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Unconscious vision spots the animal but not the dog: Masked priming of natural scenes

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ABSTRACT

The functional role of consciousness has been traditionally assumed to be related to high-level executive functions, but recent theories of visual consciousness suggest qualitative differences between conscious and unconscious processes also in lower level visual processes. We tested how specific is the information that can be extracted by unconscious processes from natural scenes. Prime images which were suppressed from consciousness by continuous flash suppression facilitated categorization of visible targets at superordinate level (animal vs. non-animal) when the prime shared a category membership with the target. Suppressed prime images did not have any effect on categorization at the basic level (e.g., horse vs. other animal). Priming occurred at basic level categorization only when the prime images were available to consciousness. This pattern supports a "coarse-to-fine" model in which the visual system can unconsciously access coarse representations, but consciousness is needed for finer analysis of visual scenes.

1. Introduction

What is the function of human consciousness? Many psychologists agree that conscious processes allow greater adaptability and flexibility of top-down control than unconscious processing (Kiefer et al., 2011). Several theories assume also that integration of perceptual and conceptual information from multiple elements in visual scene requires consciousness (Tononi & Edelman, 1998). Recent evidence suggests, however, that unconscious cognition may be able to handle rather complex processes, such as integration of objects with their background scenes (Mudrik, Breska, Lamy, & Deouell, 2011). Therefore it is reasonable to ask what specifically are the visual functions that cannot be performed by unconscious processes and thus require awareness. We approached this question by studying the specificity of the information that can be extracted by unconscious processes from visual scenes. We combined the experimental tradition studying natural scene categorization (Thorpe, Fize, & Marlot, 1996) and recent theories (Campana & Tallon-Baudry, 2013; Hochstein & Ahissar, 2002) and methods (Tsuchiya & Koch, 2005) in consciousness research.

The visual categorization of dogs, birds, or horses displayed in natural scenes into 'animal' category occurs rapidly and almost without attention (Fize, Fabre-Thorpe, Richard, Doyon, & Thorpe, 2005; Li, VanRullen, Koch, & Perona, 2002; Thorpe et al., 1996). Thorpe et al. (1996) showed that natural scenes containing animals could be discriminated from non-animal scenes by the brain already at 150 ms after scene presentation. Saccadic eye movement latencies indicate that correct categorizations can be reached even faster, within 120 ms (Kirchner & Thorpe, 2006; Wu, Crouzet, Thorpe, &

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Fabre-Thorpe, 2015). The fast categorization speed has provoked the hypothesis that, at least for some categories, scene categorization can be performed in a purely feedforward manner (Fabre-Thorpe, 2011; Thorpe & Fabre-Thorpe, 2001), that is, with activation spreading linearly from lower areas in visual hierarchy to higher ones.

Studies on natural scene categorization have challenged the standard view of categorization (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976) in which basic categories such as 'dog' or 'bird' constitute the entry level that is accessed before the superordinate level (e.g., animals) or subordinate level (e.g., 'dalmatian'). Macé, Joubert, Nespoulous, and Fabre-Thorpe (2009) found that natural images were faster to categorize at the superordinate level ('animal') than at the basic level ('dog'). Moreover, a study examining saccadic eye movements indicated that an animal (superordinate level) but not a dog (basic level) could be detected already 120 ms after the onset of the stimulus (Wu et al., 2015). Poncet and Fabre-Thorpe (2014) manipulated the stimulus duration and found that superordinate categorization was faster than basic level categorization also with long stimulus durations (e.g., 500 ms) and was not restricted to the short durations (e.g., 25 ms) that are typical in natural scene categorization experiments. These findings suggest that visual information sufficient for superordinate categorization is available earlier than that for basic level categorization. A plausible interpretation for these findings may be that the feedforward flow of information from lower visual areas to higher ones in visual hierarchy results initially in coarse representation which allows discrimination between superordinate categories (Fabre-Thorpe, 2011; Koivisto, Kastrati, & Revonsuo, 2014), but the initial representation is not detailed enough for making more fine-grained discriminations between basic categories.

