perception. Thus, our aim is to investigate whether affective processing is any different from other types of visual information processing in terms of speed, automaticity or independence from awareness. Third, we applied signal detection theory to determine each subject's capability for conscious detection of the masked stimuli, thus allowing us to take into account intersubject variability in detection sensitivity. Fourth, to ensure that our analysis would not only focus on explicit processing of emotional information reaching consciousness, we compared processing of sub- and suprathreshold affective and semantic stimuli with direct or explicit (two-alternative forced choice discrimination, 2AFC; Experiments 1–3) and indirect or implicit (affective and semantic priming; Experiments 4–5) tasks.

A Priori Power Analysis

Power calculations based on mean effect size of nonconscious affective processing ($r = .62$)[1] in previous experiments (see Meta-analysis in Table 2) suggest that at alpha level of .05, sample sizes of 24 will already be enough for establishing the predicted effect with the actual power exceeding 90%. As previous experiments were analyzed mainly by SOA, we set a minimum sample size of 24 for our analyses by SOA (Experiments 1,2,4 and 5) to ensure sufficient statistical power and comparability. Consequently, in the priming experiments the sample size was 24 for each prime-probe-SOA (total $n = 48$ in each Experiment), while having one less between-groups condition enabled slightly higher sample sizes of 32 in the discrimination experiments (total $n = 32$ in each Experiment).

Experiment 1

In Experiment 1 we compared affective and semantic categorization of consciously perceived versus nonconscious emotional and nonemotional stimuli using the signal detection approach. To ensure that we would tap processing of biologically significant signals having strong evolutionary basis (Öhman, 1993; Öhman & Mineka, 2001) we used pictures of animals and foods as stimuli. Participants were shown masked pictures depicting unpleasant and pleasant animals and foods; visual awareness of the stimuli was manipulated by varying target-mask SOA. Participants performed 2AFC affective evaluation (pleasant vs. unpleasant) of the stimuli in one block and 2AFC semantic categorization (animal vs. object) in the other. All the pictures could be unambiguously categorized with respect to the affective (unpleasant vs. pleasant) and semantic (animal vs. object) dimensions, thus the to-be-categorized stimuli were identical in both tasks.

To determine the participants' subjective perception of the stimuli, a subset of the participants rated their subjective awareness on each trial using the Perceptual Awareness Scale (PAS; Ramsøy & Overgaard, 2004). This has three advantages over dichotomous measures of awareness: First, using a four point-scale takes into account the nondichotomous nature of visual awareness. That is, the scale controls for the possibility of partially aware stimuli being classified as nonaware, which could occur if a dichotomous measure of awareness were used. Second, whereas previous studies have been limited to measuring performance at different stimulus presentation times, rating trial-wise stimulus awareness enables the analysis of performance as a function of the actual subjective level of awareness. This also takes into account mo-

[1] Throughout the text, effect sizes for t tests and planned contrasts are reported in terms of r.

mentary changes in the subject's arousal and attentiveness during the experiment, which would otherwise create uncontrolled intra-subject variance in discriminability between trials. Third, detailed measurement of awareness enables separate examination of processing of below-detection threshold and below-discrimination threshold stimuli.

To ensure that the awareness rating task would not confound with the primary affective/semantic recognition task, we ran two variants of the experiment—one with and another without the awareness rating task and compared participants' performance in these conditions. We measured RTs and accuracies at different SOAs and at different levels of awareness to contrast the speed of semantic versus affective processing and to determine whether either type of categorization can take place in the absence of awareness. We predicted that if affective categorization occurs outside visual awareness, the level of affective but not semantic discrimination performance should exceed the chance level 0.5 already for trials where participants do not consciously perceive the stimulus.

Method

Participants. Thirty-four university students (26 females and 8 males, age 18–32 years, $M = 23$ years) participated in the experiment for a course credit. All participants had normal or corrected-to-normal vision and gave informed consent.

Stimuli and apparatus. The stimuli were 160 pleasant and unpleasant pictures of animals and objects (Figure 1a). There were 40 pictures with unpleasant animals (snakes and spiders), 40 with unpleasant foods (rotten food or raw organs), 40 with pleasant animals (puppies and kittens) and 40 with pleasant palatable foods (desserts and fruits). The stimuli were presented on a 21-in computer display (100 Hz refresh rate) and subtended a visual angle of 11.4° by 11.9°; screen-to-eye distance was 60 cm. The images did not contain backgrounds or any visual elements other than the target animal or object.

In addition, 20 pattern masks constructed from scrambled stimulus parts were used for backward masking (see Figure 1). The pattern masks consisted of a central shape with randomly generated outlines, which was superimposed on a geometric pattern of black and white lines and circles. In pilot studies, this combination of high-contrast outlines and complex color patterns was found to be more efficient in blocking awareness of stimulus outlines than the scrambled rectangular image masks traditionally used in backward masking studies. Valence (pleasantness-unpleasantness) ratings were obtained from all participants after the experiment using the Self-Assessment Manikin (SAM) scale (Bradley & Lang, 1994).

Procedure. Each trial began with a fixation cross displayed at the center of the screen for 1,500 ms. The target stimulus was then presented for a either 10, 40 or 80 ms, and was followed by a randomly chosen mask displayed for 250 ms (Figure 1b). These presentation times were selected on the basis of previous studies (Nummenmaa et al., 2010; Williams et al., 2004) and piloting experiments, which suggest that a 10 ms presentation time is required for subdetection threshold presentation. Each stimulus was presented once under each SOA (10, 40, 80 ms) in a random order. In addition, the experiment included 20% catch trials, in which a blank screen was presented instead of the target stimulus. The next trial began after the participant gave their response.

Sixteen participants performed a single forced-choice discrimination task on each trial; for the remaining 18 participants the discrimination task was followed by a rating of stimulus awareness on a 4-point PAS (1 = *I did not see the stimulus at all*; 2 = *I saw a glimpse of something, but don't know what it was*; 3 = *I saw something, and think I can determine what it was*; 4 = *I saw the stimulus clearly*). This latter task was not timed. The participants gave their response to both tasks by key press; for the discrimination task, they were instructed to use their left and right index fingers.

The experiment involved two stimulus blocks of 600 trials, with identical trial structure and stimuli. In the *affective block*, participants' task was to determine the affective valence (pleasant vs. unpleasant) of the stimulus as quickly as possible, whereas in the *semantic block* their task was to decide whether the stimulus was an animal or object. Reaction times and response accuracies were measured. The order of the tasks was counterbalanced across participants.

The participants were told that each trial would consist of a briefly flashed target image, followed by a mask. They were instructed to focus on the target image and ignore the mask while trying to categorize the target image as fast and as accurately as possible. Before the experiment the participants were familiarized with the response protocol and before each stimulus block they

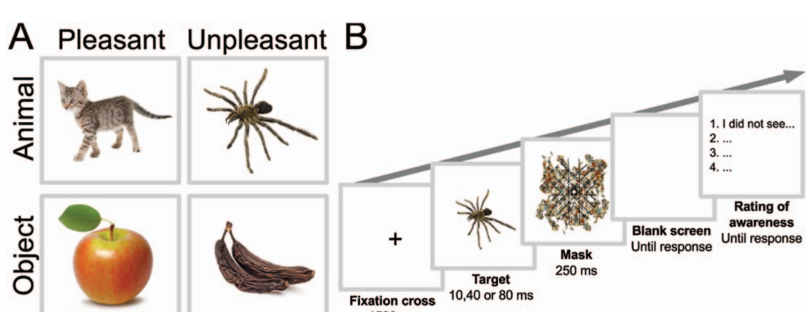


Figure 1. A: Examples of stimuli used as targets in Experiment 1. B: Trial structure in Experiment 1. Awareness rating was only presented for half of the participants at the end of each trial. Note that these pictures were not included in the actual experiment.

performed a short practice session of 20 trials with stimuli that were not included in the actual experiment.

Results

SAM scale ratings of pleasant and unpleasant stimuli differed significantly both in the animal ($M_{\text{pleasant}} = 8.46$, $SD_{\text{pleasant}} = .63$, $M_{\text{unpleasant}} = 2.63$, $SD_{\text{unpleasant}} = 1.32$) and object ($M_{\text{pleasant}} = 7.37$, $SD_{\text{pleasant}} = .81$, $M_{\text{unpleasant}} = 2.01$, $SD_{\text{unpleasant}} = .77$) stimulus groups, ts(31) > 21.41, ps < .001, rs > .929, indicating that the stimuli were perceived as pleasant and unpleasant as intended. The recognition data were first analyzed using the conventional approach by pooling the results from the two experimental variants (with and without awareness rating). To deal with outliers, we excluded RTs that were over two standard deviations from the block mean. First, one-sample t tests were conducted to examine whether the discrimination accuracy in affective and semantic tasks differed from chance level at each SOA. Discrimination accuracy was above chance level for all SOAs in both tasks (Affective task: 10 ms, $t(33) = 3.468$, $p = .001$, $r = .517$; 40 ms, $t(33) = 17.159$, $p < .001$, $r = .948$; 80 ms, $t(33) = 32.091$, $p < .001$, $r = .984$; Semantic task: 10 ms, $t(33) = 3.635$, $p = .001$, $r = .535$; 40 ms, $t(33) = 21.529$, $p < .001$, $r = .966$; 80 ms, $t(33) = 47.183$, $p < .001$, $r = .992$).

Accuracy scores and response times were then subjected to 2 (categorization task: semantic vs. affective) × 3 (SOA: 10 vs. 40 vs. 80 ms) ANOVAs. In this and subsequent experiments, if the condition of sphericity was not met, Greenhouse–Geisser correction was applied to the degrees of freedom, and the corrected p value is reported. The main results are presented in Figure 2. For accuracies, a main effect of SOA was observed, $F(2, 66) = 645.16$, $p < .001$, $\eta^2_P = .951$ with highest (>.91) accuracies for the 80-ms stimuli and lowest (<.54) for 10 ms stimuli in both tasks). Neither the main effect of task, Fs < 2.76, nor the interaction, Fs < 2.93, was statistically significant. For RTs, a main effect of task emerged, $F(1, 33) = 7.11$, $p = .012$, $\eta^2_P = .177$. Categorization RTs were approximately 70 ms faster in the semantic than in the affective task (762 vs. 833 ms). An interaction between task and SOA, $F(2, 66) = 6.88$, $p = .010$, $\eta^2_P = .173$, resulted from a larger difference between the tasks at longer stimulus presentation times. Reaction times were significantly shorter (by a difference of approximately 95 ms) in the semantic task than in the affective task in the 40 and 80 ms SOAs, ts(33) > 3.90, ps < .001, rs > .152, but not in the 10 ms SOA, $t(33) = .365$, $p = .717$, $r = .022$. No other significant effects were observed, Fs < 2.33.[2]

To measure the participants' conscious detection of the stimuli, discriminability index (d') was calculated on the basis of awareness rating responses to stimulus and catch trials. Ratings higher than 1 in PAS were defined as hits in stimulus-present trials and as false alarms in catch trials. Thus, the d' indexes the participants' ability to consciously discriminate between trials with and without any visual stimulus. The d' values for 10 ms stimuli (.776 in the affective task and .907 in the semantic tasks) were significantly higher than zero, all ts(17) > 4.114, ps < .002, rs > .672, indicating that the participants were at least partially aware of the 10 ms stimuli on some trials. Consequently, data were next analyzed as a function of awareness rating rather than SOA.

One sample t tests were carried out to evaluate discrimination performance at different levels of awareness. In both tasks, performance was at chance level, ts(17) < .471, ps >.644, rs < .052, when participants reported no awareness of the stimuli, and exceeded chance level when participants were partially or completely aware of the stimuli, all ts(17) > 4.853, ps < .001, rs > .500. Next, response accuracies and RTs were analyzed with a 2 (categorization task) × 4 (level of awareness) ANOVAs. For accuracies, a main effect of level of awareness, $F(3, 51) = 165.46$, $p < .001$, $\eta^2_P = .907$, revealed better discrimination accuracy at higher levels of awareness (Rating 1: .50 semantic .51 affective; Rating 2: .67 semantic .63 affective; Rating 3: .94 semantic .91 affective; Rating 4: .97 semantic .96 affective). The main effect of categorization task and the Categorization Task × Level of Awareness interaction were not significant, Fs < 1.46. For RTs, a main effect of level of awareness, $F(3, 51) = 19.21$, $p < .001$, $\eta^2_P = .531$ was revealed, whereas the Categorization Task × Level of Awareness interaction was not significant, $F = .372$. RTs were longest with minimal awareness of the stimulus and became faster as the participants' awareness of the target increased.

Even though there was no interaction between task and level of awareness, we conducted planned comparisons between affective and semantic tasks at each level of awareness, as the affective primacy model would specifically predict affective superiority under limited-awareness conditions. To ascertain not overlooking any indices of nonconscious processing that could be too weak to manifest as significant interactions in the multiway ANOVAs, similar planned comparisons were also conducted in all the subsequent experiments. When participants reported no awareness, or minimal awareness (Awareness Rating 1 or 2) of the stimuli, there was no difference between the affective and semantic tasks ts(17) < .797, ps > .436, rs < .058. On the contrary, under complete or near complete awareness (Awareness Rating 3 or 4), RTs were on average 60 ms faster in the semantic task, ts(17) > 2.68, ps < .017, rs > .167.

