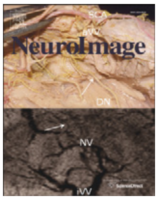
NeuroImage 73 (2013) 80–94

Contents lists available at SciVerse ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg



# Distinct brain mechanisms for conscious versus subliminal error detection

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## ARTICLE INFO

*Article history:*
Accepted 26 January 2013
Available online 4 February 2013

*Keywords:*
Error-related negativity
Consciousness
MEG
EEG

## ABSTRACT

Metacognition, the ability to monitor one's own cognitive processes, is frequently assumed to be univocally associated with conscious processing. However, some monitoring processes, such as those associated with the evaluation of one's own performance, may conceivably be sufficiently automatized to be deployed non-consciously. Here, we used simultaneous electro- and magneto-encephalography (EEG/MEG) to investigate how error detection is modulated by perceptual awareness of a masked target digit. The Error-Related Negativity (ERN), an EEG component occurring ~100 ms after an erroneous response, was exclusively observed on conscious trials: regardless of masking strength, the amplitude of the ERN showed a step-like increase when the stimulus became visible. Nevertheless, even in the absence of an ERN, participants still managed to detect their errors at above-chance levels under subliminal conditions. Error detection on conscious trials originated from the posterior cingulate cortex, while a small response to non-conscious errors was seen in dorsal anterior cingulate. We propose the existence of two distinct brain mechanisms for metacognitive judgements: a conscious all-or-none process of single-trial response evaluation, and a non-conscious statistical assessment of confidence.

## Introduction

What are the limits of non-conscious processing? In the past twenty years, evidence has accrued in favor of deep processing of subliminal stimuli (i.e., stimuli presented below the threshold of subjective visibility). Not only can early visual processing be preserved under masking conditions (Del Cul et al., 2007; Melloni et al., 2007), but subliminal primes can modulate visual (Dehaene et al., 2001), semantic (Van den Bussche et al., 2009) and motor stages (Dehaene et al., 1998; for a review, see Kouider and Dehaene, 2007). Even executive processes, once considered the hallmark of the conscious mind, can be partially influenced by non-conscious signals related to motivation (Pessiglione et al., 2007), task switching (Lau and Passingham, 2007) and inhibitory processes (Van Gaal et al., 2008). These findings raise the issue of whether subliminal stimuli could affect *any* cognitive process, or whether certain processes depend on an all-or-none conscious ignition (Del Cul et al., 2007).

Here, we investigate meta-cognition — the ability to reflect on oneself and on one's own cognitive processes. Intuitively, introspective reflection is virtually indistinguishable from conscious processing: it is hard to envisage introspection without consciousness. This intuition has served as a basis for the frequent identification of consciousness with self-oriented, metacognitive or “second-order” cognition: any information that can enter into a higher-order thought process would be conscious by definition (Kunimoto et al., 2001; Lau and Rosenthal, 2011; Persaud et al., 2007). However, this conclusion may also be disputed. Some metacognitive monitoring processes, such as those associated with the evaluation of one's performance (Logan and Crump, 2010) or the subsequent correction of one's errors (Endrass et al., 2007; Nieuwenhuis et al., 2001; Wessel et al., 2011) are conceivably sufficiently simple and automatized to be deployed non-consciously. Thus, whether metacognitive processing implies conscious processing can and should be tested empirically.

To investigate how performance monitoring relates to conscious perception, the present experiments concentrate on the error-related negativity (ERN), a key marker of error processing. The ERN is an event-related potential that peaks on fronto-central electrodes 50 to 100 ms after making an erroneous response; it is easily observed in EEG recordings (Dehaene et al., 1994; Falkenstein et al., 2000; Gehring et al., 1993), and a similar, though harder to detect MEG component has been reported (Keil et al., 2010; Miltner et al., 2003). The ERN is assumed to originate in the cingulate cortex (Agam et al., 2011; Debener

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*Abbreviations:* ERN, Error-Related Negativity; ERP, event-related potential; ERF, event-related field; SDT, Signal Detection Theory; SOA, stimulus onset asynchrony; MEEG, simultaneous magneto- and electroencephalography.

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http://dx.doi.org/10.1016/j.neuroimage.2013.01.054

et al., 2005) and its role in cognitive control has been related to error detection (Gehring and Fencsik, 2001; Nieuwenhuis et al., 2001), reinforcement learning (Holroyd and Coles, 2002) and conflict processing (Botvinick et al., 2001; Veen and Carter, 2002).

The debated issue that we address here is whether the ERN indexes a process which is automatic enough to be deployed unconsciously. In relating this issue to the existing literature, it is crucial to keep in mind that an error can fail to be consciously detected for several reasons. A distinction must be made between errors that remain unnoticed (1) because the erroneous action itself is not detected (for instance because it consists in a fast key press or eye-movement (Endrass et al., 2007; Nieuwenhuis et al., 2007; Logan and Crump, 2010; Hughes and Yeung, 2011)), (2) because the subject cannot determine which response is the correct one (e.g. when responding to a visible but confusing stimulus or instruction), or (3) because the subject is completely unaware of the stimulus and therefore of the correct response (e.g. when responding to a stimulus made invisible by masking).