Although it is widely agreed that visual categorization can occur rapidly and almost without attention (Fize et al., 2005; Li et al., 2002; Thorpe et al., 1996), it is not clear whether it can be accomplished without consciousness. Different theories of visual awareness suggest that feedforward processing proceeds unconsciously from early visual areas toward the top of visual hierarchy and results in coarse low-resolution representation, whereas detailed high-resolution perception requires an additional stage of recurrent or feedback processing (Bullier, 2001; Di Lollo, Enns, & Rensink, 2000; Hochstein & Ahissar, 2002; Lamme, 2004). These theories agree that feedforward processing proceeds unconsciously, but they disagree on whether the resulting representation at the top can be conscious (Campana & Tallon-Baudry, 2013; Hochstein & Ahissar, 2002) or whether consciousness requires an additional re-entrant phase of processing (Lamme, 2004).

We hypothesized on the basis of the view that the unconscious feedforward sweep results in coarse representation that unconscious discrimination of natural scenes might be possible at superordinate level (e.g., animal vs. non-animal). However, basic level discrimination (e.g., horse vs. non-horse) requires finer analysis of the scene, and because conscious re-entrant processes are necessary for fine-grained representations (Campana & Tallon-Baudry, 2013; Hochstein & Ahissar, 2002), basic level discrimination would require consciousness. In order to test these predictions, we measured whether or not natural images whose conscious visibility is suppressed are able to elicit priming during superordinate or basic level categorization. The use of natural images as stimuli has the advantage that they are more ecologically valid than the simple shapes or line drawings that have often been used in priming studies, but their disadvantage is that it is extremely difficult to control for all visual characteristics between categories.

In the first experiment, the primes and targets in categorically congruent pairs represented different examples from the same basic category (e.g., horse–horse). We tested whether or not such primes will facilitate categorization of the target images at superordinate level (animal or not) or at basic level (e.g., horse or other animal). For example, if an invisible prime image representing a dog speeds up categorization of a different target image representing a dog in superordinate task (animal or not?), but not in basic level categorization (dog or not?), we can conclude that the category of the prime was discriminated only at superordinate level. Vice versa, if the prime speeds up categorization only at basic level, but not at superordinate level, we would conclude that unconscious processes were able to discriminate the basic category of the prime but not its superordinate category. Thus, if the task-relevant category of the prime can be discriminated, the response corresponding to the category should be pre-activated by the prime, resulting in response priming (Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). In response priming, response times are faster in congruent trials in which the prime and target share a category membership (and a common response) as compared with responses in incongruent trials, in which they do not share a category membership (or common response).

Due to lack of previous relevant masked priming experiments using natural images as stimuli, we used two techniques to suppress the visibility of the primes in the first experiment. The visibility of the prime image was suppressed by *continuous flash suppression* (CFS) (Tsuchiya & Koch, 2005) or with traditional *backward masking* (BM) (Breitmeyer & Öğmen, 2006). CFS is currently a popular technique in studies on unconscious perception. It is a variant of inter-ocular suppression in which high contrast masks are flashed to the opposite eye relative to the eye which receives the stimulus. CFS allows a prime image to be presented invisibly for a relatively long duration (here for 94 ms) so that there is more time for information uptake than in traditional forms of masking. The disadvantage of CFS is that the masks overlap temporally with the prime and in principle can interfere also with the channels that unconsciously process the prime (Almeida, Mahon, Nakayama, & Caramazza, 2008). In BM, the prime stimulus is followed by a mask in spatially overlapping position, so that processing of the prime is given a short lead without any interfering, temporally overlapping visual stimulation. The disadvantage of BM is that rather short prime durations are possible (here 23 ms), possibly too short for deriving all the relevant information from natural images.