Finally, we performed item analysis (F2) where means are obtained separately for each stimulus by averaging over subjects. F2 analyses revealed a positive correlation between semantic and affective RTs for the stimuli that reached awareness $r(158) = .306$, $p < .001$, while no correlation between affective and semantic RTs of nonaware stimuli was observed, $r(156) = .024$, $p = .770$ (see Figure 3). The correlation was also significantly stronger for aware versus nonaware stimuli, $z = 2.47$, $p < .01$ in Meng's z test.

Discussion

Experiment 1 established that both affective and semantic categorization require at least partial visual awareness. Critically, when participants reported no stimulus awareness, neither affective nor semantic categorization could be accomplished above chance level. Furthermore, there were no differences between affective and semantic categorization accuracies neither at any level of awareness nor at any SOA; thus, affective discrimination is not more automatic or effortless than semantic processing of

[2] We also performed full omnibus ANOVAs with presence of awareness rating task as between-participants factor. Overall, RTs in the primary task were longer when participants were performing the additional awareness rating task, $F(1, 32) = 28.10$ $p < .001$ but as no interactions were observed, Fs < 2.33, in the following experiments the results from the two groups are reported separately for the sake of conciseness.

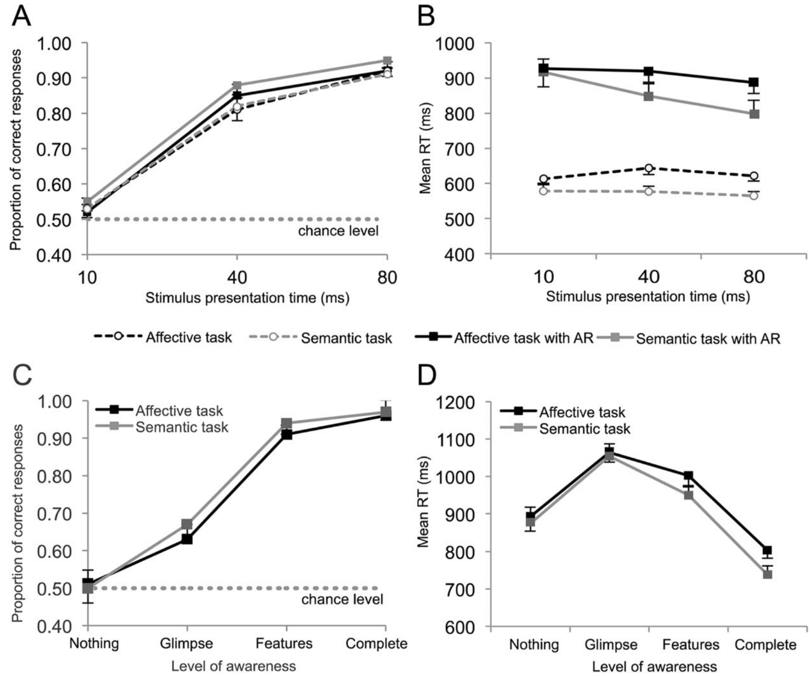


Figure 2. Means and standard errors for response accuracies (left) and latencies (right) in Experiment 1. Top row (A and B) shows performance as a function of SOA and lower row (C and D) as a function of level of awareness. In this and subsequent figures, within-subject error bars were calculated according to Cousineau (2005) and corrected according to Morey (2008). RT = response time, AR = awareness rating.

visual information. These results accord with conventional models of visual awareness, where visual categorization operations cannot take place in the complete absence of sensory awareness (Sandberg et al., 2010). Thus, in this respect affective categorization does not seem to constitute a special case of information processing.

Moreover, the data contradict the affective primacy hypothesis (LeDoux, 1998; Murphy & Zajonc, 1993; Zajonc, 1980) by showing that whenever stimulus awareness is established and any type of visual categorization becomes possible, semantic categorization is actually *faster* than affective target evaluation, suggesting that semantic recognition may be a prerequisite for affective evaluations. In line with this, F2 analyses confirmed that affective discrimination speeds for individual stimuli reaching awareness were linearly contingent on the corresponding semantic recognition latencies, thus suggesting that affective recognition would constitute an extra visual processing step taking place after semantic recognition (cf. Nummenmaa et al., 2010). Critically, no such association could be observed for the stimuli not reaching awareness, thus this effect indeed reflects strictly visual processes operating under awareness. These data thus support the recent claims postulating primacy of semantic recognition over affective evaluation of visual sensory signals, and suggesting that feature integration and object identification must occur before affective analysis can be accomplished (Nummenmaa et al., 2010; Storbeck et al., 2006).

Finally, the signal detection analysis revealed that even 10 ms masked stimuli could be consciously perceived on some trials and categorized with respect to the affective and semantic dimensions with above-chance level accuracy (.53 affective, .54 semantic) thus leading to d' values exceeding 0.75. Importantly, in numerous

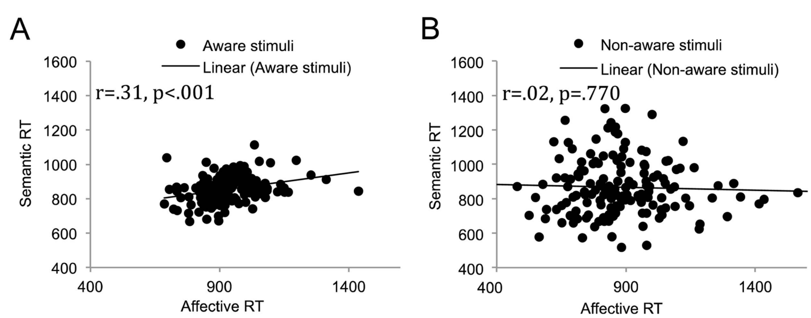


Figure 3. Correlations of itemwise mean RTs in the affective and semantic discrimination tasks for aware (A) and nonaware (B) stimuli. RT = response time.

previous studies on unconscious affective processing where awareness was controlled solely by SOA, stimulus duration of 33 ms has been considered reliably below conscious perception (e.g., Dimberg et al., 2000; Juruena et al., 2010; Li et al., 2008; Sweeny et al., 2009; Whalen et al., 1998). Yet, by controlling awareness more precisely, we systematically obtained indices of stimulus awareness at a much shorter SOA. However, it must be stressed that even though affective recognition was possible with such short SOAs when awareness emerged, there was still no evidence of affective primacy.

Experiment 2

Experiment 1 established that biologically relevant affective stimuli (animals and foods) cannot be categorized above chance level either semantically or affectively when their access to visual awareness is prevented with backward masking. Nevertheless, it could be argued that the affect system could be better prepared to detect other types of emotional information. Specifically, humans live in large groups and monitoring affective signals conveyed by conspecifics is critical for social interaction (Ekman, 1992; Scherer & Wallbott, 1994). Several lines of evidence have also established the existence of cortical and subcortical circuitry specialized in the detection of faces (e.g., Vuilleumier & Pourtois, 2007), and it has been proposed that these circuits might operate independently from those involved in conscious visual perception (Moutoussis & Zeki, 2002; Morris et al., 1998; Öhman, Flykt, & Esteves, 2001). Thus, facial expressions could constitute a special category of affective stimuli that could be processed outside of awareness. In line with this proposal, prior studies have reported preattentive, almost parallel visual search of threatening facial expressions (Öhman et al., 2001); moreover, responses in the amygdala—a key component of emotional circuits—to 'unseen' fearful faces (Morris et al., 1999) have also been observed. Consequently, it is possible that facial expressions constitute a special class of emotional signals that would be recognized outside of visual awareness. We tested this hypothesis in Experiment 2 where we essentially replicated Experiment 1 with happy and fearful emotional facial expressions of male and female actors. These emotions were chosen for their evolutionary significance as they convey information about invitations for engaging in cooperation and pleasurable interaction (happy) versus threats and presence of harmful events in the environment (fearful; Calvo & Nummenmaa, 2008; Öhman et al., 2001; Scherer & Wallbott, 1994). Again, we used masking to present the faces either consciously or nonconsciously while the participants performed an affective (fearful vs. happy) categorization task in one block and semantic (male vs. female) categorization in the other. As in Experiment 1, half of the participants rated their subjective perception of the stimuli on the PAS.

Method

Participants, stimuli, and procedure. Thirty-two undergraduate psychology students (20 female and 12 male, age 18–29 years, $M = 23$ years) participated in the experiment for a course credit. All participants gave informed consent and had normal or corrected-to-normal vision. The stimuli were 80 pictures of emotional facial expressions (20 fearful males, 20 fearful females, 20 happy males, 20 happy females) selected from the Karolinska Directed Emotional Faces (KDEF) database (see Figure 4). Normative data (Calvo & Lundqvist, 2008) confirmed that these expressions are classified with high accuracy ($M = 97.6\%$, happy; $M = 79.3\%$, fearful).

In addition, 20 pattern masks were constructed from images of the same actors with neutral facial expressions by dividing the pictures into 1,600 square cells that were randomly rearranged. In pilot studies, these masks were found to effectively mask all features of the target stimuli. Stimulus size, presentation method, trial structure and experiment design were identical to those of Experiment 1 (i.e., three SOAs, 20% catch trials, PAS ratings of stimulus awareness from 16 participants). As in Experiment 1, the participants performed affective and semantic categorization of the same stimuli in two separate blocks, with each block involving 300 trials (60 fearful males, 60 fearful females, 60 happy males, 60 happy females, 60 catch). Each stimulus was displayed three times in each block (once at each SOA). The affective task involved differentiating between fearful and happy facial expressions, whereas the semantic task involved discriminating between males and females.

Results

The results are summarized in Figure 5. Again, one-sample t tests were first performed to determine whether discrimination accuracy differed from chance level at each display duration. In both tasks, accuracy was at chance level at 10 ms SOA, $ts(31) < .84$, $ps > .407$, $rs < .145$, and significantly above chance level for 40 and 80 ms SOA, $ts(31) > 20.51$, $ps < .001$, $rs > .675$. The d'

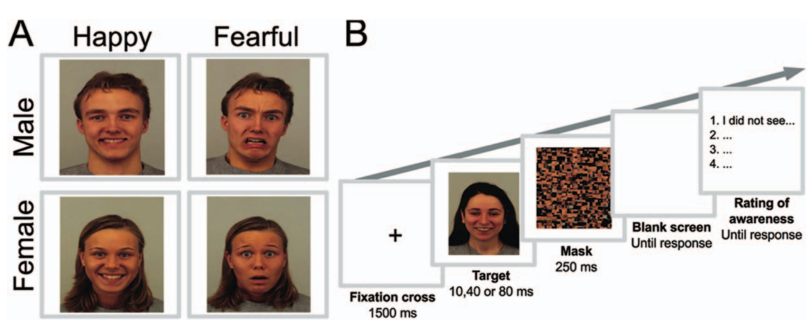


Figure 4. A: Examples of KDEF stimuli used as targets in Experiment 2. B: Trial structure in Experiment 2. Note that awareness rating at the end of each trial was presented only for half of the participants.

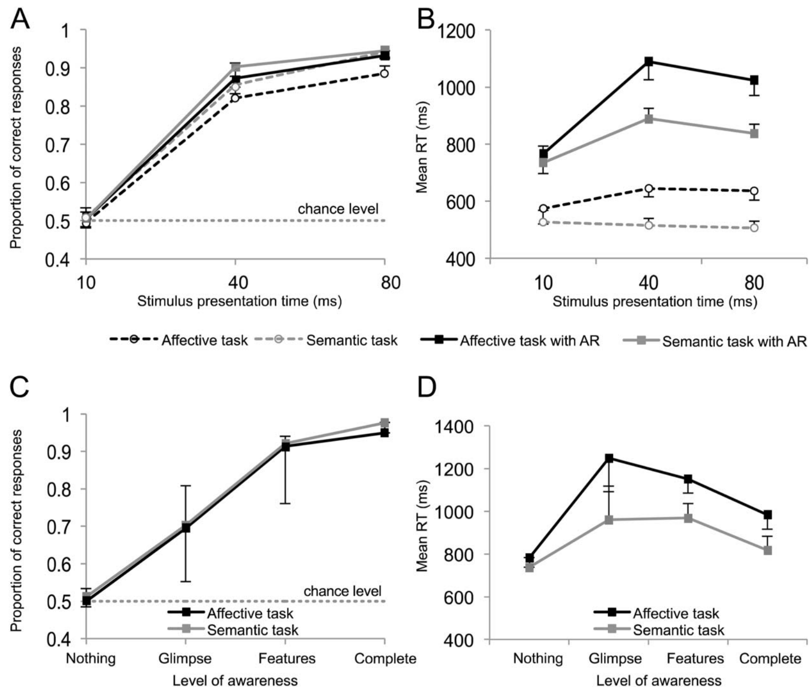


Figure 5. Results from Experiment 2 with emotional facial expressions as stimuli. A: Semantic and affective categorization accuracies as a function of target-mask SOA. B: Reaction times in the semantic and affective categorization tasks as a function of target-mask SOA. C: Semantic and affective categorization accuracies as a function of awareness. D: Semantic and affective categorization RTs as a function of awareness. RT = response time, AR = awareness rating.

values for 10 ms condition (0.33 in the affective task and 0.37 in the semantic task) were not significantly above zero, *t*s(15) $< .51$, *p*s $> .174$, *r*s $< .327$, indicating that the participants could not discriminate between catch trials and trials where the stimulus was presented for 10 ms.