Initially, the relationship between consciousness and the ERN was explored in the context of case (1), i.e. unaware actions (Nieuwenhuis et al., 2001). It suggested that the ERN may remain present even when participants are unaware of having made a partially erroneous eye-movement (Endrass et al., 2007; Nieuwenhuis et al., 2001; but see Wessel et al., 2011). In these studies, crucially, subjects performed a difficult antisaccade task and were sometimes unaware of their erroneous glances in the pro-saccade direction. These results were further extended to case (2) (i.e., confusion about which response is the correct one), in paradigms where undetected errors were induced by conflicting stimuli evoking two contradictory responses (Dhar et al., 2011; Hughes and Yeung, 2011; O'Connell et al., 2007 but see Maier et al., 2008; Steinhauser and Yeung, 2010). These studies have typically used the Eriksen flanker task, in which the presence of multiple conflicting letters may purposely confuse the participant as to the nature of the correct response.

Here, however, we aimed at testing the third case, i.e. whether an ERN can be elicited by an unseen masked stimulus. Our main motivation was to extend the existing literature on the depth of subliminal processing of masked words and digits (Kouider and Dehaene, 2007). In masking experiments, it is well known that participants may deny seeing the stimuli, yet still perform above chance level in a broad range of categorization task, such as deciding whether a digit is larger or smaller than 5 (Dehaene et al., 1998; Del Cul et al., 2007). As an extreme case, in blindsight, a patient may deny any conscious experience, while remaining able to perform way above chance in simple tasks on stimuli presented in their blind hemi-field (Kentridge and Heywood, 1999; Weiskrantz, 1996).

The specific question for the present research is whether, in subliminal conditions induced by masking, the error detection system may also be triggered non-consciously. We evaluate this question both by monitoring the presence of the ERN, as well as by asking the participants for a second-order behavioral response. On each trial, the participant first makes a forced-choice number comparison, and is then asked to decide whether he made an error or not. The finding of either an unconscious ERN, or of an above-chance second-order metacognitive performance on subliminal trials, would expand the range of unconscious operations. Corroborating recent evidence that even executive processes of task switching and response inhibition may be partially initiated non-consciously (Lau and Passingham, 2007; van Gaal et al., 2008), it would indicate that an unseen masked stimulus is capable of progressing through a hierarchy of successive processing stages, all the way up to a level of metacognitive monitoring. A negative answer, on the other hand, would support the view that there are sharp limits to unconscious processing, and that some cognitive operations only proceed once the stimulus has crossed an all-or-none threshold for conscious access (Aly and Yonelinas, 2012; Dehaene and Changeux, 2011; Province and Rouder, 2012; Sergent and Dehaene, 2004a).

Only two studies (Pavone et al., 2009; Woodman, 2010) investigated the existence of an ERN on subliminal trials, yet they obtained contradictory results: Woodman (2010) found that the ERN was absent for masked stimuli, while Pavone et al. (2009) found that it could still be detected. Crucially, in order to contrast conscious versus non-conscious processing, both studies manipulated parameters of contrast or duration. Such sensory manipulations *per se* can have a large impact on the amount of information available on subliminal trials compared to conscious trials. Their findings may therefore result in a large part from this objective change in stimulus strength. One of our aims was therefore to determine if changes in subjective perception alone, in the presence of a constant stimulus, would modulate the ERN and metacognitive performance. To this end, we measured error responses to visual stimuli of variable masking strength, ranging from fully visible to fully invisible (Fig. 1). Such design allowed us to determine how subjective perception of a stimulus, by itself, affects performance-monitoring processes, as assessed by behavioral and error-related MEEG brain measures.

In two masking experiments, participants performed a number comparison task on a masked digit, while perceptual evidence was systematically manipulated by varying the target-mask Stimulus Onset Asynchrony (SOA; Del Cul et al., 2007). To maximize the number of errors, a strong pressure to respond fast was imposed in experiment 1. The main results were replicated in a second experiment in which this pressure was reduced. Crucially, subjective perception was assessed on a trial by trial basis by asking participants to report their visibility of the target (*Seen*/*Unseen*) as well as their perceived performance (*Error*/*Correct*) in the number comparison task. Given that subjective reports vary spontaneously across trials, this approach allowed us to study how the ERN and error-detection performance were modulated by subjective perception of the stimulus (subliminal/subjectively *unseen* trials versus conscious/*seen* trials), independently of the objective variation in masking strength.

## Materials & methods

### Participants

In the first experiment, seventeen volunteers were tested (5 women and 12 men; mean age 23.8 years). Because our experimental conditions were partially determined by subjective reports, four participants were discarded for having insufficient numbers of trials in some of the conditions. Specifically, we removed participants with false-alarm rate superior to 10% in the mask-only condition, or with less than 15% of *seen* trials in the 50 ms SOA condition. In the second experiment, sixteen participants were tested (6 women and 10 men; mean age 23.2 years). Two had to be discarded due to technical problems during MEG recording. One participant was discarded using the same behavioral criteria as in the first experiment. In the end, each experiment comprised data from 13 participants. All participants had normal or corrected-to-normal vision.

### Design & procedure

A masking paradigm similar to Del Cul et al. (2007) was used in this experiment. The target-stimuli (the digits 1, 4, 6, or 9) were presented on a white background screen using E-Prime software. The trial started with a small increase in the size of the fixation cross (100 ms duration) signalling the beginning of the trial. Then the target stimulus appeared for 16 ms at one of two positions (top or bottom, 2.29° from fixation), with a 50% probability. After a variable delay, a mask appeared at the target location for 250 ms. The mask was composed of four letters (two E's and two M's, see Fig. 1) tightly surrounding the target stimulus without superimposing or touching it. The stimulus-onset asynchrony (SOA) between the onset of the target and the onset of the mask was varied across trials.