The 2 (categorization task) × 3 (SOA) ANOVA on response accuracies yielded significant main effects of categorization task $F(1, 31) = 13.767$, $p = .001$,$\eta_P^2 = .308$, and SOA $F(2, 62) = 748.66$, $p < .001$, $\eta_P^2 = .960$. Accuracies were higher in the semantic task than in the affective task (.78 vs. .75), and increased with longer stimulus exposure times. The interaction was not significant, $F = 1.82$. The corresponding ANOVA on RTs revealed main effects of SOA, $F(2, 62) = 8.95$, $p = .005$, $\eta_P^2 = .224$ and categorization task, $F(1, 31) = 40.78$, $p < .001$, $\eta_P^2 = .568$. Overall, RTs were fastest for 10 ms stimuli and longest for 40 ms stimuli. RTs were faster in the semantic task than in the affective task (669 vs. 789 ms). An interaction of SOA × Categorization Task, $F(2, 62) = 16.58$, $p < .001$, $\eta_P^2 = .348$, revealed that RTs were significantly faster in the semantic task than in the affective task under 40 and 80 ms SOA, *t*s(31) > 6.64, *p*s $< .001$, *r*s $> .282$, but not under 10 ms SOA, $t(31) = 1.77$, $p = .086$, $r = .093$.[3]

Next, the data were analyzed as a function of the awareness ratings. One-sample *t* tests for discrimination accuracy at different levels of awareness indicated that, in both tasks, when participants reported no awareness of the target their performance was at chance level, *t*s(15) < 1.341, *p*s $> .199$, *r*s $< .166$, but exceeded chance level when they were at least partially aware of the target, *t*s(13) > 3.63, *p*s $< .004$, *r*s $> .684$. The 2 (categorization task) × 4 (level of awareness) ANOVAs were then performed on accuracies and RTs for the awareness rating group. For accuracies, a main effect of level of awareness, $F(1, 16) = 96.08$, $p < .001$, $\eta_P^2 = .889$, revealed increased accuracies at higher levels of awareness. Neither the main effect of task nor the interaction were significant, *F*s $< .662$. For RTs, main effects of level of awareness, $F(3, 33) = 18.99$, $p < .001$, $\eta_P^2 = .433$, and categorization task, $F(1, 11) = 8.395$, $p = .015$, $\eta_P^2 = .633$, emerged. RTs were fastest when the participants reported no subjective percept of the stimulus, longest with minimal stimulus awareness and decreased as the participants' awareness of the stimulus increased (see Figure 5D). Again, RTs were significantly shorter in the semantic task than in the affective task. An interaction of Task × Level of Awareness, $F(3, 33) = 3.61$, $p = .023$, $\eta_P^2 = .247$, revealed that RTs did not differ significantly across affective and semantic tasks when the participants reported no awareness, $t(15) = 1.47$, $p = .160$, $r = .107$, or minimal awareness, $t(11) = 1.93$, $p = .080$, $r = .354$, but were on average 190 ms faster in the semantic task than in the affective task when the participants were partially or fully aware of the stimulus, *t*s(13) > 3.70, *p*s $< .002$, *r*s $> .449$. The F2 analyses did not reveal significant correlations between semantic

[3] As in Experiment 1, the data from the two groups (with or without PAS-rating) was also analyzed separately. For both groups, RTs in the semantic task, as opposed to the affective task, were significantly faster under 40 and 80 ms SOA, *t*s(15) > 4.53, *p*s $< .001$, *r*s $> .439$, but not under 10 ms SOA, *t*s(15) < 1.76, *p*s $> .095$, *r*s $< .171$.

and affective RTs for conscious, or nonconscious stimuli, *r*s < .080.

Discussion

Experiment 2 demonstrated that affective and semantic discrimination of facial expressions also requires awareness. The d' values for stimuli shown for 10 ms did not significantly differ from zero, indicating that they did not reach awareness. Correspondingly, categorization accuracy in both affective and semantic tasks was at chance level when the stimuli were shown for 10 ms, indicating that affective and semantic processing do not take place in the absence of awareness. This was further supported by analyses of trial-wise awareness rating data, which showed chance level performance in both task for trials where the participants report no awareness of the stimuli. Analysis of semantic and affective recognition RTs provided further evidence for the absence of affective recognition in the absence of awareness: If affective recognition of stimuli below this threshold indeed took place, we would expect to see some indication of this processing reflected as a difference between affective and semantic RTs for unaware stimuli. However, differences between semantic and affective categorization RTs were, again, only observed for stimuli above the discrimination threshold. Furthermore, for these stimuli semantic categorization was again faster than affective processing, not vice versa, suggesting that affective discrimination of emotional facial expressions requires visual awareness and follows semantic categorization. Thus, in line with Experiment 1, the results of Experiment 2 support the notion of semantic primacy (Nummenmaa et al., 2010; Storbeck et al., 2006). Consequently, even though facial expressions may indeed constitute a special communicative signal with high adaptive value, even their recognition cannot bypass the conventional visual processing stream.

Experiment 3

Experiments 1 and 2 conclusively established that neither affective nor semantic discrimination of visual stimuli takes place outside of awareness. Additionally, in both of these experiments conscious semantic recognition was found to be faster than affective recognition. Nevertheless, a critical question regarding the hierarchy of affective and semantic categorization operations remains unanswered. First, both prior experiments relied on conscious affective categorization of pleasant versus unpleasant affective valence. Traditional models of object recognition propose that semantic categorization operates hierarchically such that one of the levels in the semantic taxonomy (superordinate, basic, and subordinate level) is always accessed first (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), even though it is still debated whether basic versus superordinate level serves as the entry level category, or whether the entry level could vary flexibly across recognition tasks (Macé, Joubert, Nespoulous, & Fabre-Thorpe, 2009; Nummenmaa et al., 2010). Recently, these findings have also been extended to show that affective valence (pleasantness vs. unpleasantness) is accessed after both superordinate and basic-level categorization (Nummenmaa et al., 2010) thus suggesting a primacy of semantic over affective categorization operations.

Critical to the aims of the present study, the affective categorization task employed in Experiments 1 and 2 can be thought to involve basic-level affective classification, as it requires differentiation between "goodness" and "badness" of the stimuli; that is, the elementary concepts used for referring to the hedonic value of an event. On the contrary, the semantic task involves superordinate level categorization because participants were required to categorize animals from foods (or males from female). Consequently, the affective and semantic task differed not only with respect to the categorized dimension, but also with respect to the taxonomical level of the demanded categorization operations. It is indeed likely that superordinate level categorization—that is, perception of the mere presence of emotionality or *relevance* (see Sander, Grafman, & Zalla, 2003)—could be the entry level for categorization in the affective taxonomy (cf. primacy of superordinate semantic categorization in Macé et al., 2009). Consequently it is possible that the lack of emotional recognition outside awareness in Experiments 1 and 2 results from the fact that we were actually addressing an emotional recognition process that occurs upstream in the ventral visual stream and thus requires high levels of stimulus awareness.

To address the issue concerning the hierarchy of emotional and semantic categorization operations and their demands on visual awareness we conducted Experiment 3, in which the participants performed basic- and superordinate-level affective and semantic classification split into four blocks. To test whether affective detection is possible outside of awareness, the affective superordinate-level task involved a detection task where the participants were to distinguish between emotional and unemotional (neutral) animal and object stimuli. The semantic superordinate task involved categorizing the same set of stimuli as animals and objects. The basic-level affective task involved discriminating between pleasant and unpleasant animals, and the basic-level semantic task involved categorizing between snakes and spiders.

Method

Participants, stimuli, apparatus, and procedure. Sixteen university students (12 females and 4 males, age 18–27 years, $M = 22$ years) participated in the experiment. All had normal or corrected-to-normal vision and gave informed consent. The stimuli were 80 emotional pictures of animals and objects and 20 pattern masks, used in Experiment 1. Additionally, 40 neutral animal (fishes and birds) and 40 neutral object (vegetables and cereal) pictures were selected from public domain Internet databases and edited as in Experiment 1. Stimulus size and presentation method were identical to the previous experiments.

Stimulus size, presentation procedure, trial structure and stimulus presentation times were identical to those in Experiment 1 (i.e., three SOAs, 20% catch trials, forced-choice task on each trial). Given that Experiment 1 confirmed that the PAS task only resulted in slight increase in RTs, all participants now rated their awareness of the masked stimulus on the PAS after the forced-choice task on each trial. The experiment consisted of four stimulus blocks, presented in counterbalanced order.

In the *superordinate-level affective categorization task*, the participants' task was to categorize the stimuli as emotional (i.e., either pleasant *or* unpleasant) or nonemotional (neutral). The block contained of 600 trials (120 emotional animals involving snakes and kittens; 120 emotional foods involving desserts and rotten food; 120 neutral animals involving birds and fish; 120 neutral foods involving seeds and cereal, 120 catch). The *superordinate-level semantic categorization block* was otherwise identical to the corresponding affective block, except that now the participants' task was to categorize the stimuli as animals versus objects. The *basic-level affective categorization block* contained 300 trials (120 emotional animals involving snakes and kittens, 120 emotional foods involving desserts and rotten food, 60 catch) and involved classifying the stimuli as pleasant or unpleasant, whereas the *basic-level semantic categorization block* consisted of 150 trials (60 snakes, 60 spiders, 30 catch) and involved classifying them as snakes or spiders.

Results

A summary of the results is presented in Figures 6 and 7. One-sample t tests showed that accuracy was above chance level in all blocks at all stimulus durations, all ts(15) > 2.684, ps $< .018$, rs $> .545$. The d' values for 10 ms stimuli (Semantic superordinate: 1.066, Affective superordinate: 0.916, Semantic basic: 1.439, Affective basic: 0.998) were significantly above zero in all blocks, all ts(15) > 7.908, ps $< .001$, rs $> .702$, indicating that the participants were at least partially aware of the 10 ms stimuli on some trials. Analysis by awareness level revealed that all types of visual categorization operations were nevertheless contingent on awareness. When the participants had no awareness of the stimulus (Awareness Rating 1), their performance was at chance level in all blocks, all ts(15) $< .959$, ps $> .353$, rs $< .119$. When the participants were able to detect the presence of the stimulus but could not discern any features (Awareness Rating 2), their discrimination accuracy was significantly above chance level in both semantic tasks ts(15) > 5.268, ps $< .001$, rs $> .702$, but not in either affective task, ts(15) > 1.784, ps $> .094$, rs $> .396$. Finally, when the participants were able to discern stimulus features or saw the stimulus completely (Awareness Rating 3 or 4), response accuracies were significantly above chance level in all tasks, all ts(15) > 18.715, ps $<.001$, rs $> .702$.

The 2 (task: affective vs. semantic) $\times$ 2 (categorization level: basic vs. superordinate) $\times$ 4 (level of awareness) ANOVA on accuracies revealed main effects of task, $F(1, 13) = 7.10$, $p = .019$, $\eta_P^2 = .353$, categorization level, $F(1, 13) = 9.45$, $p = .009$, $\eta_P^2 = .421$, and level of awareness, $F(3, 39) = 205.52$, $p < .001$, $\eta_P^2 = .941$, as well as an interaction of task $\times$ level of awareness interaction $F(2, 19) = 4.377$, $p = .037$, $\eta_P^2 = .252$. Overall, accuracies were higher in the semantic task than the affective task, and higher for basic-level than superordinate-level categorization (semantic basic: .89; affective basic: .80; semantic superordinate: .80; affective superordinate: .74). Paired sample t tests showed that when the participants had no awareness of the stimulus (Awareness Rating 1), semantic and affective categorization accuracies did not differ at the basic, $t(14) = -.116$, $p = .909$, $r = .023$, nor superordinate, $t(15) = .689$, $p = .501$, $r = .099$, level. When the participants detected the presence of the stimulus (Awareness Rating 2), accuracies were significantly higher in the semantic task than in the affective task at both basic (affective: 58%, semantic: 73%), $t(14) = -3.77$, $p = .002$, $r = .468$, and superordinate- (affective: 55%; semantic: 62%), $t(15) = -2.60$, $p = .020$, $r = .338$ levels of categorization. In superordinate-level categorization, semantic discrimination was also more accurate than affective discrimination (affective: 84%, semantic: 92%) when the partici-

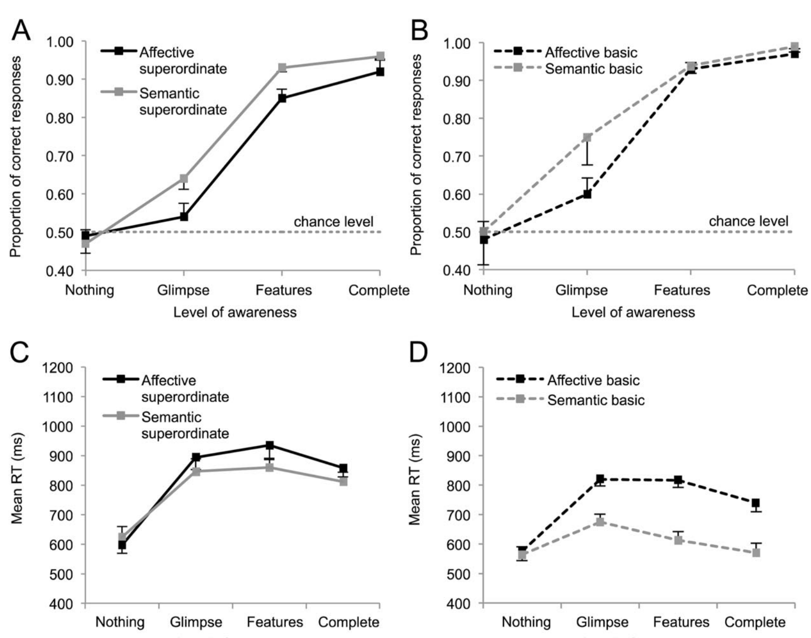


Figure 6. Results from Experiment 3 with pleasant and unpleasant animals and objects as stimuli. A: Superordinate level semantic and affective categorization accuracies as a function of awareness. B: Basic-level semantic and affective categorization accuracies as a function of awareness. C: Superordinate level semantic and affective categorization RTs as a function of awareness. D: Basic-level semantic and affective categorization accuracies as a function of awareness. RT = response time.

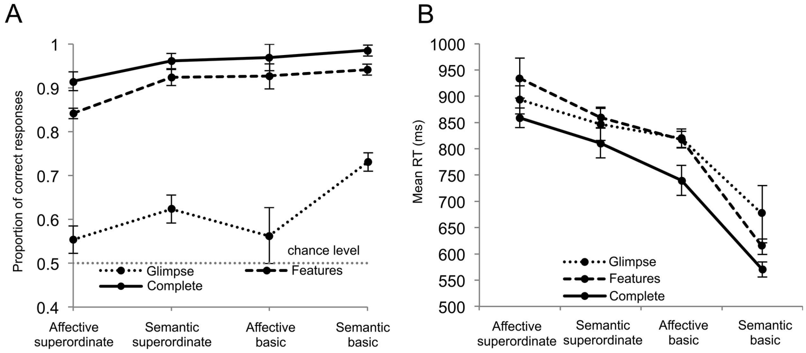


Figure 7. Comparison of basic and superordinate level affective and semantic categorization task accuracies (A) and RTs (B) for aware stimuli. RT = response time.

pants were able to discern some features (Awareness Rating 3), $t(15) = -4.36, p < .001, r = .626$. Finally, when the participants were fully aware of the stimulus (Awareness Rating 4), there were no significant differences between affective and semantic categorization accuracies in either block, $ts(15) < 1.809, ps > .090, rs < .246$.

The corresponding ANOVA on RTs essentially mirrored the findings from the accuracy data. There were main effects of Task, $F(1, 12) = 11.53$, $p = .005$, $\eta_P^2 = .490$, Categorization Level, $F(1, 12) = 58.89$, $p < .001$, $\eta_P^2 = .831$, and Level of Awareness, $F(2, 27) = 47.19$, $p < .001$, $\eta_P^2 = .797$. RTs were faster in the semantic task than in the affective task, and faster in the basic-level categorization than superordinate level categorization (Semantic basic: 637 ms, Affective basic: 884 ms, Semantic superordinate: 836 ms, Affective superordinate: 903 ms). As in Experiments 1 and 2, RTs were shortest when the participants had no awareness of the stimulus, and longest with partial awareness of the stimulus (see Figure 6C and 6D). The main effects were qualified by interactions of Task × Categorization Level, $F(1, 12) = 8.62, p < .012, \eta_P^2 = .418$, Task × Level of Awareness, $F(2, 24) = 9.45$, $p = .001$, $\eta_P^2 = .440$, and Categorization Level × Level of Awareness, $F(2, 28) = 16.47, p < .001, \eta_P^2 = .578$. The three-way interaction was not significant, $F(2, 25) = 1.12$, $p = .343$, $\eta_P^2 = .086$.

Simple effects test revealed that when the participants had no conscious perception of the stimuli (Awareness Rating 1), there were no differences between affective and semantic categorization RTs at the basic or superordinate level, $ts(15) < .739, ps > .471, rs < .068$, and no differences between basic- and superordinate-level RTs in affective, or semantic categorization, $ts(15) < .1.10, ps > .291, rs < .086$. At the basic level, semantic categorization was faster than affective categorization when the participants reported any awareness of the stimuli (Awareness Rating 2, 3 or 4), all $ts(15) > 4.886, ps < .001, rs > .482$. At the superordinate level a similar trend was apparent and approached significance when the participants could discriminate some stimulus features (Awareness Rating 3), $t(15) = 2.047$, $p = .059$, $r = .161$. In comparisons of basic versus superordinate categorization speeds, basic-level categorization was faster than superordinate level categorization in both tasks when the participants reported any awareness of the stimulus (Awareness Rating 2, 3 or 4), all $ts(15) > 3.255, ps < .006, rs > .204$. In the absence of awareness (Awareness Rating 1), there were no differences between basic and superordinate level categorization speeds in either task, $ts(15) < 1.100, ps > .291, rs < .086$. To control for a possible bias originating from differences in basic visual features of the stimuli in different blocks, we performed separate analyses of reaction time (RT)'s for the snake stimuli, which were identical across all blocks. There were no differences between affective versus semantic tasks, or between basic versus superordinate tasks when participants reported no awareness of the stimuli, $ts(15) < 1.134, ps > .275, rs < .075$. When stimuli were consciously perceived, semantic categorization was faster than affective categorization for partially and completely aware stimuli at the basic level, $ts(15) > 2.64, ps < .291, rs > .310$, and for completely aware stimuli at the superordinate level, $t(15) = 3.53$, $p = .003$, $r = .346$.

Finally, F2 analyses on superordinate level affective and semantic categorization RTs showed a positive correlation with each other for stimuli that reached awareness, $r(160) = .230, p = .003$. On the other hand, there was no correlation between affective and semantic RTs for stimuli that were not consciously perceived, $r(150) = -.129$, $p = .115$. (see Figure 8), and the correlation was significantly more positive for aware versus nonaware stimuli, $z = 3.09$, $p < .01$ in Meng's z test. For basic-level affective and semantic categorization RTs, no significant correlations were observed.

Discussion

Experiment 3 shows that affective and semantic categorization function in a similar manner with respect to hierarchies of categorization operations: For both types of classification the basic-level category was accessed before superordinate levels, which fits with the classic findings of Rosch and colleagues (1976). As basic-level semantic categorization was systematically fastest and most accurate for all aware stimuli, the results of Experiment 3 would suggest that basic level could serve as the entry level for all visual categorization operations, both semantic and affective. However, several studies have reported a superordinate advantage (for a review, see Fabre-Thorpe, 2011), and argued that the contradicting findings may be explained by differences in the tasks used in different studies (e.g., naming vs. verification). In light of these findings, we take the results of Experiment 3 to indicate that the entry level for semantic categorization operations may vary

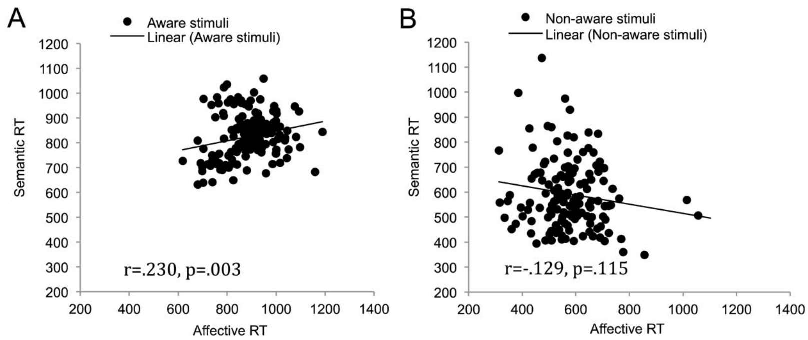


Figure 8. Correlations of itemwise mean RTs in the superordinate level affective and semantic discrimination tasks for aware (A) and nonaware (B) stimuli. RT = response time.

flexibly depending on task and stimuli used. Further, since basic-level affective categorization was faster than superordinate-level semantic categorization, it is possible that once rudimentary object recognition on a semantic level has been completed, affective and further semantic analysis proceed partially in parallel. Thus, the precedence of semantic over affective categorization speed is not completely universal. Instead, low-level affective categorization may sometimes be faster than more complex forms of semantic categorization. However, Experiment 3 highlights that regardless of the level of categorization, all affective categorization requires that at least coarse semantic object recognition is first successfully carried out.

As in Experiments 1 and 2, level of awareness modulated performance similarly across all tasks, with increased accuracy and faster processing at higher levels of awareness. Critically, Experiment 3 shows that the relative order of speed for different categorization operations is the same at all levels of awareness, thus there is no support for the notion that affective processing is independent from awareness. Further, F2 analyses again showed a positive correlation between affective and semantic RTs, strengthening the notion that affective recognition follows semantic categorization. Categorization Experiments 1 through 3 thus consistently find evidence supporting the postulation of semantic primacy (Nummenmaa et al., 2010; Storbeck et al., 2006).

Experiment 4

Experiments 1–3 established that none of the tested biologically relevant affective stimulus categories (animals, foods, facial expressions) could be categorized above chance level either semantically or affectively when their access to visual awareness was prevented. However, it is possible that the emotional information of the unconsciously seen stimuli could have been extracted to some extent, but not sufficiently to guide conscious, explicit decision-making. Consequently, in Experiment 4 we tested processing of affective and semantic information using an implicit measure, specifically masked priming (see Hermans, De Houwer, & Eelen, 2001; Klauer & Musch, 2003).

The participants performed affective and semantic categorization of probes that were preceded by masked affective and semantic primes. Critically, all primes and probes could be categorized along both affective and semantic dimensions thus yielding a fully symmetric design, where we could analyze both semantic and affective priming in each prime-probe pair type. Prime-mask SOA was varied to manipulate awareness of the prime, yet the probe stimuli were always fully visible. Because we wanted to test for the primacy of affective processing, prime-target SOAs were chosen to maximize the sensitivity for affective priming (150 and 300 ms; Hermans et al., 2001).

The primes and probes were pleasant and unpleasant pictures of animals and objects selected from the stimulus set of Experiment 1. They were combined so that the prime-probe pair could be congruent in both dimensions (e.g., pleasant animal followed by pleasant animal), incongruent in both (e.g., pleasant animal followed by unpleasant food), or congruent in one and incongruent in the other (e.g., pleasant animal followed by pleasant food; pleasant animal followed by unpleasant animal), resulting in 16 different prime-probe congruency combinations (see Figure 9). To measure the participants' awareness of the primes, a subset of the participants again rated their awareness of the prime on the PAS on each trial in addition to the categorization task.

Method

Participants, stimuli, and apparatus. Altogether 48 university students (33 females and 11 males; age 18–28 years; mean age 22 years) participated in the experiment for a course credit. All participants gave informed consent and had normal or corrected-to-normal vision. The stimuli were 80 pleasant and unpleasant animal and object pictures (20 pleasant animals, 20 pleasant foods, 20 unpleasant animals, 20 unpleasant foods) selected from the stimulus set used in Experiment 1, and the 20 pattern masks used in Experiment 1.

Procedure. Each trial consisted of three consecutive images: prime, mask and probe (see Figure 10). The trial began with a fixation cross displayed for 2000 ms, followed by a prime shown for 10 ms or 80 ms; these display durations produced a sufficient count of no conscious recognition versus reliable conscious recognition responses in Experiments 1–3, respectively. A randomly selected mask image was then presented for 140 ms (for 10 ms primes) or 70 ms (for 80 ms primes), thus resulting in constant 150 ms duration for the prime plus mask presentation. The probes were displayed for 250 ms.

Half (24) of the participants were assigned to the 150 ms prime-probe SOA condition and the other half to the 300 ms SOA condition. In the 150 ms SOA condition, the probe was displayed

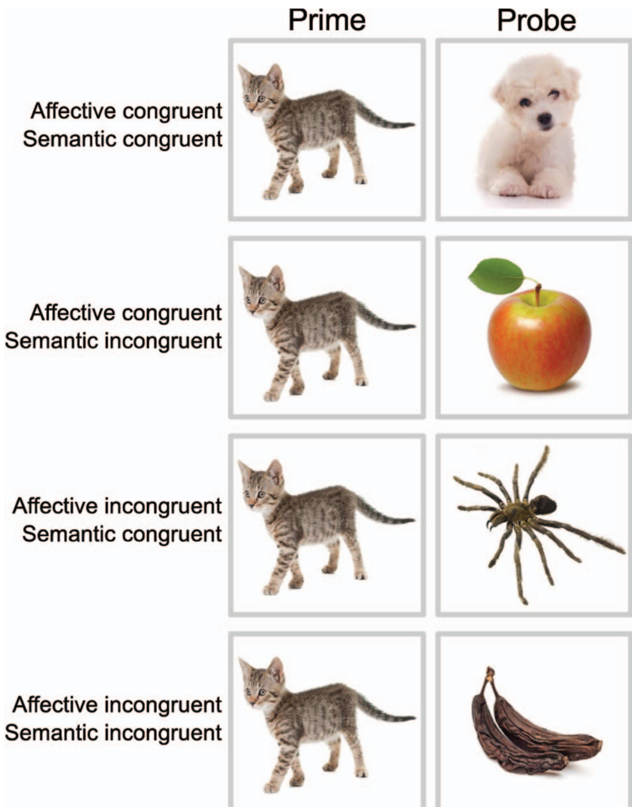


Figure 9. Examples of prime-probe congruency combinations for one prime category (pleasant animal).

immediately after the mask, while in the 300 ms SOA condition a blank screen was displayed for 150 ms between the mask and the probe. In both conditions, 16 participants performed the probe categorization task only, while eight additional participants performed the prime awareness rating task in addition to the probe categorization task. The awareness rating task followed the categorization task on each trial and was not time-stressed.

As in Experiment 1, the participants performed one block of affective (pleasant/unpleasant) and another of semantic (animal/object) discrimination task. Both blocks consisted of 720 trials with 20% catch trials. The participants were told that on each trial they would see three consecutive images, and that they were to ignore the first two while trying to categorize the last image as quickly as possible. Block order was counterbalanced between participants and response protocols and practice sessions corresponded to those in Experiment 1. Each picture was presented 16 times in each block (four times as a nonconscious prime, four times as conscious prime, and eight times as probe). RTs and accuracies were measured. For statistical analysis, affective and semantic priming scores (incongruent - congruent) were calculated for accuracies and RTs in both tasks.

Results

The results are summarized in Figure 11. The d' values for 10 ms primes (150 ms prime-probe SOA: affective 0.28, semantic 0.46; 300 ms prime-probe SOA: affective 0.48; semantic 0.74) suggested marginal awareness of the 10 ms primes, $ts(7) < 2.12$, $ps > .071$, $rs < .626$, indicating that in the majority of trials the participants were not able to distinguish between 10 ms primes and trials where no prime was present. At 150 ms prime-probe-SOA, priming scores (incongruent—congruent) for both accuracies and RTs differed significantly from zero for 80 ms primes in both the affective and semantic tasks $ts(23) > 2.65$, $ps < .015$, $rs > .261$, while no priming effects were observed for 10 ms primes in either task, $ts(23) < 1.21$, $ps > .238$, $rs < .124$. At 300 ms SOA, no priming effects were observed for accuracies in either task, $ts(23) < 1.23$, $ps > .231$, $rs < .125$. For RTs, significant priming effects were observed in both tasks for 80 primes, $ts(23) > 2.23$, $ps < .038$, $rs > .220$, but not for 10 ms primes, $ts(23) < 1.53$, $ps > .139$, $rs < .155$.

Priming scores for accuracy and RTs were then subjected to 2 (categorization task: affective vs. semantic) × 2 (prime presentation time: 10 vs. 80 ms) × 2 (prime-probe SOA: 150 vs. 300 ms) with prime-probe SOA as a between-participants factor. For accuracies, a main effect of prime presentation time, $F(1, 46) = 16.06$, $p < .001$, $\eta^2_P = .259$ emerged. There were no other significant main effects or interactions, $Fs < 2$.[4] Paired sample t tests indicated that, in the 150 ms prime-probe SOA group, accuracy priming scores for 80 ms were greater than zero in both the affective, $t(23) = 2.73$, $p = .012$, $r = .479$, and semantic, $t(23) = 3.28$, $p = .003$, $r = .553$, tasks, but did not differ between tasks, $t(23) = .729$. Differences were nonsignificant for 10 ms primes in both tasks, $ts(23) < 1.21$, $ps > .238$, $rs < .236$. For the 300 ms prime-probe SOA group, there were no significant effects, $ts(23) < 1.23$, $ps > .232$, $rs < .239$.

The corresponding ANOVA on RTs yielded a main effect of prime presentation time, $F(1, 46) = 18.34$, $p < .001$, $\eta^2_P = .285$. There were no other significant main effects or interactions, $Fs < 1.89$. With both prime-probe SOAs, RTs were shorter for congruent in comparison to incongruent probes in both the affective, $ts(23) > 2.65$, $ps < .015$, $rs > .464$, and semantic, $ts(23) > 2.21$, $ps < .038$, $rs = .403$, tasks when the prime was displayed for 80 ms. No priming effects for 10 ms primes were observed with either prime-probe SOA, $ts(23) < 1.53$, $ps > .139$, $rs < .293$.

Again, because d' analysis was indicative of stimulus awareness at the 10ms stimulus display duration, accuracy and RT priming scores from the awareness rating group were subjected to a separate 2 (prime-probe SOA) × 2 (categorization task) × 4 (level of awareness) ANOVAs. For accuracies, no significant effects or interactions were revealed, $Fs < 2.23$. For RTs, a main effect of level of awareness emerged, $F(3, 21) = 6.01$, $p = .022$, $\eta^2_P = .462$. In the 150 ms prime-probe SOA group, significant priming effects were observed in the semantic task, $ts(5) > 2.67$, $ps < .034$, $rs > .738$[5], when the primes were above the discrimination threshold

[4] We also analyzed the data of the group performing the additional awareness rating task and the group performing the single categorization task separately. The analyses showed that the affective priming effect was amplified in the 150 ms prime-probe SOA group for 80 ms primes when they were also performing the awareness rating task (accuracy priming scores .0550 vs. .0200).

[5] In the priming experiments, some presentation times did not produce subjective perceptive experiences across the whole dimension represented by the PAS. Consequently, participants did not employ the whole range of the PAS. Therefore, when pooling results from awareness rating data, the reported degrees of freedom represent the pool lower bound.

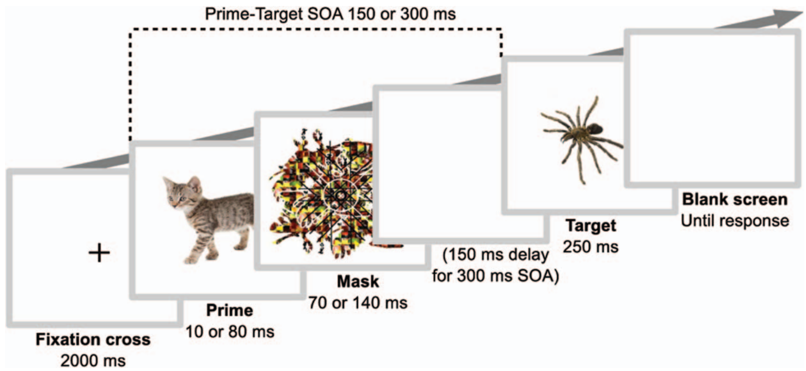


Figure 10. Trial structure in Experiment 4.

(awareness Rating 3 or 4). There was also a borderline effect for completely aware primes (awareness Rating 4) in the affective task, $t(5) = 2.37$, $p = .064$, $r = .667$. In the 300 ms prime-probe SOA group, significant priming effects in both tasks were observed when the participants were completely aware of the primes (awareness Rating 4), $ts(5) > 2.91$, $ps < .028$, $rs = .757$. In the complete absence of awareness of the primes (awareness Rating 1), the priming scores did not differ from zero in the semantic, $ts(6) < .439$, $ps > .675$, $rs < .153$, or affective, $ts(6) < 1.18$, $ps > .282$, $rs < .386$, task with either prime-probe SOA.

Discussion

Experiment 4 confirmed that also implicit affective and semantic categorization of biologically relevant stimuli requires visual awareness, and that this reliance on visual awareness demonstrated in Experiments 1 and 3 is not a byproduct of reliance on explicit reporting of the contents of the sensory stream that are accessible to consciousness. Even when an indirect priming measure relying on implicit stimulus processing was used to tap semantic and affective processing, neither semantic nor affective priming was observed in the conditions where visual awareness of the prime did not emerge.

In this experiment the 10 ms SOA also seemed sufficient for blocking visual awareness of the primes. Although the *d* prime values for 10 ms primes did not significantly differ from zero, it should be noted that borderline effects with considerable d' values and effect sizes were observed at both 150 and 300 ms prime-probe SOAs, implicating some awareness of the 10 ms primes.

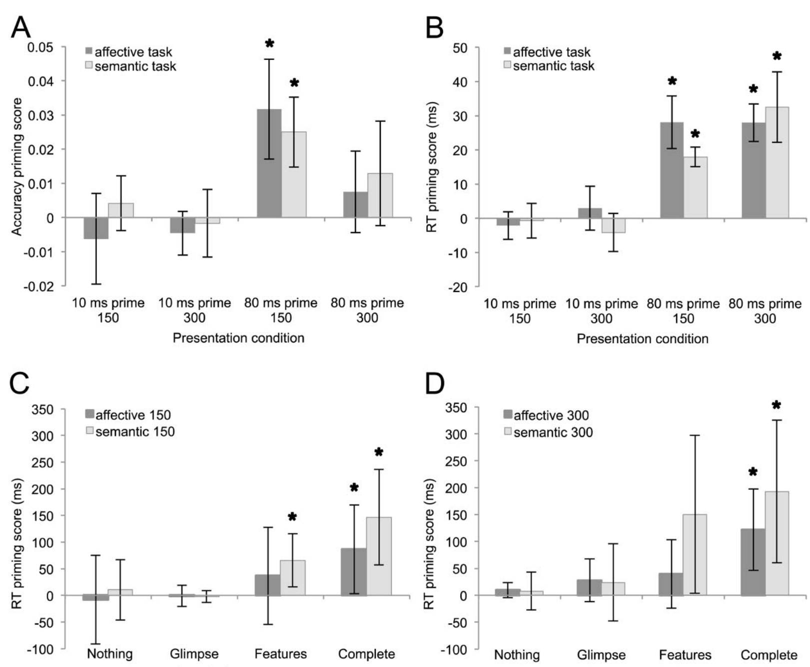


Figure 11. Means and standard errors of mean of priming scores for accuracy and RTs in Experiment 4. (A) Accuracy priming scores for affective and semantic categorization for 150 ms and 300 ms prime-probe SOAs. (B): RT priming scores at 150 ms and 300 ms SOA. (C): RT priming scores as a function of awareness, 150 ms SOA. (D): RT priming scores as a function of awareness, 300 ms SOA. RT = response time.

This marginal stimulus awareness probably accounts for the weak yet nonsignificant priming effects observed for 10 ms primes. Yet, when priming effects are measured as a function of awareness ratings, the results demonstrated complete lack of priming effects in the absence of awareness, regardless of the prime duration.

In Experiment 4, both affective and semantic priming were observed for primes that reached awareness. Here, our results are in line with previous studies which have shown priming effects to be maximal at 150 ms SOA, at which stage processing is thought to be highly automatic (Calvo & Nummenmaa, 2008; Hermans et al., 2001). Critically, Experiment 4 confirms that even though the emotional (and semantic) stimulus dimensions are indeed evaluated quickly and automatically, such automatic categorization is strictly dependent on the stimulus reaching visual awareness. Importantly, affective priming was never stronger than semantic priming, even though the prime-probe SOA was specifically tailored for effective affective priming. In conclusion, Experiment 4 confirms that both implicit affective and semantic categorization requires visual awareness.

Experiment 5

Experiments 1–3 have consistently demonstrated that explicit affective and semantic recognition require visual awareness; furthermore Experiments 1 and 2 suggest that visual awareness imposes similar constraints of explicit processing of complex emotional scenes and facial expressions. Even though Experiment 4 confirmed that even implicit affective (and semantic) categorization requires awareness, we decided that it would be imperative to test whether this is also true for facial expressions. Despite negative findings in Experiment 4, this possibility should be ruled out carefully, given that much of the prior work claiming to find evidence for affective processing outside awareness has used facial stimuli. These studies have suggested that subthreshold facial expressions may lead to affective priming (Murphy & Zajonc, 1993), peripheral physiological changes such as electrodermal responses (Öhman & Soares, 1998) and facial expression related electromyographic responses (Dimberg, Thunberg, & Elmehed, 2000), as well as activation in subcortical and face-specific cortical areas as indexed by fMRI (Morris et al., 1998; Morris et al., 2001). To rule out the contribution of partial stimulus awareness (see Introduction) on implicit facial expression recognition, we replicated the masked priming design of Experiment 4 with the facial stimuli from Experiment 2 to test for affective or semantic priming of nonconscious facial stimuli.

Method

Participants. Forty-eight university students (38 females and 10 males; age 18–30 years; mean age 24 years) participated in the experiment for a course credit. All participants gave informed consent and had normal or corrected-to-normal vision.

Stimuli and procedure. The design and procedure (see Figure 12) was similar to that in Experiment 4 with two exceptions. First, stimuli were those used in Experiment 2 and second, the affective block involved discriminating between fearful and happy facial expressions and the semantic block involved discriminating between males and females. Eight participants in each SOA group performed the PAS-rating of the primes in addition to the categorization task.

Results

The results are summarized in Figure 13. The d' values for detection of 10 ms primes (150 ms prime-probe SOA: affective -0.02, semantic 0.11; 300 ms prime-probe SOA: affective 0.03, semantic 0.12) did not differ from zero, $ts(7) < .915$, $ps > .390$, $rs < .327$. At both 150 and 300 ms prime-probe-SOAs, both accuracies and RT priming scores differed significantly from zero for 80 ms primes in both the affective and semantic tasks $ts(23) > 2.52$, $ps < .020$, $rs > .249$, whereas no priming effects were observed for 10 ms primes in either task, $ts(23) < 2.06$, $ps > .50$, $rs < .240$. The 2 (categorization task: affective vs. semantic) $\times$ 2 (prime duration: 10 vs. 80 ms prime-probe SOA) $\times$ 2 (prime-probe SOA: 150 vs. 300 ms) ANOVA on accuracy priming scores revealed main effects of Task, $F(1, 46) = 14.46$, $p < .001$, $\eta_P^2 = .239$, Prime Duration, $F(1, 46) = 35.98$, $p < .001$, $\eta_P^2 = .439$, and Prime-probe SOA, $F(1, 46) = 4.89$, $p = .032$, $\eta_P^2 = .244$, indicating that priming effects were greater in the semantic task than in the affective task, greater for 80 versus 10 ms primes, and greater with 150 versus 300 ms prime-probe SOA. Interactions of Prime Duration $\times$ Task, $F(1, 46) = 14.82$, $p < .001$, $\eta_P^2 = .244$, and Task $\times$ Prime-probe SOA, $F(1, 46) = 4.33$, $p = .043$, $\eta_P^2 = .086$ were also observed. For 80 ms primes, congruent primes increased accuracy in the affective and semantic tasks at both 150 ms prime-probe SOA (semantic priming scores .079, affective

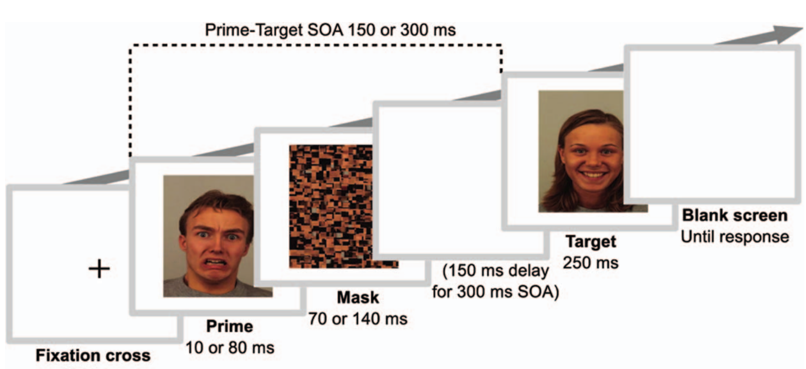


Figure 12. Trial structure in Experiment 5.

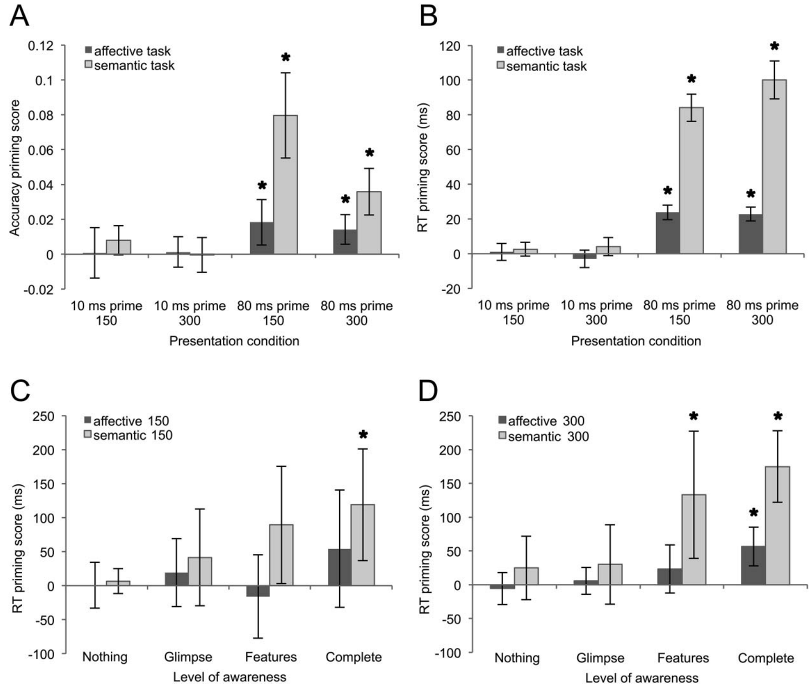


Figure 13. Means and standard errors of priming scores for accuracy and RTs in Experiment 5. Positive values indicate facilitation. (A) Accuracy priming scores for affective and semantic categorization for 150 ms and 300 ms prime-probe SOAs. (B): RT priming scores at 150 ms and 300 ms SOA. (C): RT priming scores as a function of awareness, 150 ms SOA. (D): RT priming scores as a function of awareness, 300 ms SOA. RT = response time.

priming scores .018), $ts(23) > 2.86$, $ps < .010$, $rs > .495$, and 300 ms prime-probe SOA (semantic .036, affective .014), $ts(23) > 2.50$, $ps < .020$, $rs > .450$, prime-probe SOAs. Critically, no priming effects were observed for 10 ms primes, $ts\ (23) < 2.055$, $ps > .050$, $rs < .382$. There were no other interactions or main effects, $Fs < 3.0$.

For RTs, the corresponding ANOVA revealed main effects of Task, $F(1, 46) = 36.38$, $p < .001$, $\eta_P^2 = .442$, and Prime Duration, $F(1, 46) = 66.69$, $p < .001$, $\eta_P^2 = .592$, and an interaction of Task × Prime Duration, $F(1, 46) = 43.72$, $p < .001$, $\eta_P^2 = .487$. For 80 ms primes, congruent primes resulted in faster response times than incongruent primes in semantic and affective tasks at both 150 ms (affective, 23.9 ms difference; semantic, 84.1 ms difference) and 300 ms (affective, 17.1 ms difference; semantic, 80.1 ms difference) prime-probe SOAs, all $ts\ (23) > 3.01$, $ps < .007$, $rs > .517$. Again, priming effects were stronger in the semantic than affective task.[6] As with accuracy scores, no priming effects were observed for 10 ms primes, all $ts(23) < .875$, $ps > .390$, $rs < .175$.

In the separate analysis for the awareness rating group, the 2 (categorization task) × 2 (prime-probe SOA) × 4 (level of awareness) ANOVA on accuracies revealed an interaction of Task × Prime-probe SOA, $F(1, 11) = 7.15$, $p = .022$, $\eta_P^2 = .394$, resulting from stronger priming effects in the semantic task at 150 ms SOA in comparison to 300 ms SOA. However, decomposing the interaction did not reveal any further effects. There were no other significant effects or interactions, $Fs < 2.23$. The corresponding ANOVA on RTs revealed main effects of task, $F(1, 10) = 10.976$, $p = .008$, $\eta_P^2 = .523$, and level of awareness, $F(3, 30) = 6.25$, $p = .006$, $\eta_P^2 = .384$. Semantic priming was significant for above discrimination threshold primes (awareness Rating 3 or 4) under 300 ms, $ts(7) > 2.53$, $ps < .044$, $rs > .667$, and for completely aware primes (awareness Rating 4) under 150 ms prime-probe SOA, $t(7) = 2.36$, $p = .049$, $r = .621$. Affective priming was only significant for completely aware primes under 300 ms prime-probe SOA, $t(6) = 3.79$, $p = .009$, $r = .802$. No priming effects were observed for primes that did not reach awareness in either task or either prime-probe SOA, $ts(6) < .998$, $ps > .351$, $rs < .338$.

Discussion

Experiment 5 confirmed that implicit affective and semantic face categorization require visual awareness. In this respect, the processing of facial expressions does not appear to differ from the processing of other biologically relevant emotional stimuli. As in Experiment 4, affective and semantic priming were only observed when the participants were aware of the primes. This conclusion was supported both by subjective reports and signal detection analysis. The d' values for 10 ms primes did not differ from zero and, consequently, 10 ms primes did not elicit significant priming effects in either task. Both affective and semantic priming effects were observed only for 80 ms primes under both 150 and 300 ms

[6] As in Experiment 4 we also analyzed the data of the two groups separately. The analyses showed that affective and semantic priming effects were amplified in the group performing the awareness rating task (affective: 27.9 vs. 16.9 ms; semantic: 135.2 vs. 55.5 ms); this amplification was greater for the semantic task.

prime-probe SOAs. Yet, under 300 ms SOA, affective priming was only apparent for primes participants were completely aware of, while semantic priming occurred for partially as well as completely aware primes. This suggests that facial features undergo some degree of semantic classification even under conditions where the subjective percept is too weak to permit affective processing, which fits well with the proposed hierarchy of the face recognition stages in human occipitotemporal cortices (Haxby, Hoffman, & Gobbini, 2000).

In general sense our results are consistent with previous studies on facial priming (e.g., Carroll & Young, 2005; Nummenmaa, Peets, & Salmivalli, 2008) in that we demonstrate priming effects to both affective and nonaffective facial cues; yet we failed to find any evidence for processing of facial affect outside awareness (cf. Dimberg, Thunberg, & Elmehed, 2000; Murphy & Zajonc, 1993; Öhman & Soares, 1998). Instead, in line with some previous research (Banse, 2001) we found that facilitative priming effects are only observed for clearly visible primes, but did not find significant reverse priming effects for marginally visible primes comparable to those in Banse's study. Yet, the affective priming scores for partially aware primes at 150 ms SOA, as well as the accuracy priming scores for partially visible 10 ms primes in Experiment 4 suggest such an effect is possible. However, as revealed by the awareness rating data, these effects clearly do not extend to completely nonconscious primes.

General Discussion

The main findings of our study were that i) neither affective nor semantic categorization occurs in the absence of visual awareness, and ii) that semantic categorization always precedes affective recognition. In the absence of stimulus awareness, all tested types of explicit and implicit semantic and affective recognition processes were at chance level across a large array of stimuli (n = 280) and stimulus categories. When visual awareness emerged, semantic categorization immediately took the lead and was completed prior to any type of affective evaluations. Finally, F2 analysis and manipulations of the demanded affective and semantic categorization level (superordinate vs. basic level) revealed a clear hierarchy in the classification operations, in that affective evaluations are dependent on the preceding semantic categorization levels, and that basic-level semantic and affective evaluations may sometimes precede the corresponding superordinate level categorization operations. Altogether these results cast doubts on the widely assumed human capability for nonconscious affective recognition, and instead suggest that evaluative affective processes operate under similar visual constraints as all other object recognition operations.

Emotional Processing Requires Visual Awareness

The present results contradict the widely accepted view that affective processing occurs outside of awareness (Tamietto & DeGelder, 2010). When both subjective and objective criteria were employed for assessing stimulus awareness with trial-wise, continuous qualification of subjective visual awareness (Ramsøy & Overgaard, 2004) and signal detection analysis (Macmillan & Creelman, 2004; Pessoa & Ungerleider, 2005), both implicit and explicit measures consistently showed that affective recognition could be accomplished only when visual awareness emerged. In explicit recognition Experiments 1–3, above chance level performance was found only when at least partial stimulus awareness emerged, as indexed by d' values and self-reports. Paralleling these findings, Experiments 4–5 employing the priming paradigm revealed that both affective and semantic priming was observed only for stimuli that were consciously perceived, and, when participants reported no awareness or when d' values indicated that the participants were not able to distinguish target or prime stimuli from catch trials, neither above-chance discrimination nor significant priming effects were observed. With increasing awareness, both recognition performance and priming effects grew proportionately in both tasks, indicating that conscious discrimination is an essential prerequisite for affective and semantic categorization in both implicit and explicit tasks.

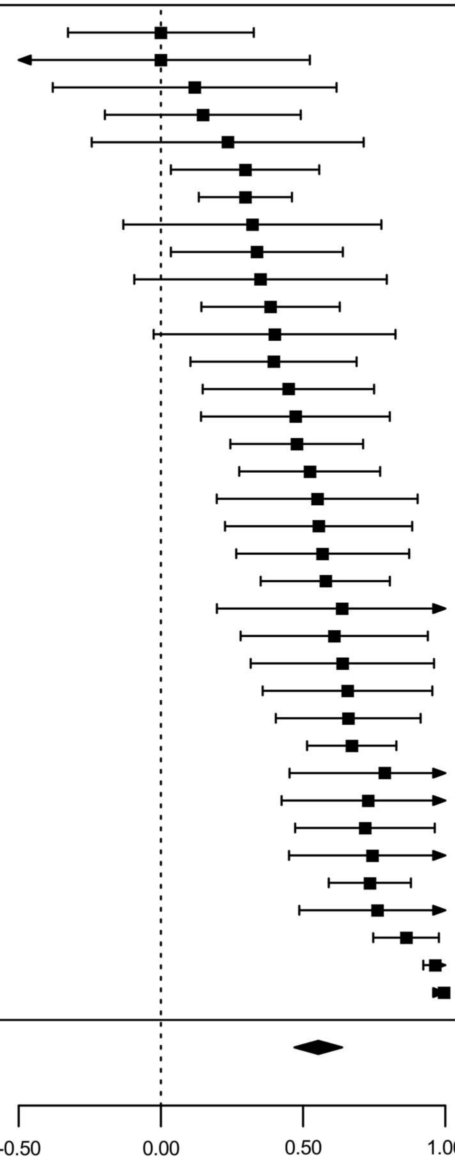
The present data nevertheless revealed that affective and semantic processing of extremely low-intensity stimuli (see summary of consciousness ratings by SOA in Table 1) is possible. In Experiments 1–3 we observed above chance recognition performance and d' values above zero even for targets shown for 10 ms and suppressed by carefully constructed postmasks. But as indicated by the d' values and subjective reports for 10 ms stimuli, participants could *sometimes* consciously detect these stimuli and discriminate them from trials where no stimulus was present. Thus, even low-intensity sensory stimuli can lead to partial emergence of visual awareness (see also Pessoa et al., 2005) and even though the stimulus intensity on 10-ms trials is often too weak for emergence of subjective sensation of stimulus awareness, it may be sufficient to gain access to awareness on a substantial number of trials. In the present recognition tasks (Experiments 1–3) this occurred on average 25% of the 10-ms trials (see Table 1). Consequently, the net performance for all the 10-ms trials is consistent with the models assuming affective processing outside awareness (see Tamietto & de Gelder 2010, for a review). Yet, when recognition performance is evaluated as a function of the subjective percept obtained from trial-wise ratings of awareness rather than by stimulus display

Table 1
Distribution of Awareness Rating Responses for Each Display Duration in Each Experiment

	Display duration	Proportion of awareness rating responses			
		Nothing	Glimpse	Features	Complete
Experiment 1	10	0.52	0.43	0.03	0.02
	40	0.03	0.31	0.29	0.37
	80	0.01	0.14	0.26	0.60
Experiment 2	10	0.91	0.07	0.01	0.01
	40	0.05	0.22	0.38	0.35
	80	0.03	0.09	0.29	0.59
Experiment 3	10	0.51	0.26	0.18	0.05
	40	0.06	0.15	0.38	0.41
	80	0.03	0.06	0.26	0.65
Experiment 4a	10	0.27	0.60	0.08	0.05
	80	0.11	0.28	0.25	0.36
Experiment 4b	10	0.40	0.54	0.05	0.01
	80	0.11	0.32	0.20	0.36
Experiment 5a	10	0.62	0.32	0.05	0.01
	80	0.09	0.11	0.42	0.38
Experiment 5b	10	0.71	0.23	0.03	0.04
	80	0.06	0.11	0.28	0.55

Table 2
Meta-Analysis of Backward Masking Studies on Nonconscious Affective Processing and the Measures Used to Control Stimulus Awareness

Author and year	Aw. control	Study type	Stimuli	SOA
Pessoa et al. 2006	2	fMRI	face	33 ms
Eimer et al. 2008	2	ERP	face	17 ms
Lahteenmaki et al. Exp 1b	1	Behavioral	animal / food	10 ms
Lahteenmaki et al. Exp 2a	3	Behavioral	face	10 ms
Lahteenmaki et al. Exp 3	1	Behavioral	animal / food	10 ms
Lahteenmaki et al. Exp 4a	3	Behavioral	animal / food	10 ms
Dimberg et al 2000	4	EMG	face	30 ms
Lahteenmaki et al. Exp 2b	1	Behavioral	face	10 ms
Li et al. 2008 ERP	4	ERP	face	30 ms
Lahteenmaki et al. Exp 5b	3	Behavioral	face	10 ms
Lahteenmaki et al. Exp 5a	3	Behavioral	face	10 ms
Lahteenmaki et al. Exp 4b	1	Behavioral	animal / food	10 ms
Hermans et al. 2003 Exp 2	4	Behavioral	face/animal/object	20 ms
Hermans et al. 2003 Exp 1	4	Behavioral	face/animal/object	20 ms
Liddell et al. 2005	3	fMRI	face	17 ms
Sweeny et al 2009	4	Behavioral	face	30 ms
Lahteenmaki et al. Exp 1a	3	Behavioral	animal / food	10 ms
Murphy and Zajonc, 1993 Exp 2	3	Behavioral	face	4 ms*
Pegna et al. 2008	2	ERP	face	16 ms
Liddell et al. 2004	3	ERP	face	10 ms
Li et al. 2008 Behav.	4	Behavioral	face	30 ms
Phillips et al. 2003	3	fMRI	face	30 ms
Smith, 2012	2	ERP	face	8 ms
Kiss & Eimer 2008	2	ERP	face	8 ms
Williams et al. 2006	3	fMRI	face	17 ms
Williams et al. 2004	3	ERP	face	10 ms
Ohman & Soares 1998 Exp 2	3	SCR	animal	30 ms
Morriset al., 2000	2	fMRI	face	30 ms
Morris et al., 1998	2	PET	face	30 ms
Murphy and Zajonc, 1993 Exp 1	3	Behavioral	face	4 ms*
Whalen et al. 1998	4	fMRI	face	33 ms
Ohman & Soares 1998 Exp1	5	SCR	animal / plant	30 ms
Juruena et al. 2010	4	fMRI	face	33 ms
Whalen et al. 2004	4	fMRI	eye whites	17 ms
Killgore & Yurgelun-Todd 2004	4	fMRI	face	20 ms
Nomura et al. 2004	3	fMRI	face	35 ms



Note. Coding for Awareness control: 1 = trialwise detection threshold; 2 = trialwise discrimination threshold; 3 = predetermined SOA; 4 = post-experimental interview; 5 = none, * =stimuli presented via shutters. Studies are listed in order of increasing effect size.

duration, performance is at chance level in both affective and semantic tasks in all experiments for trials where participants reported no awareness of the stimulus. These results thus do not support the notion of affective recognition outside awareness. Because above chance level affective categorization and priming effects require at least partial awareness of the stimulus, they do not qualify as nonconscious. Importantly, nonaffective visual categorization operations also appear to have similar constraints with respect to requiring marginal stimulus awareness (see Ramsøy & Overgaard, 2004 for a review).

Critically, in many previous studies stimuli presented for 10 ms duration or even longer have been considered to be reliably below the threshold for conscious perception (e.g., Williams et al., 2004; Liddell et al., 2004; see also Pessoa, 2005 and Table 2), even though their access to awareness was not evaluated on a trial-by-trial basis. However, the present experiments highlight that such SOA manipulation alone is not a reliable and consistent method for controlling stimulus awareness. To account for both between- and within-participant variance in discriminability, trial-wise measurement of awareness should thus be routinely used whenever conclusions concerning awareness are to be drawn. This is a particularly serious concern, given that majority of evidence for affective discrimination in the absence of awareness comes from studies where trial-wise measurement has not been employed (Dimberg et al., 2000; Hermans et al., 2003; Juruena et al., 2010; Killgore & Yurgelun-Todd, 2004; Li et al., 2008; Liddell et al., 2004, 2005; Morris et al., 1998, 2000; Murphy & Zajonc, 1993; Nomura et al., 2004; Philips et al., 2004; Sweeny et al., 2009; Whalen et al., 1998, 2004; Williams et al., 2004, 2006; Öhman & Soares, 1998). Hence it remains possible that the low-intensity trials where partial stimulus awareness has nevertheless arisen could account for the results. Consequently, it is possible that prior studies demonstrating affective processing outside of visual awareness do so due to insufficient control of visual awareness of the stimuli and consequent leakage of affective information to awareness.

To provide quantitative support for this hypothesis, we conducted a random effects meta-analysis on existing behavioral and neurophysiological studies on affective processing outside awareness in healthy populations. Mean effect sizes (r) for indices of emotional processing in limited awareness conditions were computed in such way that positive value reflects emotional processing outside awareness. We also coded the level of awareness control used in the study (1 = trial-wise detection threshold; 2 = trial-wise; discrimination threshold 3 = predetermined SOA; 4 = postexperimental interview; 5 = none), the SOA used for indexing 'unconscious' emotional processing (ranging from 4 to 35 ms) as well as stimulus type (facial expressions, animals, etc.) used in the study. Subsequently, weighted effect sizes were computed and subjected to meta-analysis using a random effects model with unbiased estimates of correlation coefficients and restricted maximum likelihood estimator, yielding mean and 95% confidence intervals (CIs) for the effect sizes. This model assumes that the effect sizes are contingent on study parameters, thus allowing for an estimation of both within and between studies variances, and is consequently well-suited for analyses where studies vary with respect to methodological aspects as is the case here.

The omnibus meta-analysis provided support for emotional processing outside awareness, with large positive mean effect size of .554 with a confidence interval (.470 to .637) not overlapping zero (see Table 2). However, moderator analysis confirmed that the effect size for affective processing outside awareness is actually contingent on the level of awareness control used in the studies, $Q_M(1) = 3.92$, $p = .048$, with weaker awareness control consistently leading to larger effect sizes. Neither SOA nor stimulus type were associated with the effect size estimates. This suggests that across the current body of studies, lack of strict control of stimulus awareness and consequent leakage of affective information to awareness best explains the observed nonconscious affective processing. It must nevertheless be stressed that even though the results of the present study and those of the meta-analysis suggest that affective processing requires visual awareness, they do not undermine the claim that emotional processing can be accomplished with very limited visual resources, given that some above chance level emotional processing could indeed sometimes be accomplished with the shortest 10-ms SOAs, as long as the participants become aware of the stimuli. In other words, emotional recognition sometimes operates quickly and with limited visual resources (Nummenmaa et al., 2010) but rarely in the absence of awareness. Finally, even though the results of the omnibus meta-analysis suggesting affective processing outside awareness would be taken at face value, we want to stress that the present experiments clearly show that whenever affective recognition is possible, semantic recognition may occur equally accurately as well. Thus, the evidence for 'specialized' affective processing outside of awareness is elusive.

Semantic Recognition Precedes Affective Recognition

Our second main finding was that affective evaluations are not a 'special' case of visual recognition. Instead, both affective and semantic recognition were similarly dependent on visual awareness, which is in line with the semantic primacy hypothesis which predicts that semantic recognition precedes affective evaluations hypothesis (Calvo & Nummenmaa, 2008; Lazarus, 1984; Nummenmaa et al., 2010; Rolls, 1999; Storbeck & Clore, 2007; Storbeck, Robinson, & McCourt, 2006). Two lines of evidence further support this model. First, when recognition performance was assessed as a function of visual awareness, affective recognition never occurred with more limited awareness than semantic recognition. Actually, both affective and semantic recognition were similarly dependent on visual awareness in that whenever even limited stimulus awareness emerged both semantic and affective recognition could be accomplished above chance level. Because the participants were able to categorize these minimally aware stimuli equally well in the affective and semantic dimensions, the results suggest that ability to extract category information from partially aware stimuli is a general principle of visual information processing and is not by any means specific to emotional categorization. Second, the analyses systematically showed that semantic categorization was always faster than affective discrimination of *exactly the same stimuli* for the trials leading to the emergence of at least a partial stimulus awareness, yet in the absence of awareness no differences were observed between semantic and affective categorization.

Two different models can explain this primacy of semantic over affective categorization. First, affective and semantic recognition could be assumed to be parallel and independent, and affective recognition could simply take longer to accomplish. Second, it could also be postulated that affective and semantic recognition would operate in an initially serial, interacting systems, where the affective analysis would constitute an extra processing step, whose execution would consume additional time. Several lines of evidence lend support for the latter view. First, our F2 analyses showed a positive correlation between semantic and affective categorization RTs for stimuli that reached awareness, suggesting that semantic recognition is a necessary prerequisite for affective recognition: Time taken for completing the affective analysis sums up with the semantic recognition time, thus suggesting that affective analysis constitutes an extra visual processing step in a linearly operating hierarchy of recognition operations (cf. Nummenmaa et al., 2010).

Second, Experiment 3 showed that for partially and fully aware stimuli, basic-level semantic categorization was always both fastest and most accurate. This finding could be interpreted to confirm that basic-level semantic categorization serves as the entry level for visual categorization, which is accessed before all affective and superordinate level semantic categorization operations. However, to move beyond the age-old debate on primacy of different semantic taxonomies, object recognition speed in the ventral stream is perhaps better viewed in terms of categorization operations that can be carried out on fast but coarse magnocellular versus slower but more fine-grained parvocellular information. Semantic recognition thus proceeds *from coarse to fine* (Fabre-Thorpe, 2011). In Experiment 3, the snakes versus spiders task could be carried out with low spatial frequency magnocellular information, thus, we observed a basic-level advantage. Furthermore, Experiment 3 showed that semantic categorization was faster and more accurate than affective categorization in both superordinate and basic-level categorization tasks, indicating that the semantic primacy observed in the present and previous studies (Nummenmaa et al., 2010) is not a task-dependant effect but reflects are more general trait of information processing, namely, the dependence of affective evaluation on semantic recognition. This effect of semantic primacy in visual categorization could thus explain why both semantic and affective evaluations are similarly dependent on visual awareness: If this initial semantic recognition step cannot be carried out, further affective categorization is not possible.

Third, anatomical data clearly indicates that visual information is first relayed to the inferotemporal cortex (IT), which performs semantic categorization and identification (Storbeck, Robinson, & McCourt, 2006), and from IT to the amygdala, which is responsible for affective evaluation. As there is no anatomical evidence for the existence of an alternative route for emotional evaluation (see Introduction), it remains a mystery how the brain could even accomplish the speeded processing of affect in the first place. Fourth, the anatomical data is backed by single neuron recordings from the human amygdala, which show that affective amygdala responses to visual stimuli depend on output from IT (Kreiman, Fried, & Koch, 2002). Moreover, in monkeys, synaptic cooling of the affect-invariant IT neurons attenuates affective responses in the amygdala (Rolls, 1999), and also tunes specific food-selective cells to nonselective (Fukuda, Ono, & Nakamura, 1987). Fifth, neuropsychological evidence confirms that affective evaluation is impaired when the output of the semantic processing performed by area IT cannot reach the amygdala. The most well-documented example of this is patient LF who, following destruction of fibers from IT to amygdala, lost the ability to become aroused by visual stimuli (Bauer, 1984).

Taken together, these results confirm that at least rudimentary semantic classification is an essential prerequisite for affective recognition, and show that semantic and affective categorization operate in a linear fashion. The object recognition system must first encode the basic semantic properties of the visual stimulus, and only subsequently this information is fed forward for affective analysis and the affective and semantic processing streams diverge.

Can Affective Processing Sometimes Occur Without Visual Awareness?

Despite the systematic evidence against nonconscious affective recognition emerging from five experiments, we must nevertheless seriously consider the possibility of affective processing outside awareness because such findings have been consistently reported in the literature. Our arguments against the existence of affective processing outside of awareness are of course limited to backward masking studies in the visual domain, where the lack of awareness control was found to be a prominent explanation for the unconscious affective processing obtained in prior studies (see above and Table 2). However, two other major lines of studies also suggest that affective processing can sometimes occur without awareness. First, attention manipulation paradigms have shown that emotional stimuli are processed outside of attention (Calvo & Nummenmaa, 2008), interfere with visual tasks (Eastwood, Smilek, & Merikle, 2003), and are more easily detected than neutral stimuli (Calvo & Nummenmaa, 2008; Öhman, Flykt, & Esteves, 2001). However, even though attention and awareness are often thought of as identical processes (e.g., Merikle & Joordens, 1997; Posner, 1994), they are actually two separate phenomena with separate functions supported by separable neurophysiological mechanisms (Koch & Tsuchiya, 2007; Koivisto, Revonsuo, & Lehtonen, 2006; Lamme, 2003). Therefore, unless the extent to which participants are aware of unattended stimuli is also measured, lack of awareness cannot be assumed on the basis of lack of attention. As measures for qualifying awareness are typically not employed in studies employing attention manipulations, the existing studies on affective processing of unattended visual information cannot be considered to provide direct evidence for affective processing outside awareness.

A second line of evidence for nonconscious affective processing comes from "affective blindsight" patients, who are partially or completely blind due to lesions of the primary visual cortex (V1), yet they can discriminate emotional stimuli presented to the visual field region affected by the lesion (Anders et al., 2004; de Gelder et al., 1999; Pegna, Khateb, Lazeyras, & Seghier, 2005). Previously, this discrimination has been taken as indication of a functional "low road" for emotion perception in these patients (Morris et al., 2001). However, the blindsight phenomena are not limited to emotional stimuli, but also include discrimination of nonaffective stimulus features such as color or direction of motion (Azzopardi & Cowey, 2001; Sahraie, Weiskrantz, Trevethan, Cruce, & Murray, 2002; Stoerig & Cowey, 1997), suggesting that nonconscious visual processing in blindsight patients could be mediated by connections to extrastriate cortical visual areas that bypass the primary visual cortex (Cowey & Stoerig, 1991; Schmid et al., 2010) than by subcortical structures alone. A further caveat of blindsight studies is that postlesion plasticity changes (Leh et al., 2006; Silvanto & Rees, 2011) may have altered the sensitivity of subcortical and extrastriate visual areas. Therefore, affective blindsight phenomena in patients cannot provide strong evidence for the existence of corresponding nonconscious visual processing in healthy individuals.

We must also note that the present experiments implemented only behavioral measures of affective and semantic recognition, which are not fully unproblematic. It has been shown that even when manual response latencies for different semantic targets are similar, concurrent ERP recordings may reveal robust latency differences between stimulus categories (Rousselet, Mace, Thorpe, & Fabre-Thorpe, 2007). Thus, it is possible that the neural processing of affect could begin prior to semantic processing. This is indeed possible, but it cannot rebut our main argument that the cognitive system can complete the categorization process and access the outcome of the categorization for decision making earlier for semantic than affective information. Moreover, it is noteworthy that even though prior electrophysiological (Kiss & Eimer, 2008; Liddell et al., 2004; Pegna et al., 2008; Smith, 2011;

Williams et al., 2004) and functional imaging studies (Juruena et al., 2010; Killgore & Yurgelun-Todd, 2004; Morris et al., 1998, 2000; Liddell et al., 2005; Whalen et al., 1998, 2004; Williams et al., 2006) have provided support for the nonconscious processing of affect, it must be stressed that the majority of these studies have actually not strictly controlled stimulus awareness trial-by-trial (see above and Table 2). In fact, the only imaging study that has applied more careful control of awareness during emotion perception (Pessoa et al., 2006) found no evidence for unconscious emotional processing in the brain. Be it as it may, our results clearly indicate that if such activation exists, its strength is insufficient to influence behavioral performance.

Finally, it must be emphasized that the present study involved only healthy participants. Therefore, it remains possible that nonconscious processing of affect could exist in some clinical conditions such as phobias or anxiety disorders (Öhman & Mineka, 2001). These conditions could tune the visual system for heightened sensitivity toward certain types of affective stimuli, thus enabling categorization of these stimuli outside of awareness. Future studies should thus compare, under strict control of stimulus awareness, nonconscious affective processing between healthy participants and patients from the above-mentioned clinical populations.

Interplay Between Visual Awareness and Visual Recognition

The major synthetic contribution of the present study is in showing that both affective and semantic recognition is similarly dependent on visual awareness. Apparently, both in explicit and implicit tasks, affective and semantic categorization requires that there is sufficient stimulus intensity to generate subjective percept of the stimulus. But does visual awareness always emerge before semantic and affective recognition take place? Cortical feedforward processing from visual toward motor areas can activate learned motor responses (such as catching a bottle falling from a table, or a block-counterattack in fencing) (Lamme, 2006a, 2010), and, since the feedforward sweep also reaches the amygdala through projections from inferotemporal cortex, it is possible that feedforward activation could also activate automated and overlearned affective responses (Vuilleumier, 2005).

To link our results with current neurobiological models of visual awareness and affective processing, we thus propose a schematic model of conscious and nonconscious semantic and affective processing (see Figure 14). First, prior to the emergence of visual awareness, all visual stimuli undergo core semantic recognition in the feedforward sweep. Because the feedforward activation spreads to the amygdala from the IT cortices, affective processing also begins during the feedforward stage. Visual awareness emerges in the recurrent processing stage, where again, conscious semantic classification is first performed in IT cortices, followed by conscious affective processing of the semantic information processed in the IT cortices whenever the recurrent activity encompasses the amygdala. Thus, the feedforward sweep may support some overlearned forms of some affective responses such as rapid activation of fear in phobics (Larson et al., 2006). However, this feedforward affective processing is always dependent on prior feedforward semantic classification

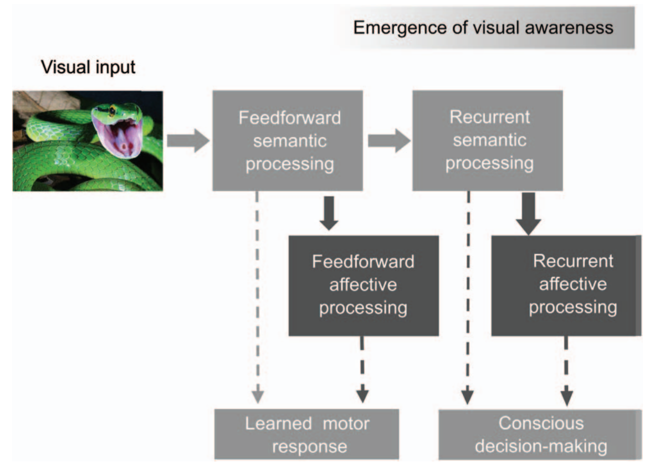


Figure 14. Schematic model of feedforward and recurrent processing of semantic and affective information.

in the ventral stream areas. Moreover, as integration of information from lateral and feedback connections is not possible in the feedforward stage of processing (Lamme, 2000), visual processing prior to awareness is limited to core object recognition, recognizing an object's identity despite large appearance variation (DiCarlo & Cox, 2007; Serre et al., 2007). Therefore, more complex forms of semantic and affective processing concerning for example, the relationships between multiple objects in a scene, are only possible in the recurrent processing stage and thus require awareness. We also stress that both feedforward and recurrent processing of visual information follow the same processing order, where semantic stimulus categorization is first performed in areas along the ventral stream, after which information is passed to amygdala and affective processing can take place.

Feedback connections from the amygdala project to ventral stream areas as well as to the primary visual cortex, and have been suggested to mediate the automated orienting of attention to emotional stimuli (Vuilleumier, 2005). This suggestion is consistent with our proposal of feedforward and recurrent processing of semantic and affective information. Consequently, we believe the feedforward sweep from ventral stream to the amygdala provides the amygdala sufficient information to guide orienting of attention to emotional stimuli prior to conscious recognition.

Additionally, the present experiments show that both affective and semantic categorization can be accomplished only under conditions where there is sufficient stimulus intensity to give rise to at least marginal awareness. This accords with major theories of visual awareness, which predict that when lack of awareness results from weak stimulus intensity, activation is limited to low sensory cortical areas (Dehaene et al., 2006), and is thus insufficient to permit affective or semantic recognition. However, though some forms of semantic and affective recognition may begin *prior* to (that is, in the feedforward stage) the emergence of visual awareness, but it must be stressed that this processing is always *followed by* conscious perception and thus does not occur without awareness.

Limitations of the Study

There are two important limitations to our study. The first concerns the limit to which generalizations to all affective processing can be made on the basis of the present experiments. As the present study involved only behavioral measures, we cannot rule out the possibility that some affect-specific brain responses could occur in the absence of awareness or independently from semantic processing. Therefore, future studies employing functional brain imaging techniques as well as measures of peripheral physiology (facial EMG, GSR), together with the subjective awareness rating methods introduced here are crucial for testing this hypothesis. However, even though the present data cannot disprove the existence of some affect-specific brain responses in the absence of awareness (and preceding semantic processing), our results do show that any affective processing potentially taking place without both awareness and prior semantic recognition does not yield sufficiently strong activity for actually influencing behavior.

A second potential criticism to the study is that the differences in categorization speed could result from low-level stimulus features or task effects. This is an important concern, given that RT latencies represent the total processing time taken to carry out early low-level visual processing, subsequent semantic and affective processing, and execution of the manual response. It can therefore be argued that low-level features made some stimuli easier to categorize along the semantic than the affective dimension, or that differences in task difficulty between the semantic and affective tasks confounded the results. There are however three arguments against this criticism: First, the stimuli used in different experiments vary considerably in terms of low-level visual features. The stimuli used in Experiments 1, 3 and 4 vary substantially in their size, color, luminosity and point of view toward the object, and it is highly unlikely that a systematic low-level bias in favor of semantic recognition could be present across all stimuli. Conversely, the stimuli used in Experiments 2 and 5 were standardized in terms of size, viewing angle and luminosity, and involved for example, both long- and short-haired men and women to avoid introduction of low-level gender cues. Yet, semantic primacy was observed with both face and animal/object stimulus sets. These finding also accord with prior work using complex natural scenes (Nummenmaa et al., 2010). Second, semantic categorization was always faster than affective categorization at both superordinate and basic levels of categorization, and with both animal/object and gender categorization tasks. Third, all the experiments used the same stimuli as targets in the affective *and* semantic tasks. Any low-level differences in general discriminability were thus the same across the affective and semantic task conditions. Finally, the presentation order of the conditions was always balanced to neutralize familiarity and arousal effects. Despite these controls, semantic primacy was consistently observed in all experiments.

All things considered, we cannot, and do not, affirm that all semantic processing must occur prior to any affective processing. Instead, we argue that some level of semantic classification—specifically, recognizing what an object is - must be accomplished before affective classification of the corresponding object can begin. Substantial amount of evidence (see the Introduction) from behavioral, electrophysiological, anatomical and neuropsychological studies also support this position. However, we acknowledge that using a more complex semantic task together with an easier affective task could result in longer semantic versus affective categorization RTs. While the total computing time for the complex semantic task would in such an instance exceed that of the affective task, this still cannot rebut our main argument that processing of the affective task can only begin after the initial semantic categorization step has been carried out

Conclusions

We conclude that neither affective nor semantic recognition take place in the complete absence of awareness, whereas stimuli that are consciously detected but too weak to be consciously recognized may undergo both semantic and affective categorization. This capability for analyzing minimally aware stimuli is nevertheless a general principle of visual information processing and is not limited to affective recognition. As semantic classification of aware stimuli precedes their affective categorization, initial recognition of objects on a semantic level is an essential prerequisite for their affective recognition, and affective and semantic recognition proceed in parallel after the initial semantic categorization operations. We conclude that affective categorization requires both visual awareness and preceding semantic categorization.

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