

**Early selection of diagnostic facial information**  
**in the human visual cortex**

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## **ABSTRACT**

There is behavioral evidence that different visual categorization tasks on various types of stimuli (e.g. faces) are sensitive to distinct visual characteristics of the same image, for example spatial frequencies. However, it has been more difficult to address the question of how early in the processing stream this sensitivity to the information relevant to the categorization task emerges. The current study uses scalp event-related potentials (ERPs) recorded in humans to examine how and when information diagnostic to a particular task is processed during that task versus during a task for which it is not diagnostic. Subjects were shown diagnostic and anti-diagnostic face images for both expression and gender decisions (created using Gosselin and Schyns' Bubbles technique), and asked to perform both tasks on all stimuli. Behaviorally, there was a larger advantage of diagnostic over anti-diagnostic facial images when images designed to be diagnostic for a particular task were shown during the performance of that task, as compared to during the performance of the other task. Most importantly, this interaction was seen in the amplitude of the occipito-temporal N170, a visual component reflecting a perceptual stage of processing associated with the categorization of faces. These results show that the influence of higher-level task-oriented processing take place at the level of visual categorization stages for faces.

## **INTRODUCTION**

To reliably categorize stimuli such as the face in Figure 1, observers must attend to the information that is most appropriate—i.e. diagnostic—for the task at hand. For example, if the task were to determine the gender of the face, a typical human observer would only require the diagnostic face information that is represented in Figure 1c. If the task was instead to judge whether the faces are smiling or not, the same observer would use the diagnostic cues represented in Figure 1a (Schyns, Bonnar, & Gosselin, 2002). Such selective use of diagnostic information is critical to the understanding of high-level visual recognition processes (Schyns, 1998).

The complement of diagnostic information will be here called “anti-diagnostic” as it captures the information that is less useful for the task at hand. For example, the information shown in Figure 1d is the least useful to resolve gender, while Figure 1b represents the anti-diagnostic information of expressivity. Diagnostic and anti-diagnostic information for different categorization tasks can be disclosed using the *Bubbles* or a reverse correlation technique (Gosselin & Schyns, 2004; Eckstein & Ahumada, 2002). These techniques confront an observer with visual information randomly sampled from stimuli in order to derive the information samples leading to better recognition performance, namely the diagnostic information to perform the task. By applying this technique to the categorization of faces, one can obtain a view of the facial cues diagnostic for the task at hand (Mangini & Biederman, 2004; Sekuler, Gaspar, Gold, & Bennett, 2004; Schyns et al., 2002; Gosselin & Schyns, 2001).

These experiments, however, do not inform a critical question: How early, in terms of processing stages, is diagnostic information extracted? In a “late” scenario, the visual system extracts identical perceptual representations in different categorization tasks, and diagnostic information is then selected from memory to make categorization decisions. In an “early”

scenario, the categorization task determines a selective perceptual representation of the input, in terms of the information required for the task at hand. This debate about whether top-down processes can influence perception can be traced back to the seminal work of Bruner & Postman (1949). In support of this ‘early’ view, evidence has been collected that experience in extracting diagnostic information for categorization seem to modify how objects are perceptually structured (e.g. Goldstone, Lippa & Shiffrin, 2001; Niedenthal et al., 2000; Schyns & Rodet, 1997; Goldstone, 1995; 1994). Yet, proponents of the cognitive impenetrability of vision (e.g. Pylyshyn, 1999; 1980; Fodor, 1983) support a “late” scenario, arguing that these effects take place after perceptual stages, and thus that perception operates prior to and independent of cognitive processes.

Several studies indicate that different categorization tasks on simple stimuli (e.g. gratings) or complex stimuli (faces, objects, letters and scenes) are sensitive to distinct visual characteristics of the same image, for example particular spatial frequencies (Sowden, Özgen, Schyns, & Daoutis, 2003; Schyns et al., 2002; Schyns & Oliva, 1999; 1997; Goldstone, 1994). Since spatial frequency processing is known to occur quite early in the visual system (De Valois & De Valois, 1990), this is taken as evidence that categorization influences early vision. However, this evidence remains indirect, given that the researcher does not have access to perceptual processes as they unfold, but only to the output of categorization tasks. A powerful way to circumvent this problem, as exemplified by studies of visual attention (e.g. Hillyard & Anllo-Vento, 1998), is to rely on event-related potentials (ERPs) to track the temporal course of perceptual processes. Although the recording of scalp ERPs offers a poor spatial resolution, making it difficult to define precisely the neural structures involved in a task, the technique offers

a view of the modifications taking place at the whole system level, non-invasively, with a millisecond time resolution (Rugg & Coles, 1995; Regan, 1989).

In the present study, our goal was to inform the question of the stage at which diagnostic facial information is extracted, by measuring the processing of diagnostic information as perceptual categorizations occur. To this end, we examined how task-dependent diagnostic and anti-diagnostic facial information influenced early perceptual categorization stages using ERPs. High-level visual stimuli such as those displayed in Figure 1 trigger a sequence of electrophysiological processes that can be recorded as field potentials on the scalp, and are thought to reflect the activation of multiple cortical areas in interlocked time-courses (Regan, 1989). The temporal parameters of these potentials, or of differential electrophysiological responses, provide information about the speed and temporal course of visual processes (e.g. Di Russo et al., 2002; Thorpe, Fize & Marlot, 1996; Clark, Fan & Hillyard, 1995; Jeffreys & Axford, 1972).

Here we concentrated our interest on a large occipito-temporal negativity, commonly referred as the N170 (Bentin et al., 1996). The N170 follows lower level visual components C1 (peaking around 70 ms at occipital sites) and P1 (around 100 ms; see e.g. Clark, Fan & Hillyard, 1995; Jeffreys & Axford, 1972), and peaks around 160 ms following the onset of a visual stimulus. The N170, also referred to as occipito-temporal N1, is thought to reflect early visual categorization processes (Kiefer, 2001; Luck, Woodman, & Vogel, 2000; Tanaka et al., 1999), since it is at the level of this visual component that the earliest reliable differences between object categories are observed (Rossion et al., 2003; Curran et al., 2002; Kiefer, 2001; Bötzel et al., 1995; Rossion et al., 2000; Tanaka et al., 1999; Schendan et al., 1998).

When evoked by face stimuli, the N170 is greatly enhanced compared to non-face objects (Itier & Taylor, 2004a; Rossion et al., 2003; 2000; Bentin et al., 1996; Bötzel et al., 1995) and appears to be the earliest and only consistent processing stage at which faces are discriminated from other object categories. Its onset latency is compatible with the timing of discharge of face selective cells in anterior infero-temporal cortex and superior temporal sulcus of the monkey that are sensitive to facial identity, eye-gaze or expression (e.g. Rolls & Tovee, 1995; Rolls, 1992; Hasselmo et al., 1989; Perrett et al. 1982)<sup>1</sup>. Accordingly, the N170 in response to faces can be conceived as reflecting the occurrence of multiple face categorization processes, taking place in a network of high-level occipito-temporal visual areas (Horovitz et al., 2004; Itier & Taylor, 2004b; Henson et al., 2003; Rossion, Curran & Gauthier, 2002). Even though there is evidence that the N170 can be modulated by categorical experience (Rossion, Kung & Tarr, in press; Curran et al., 2002; Rossion et al., 2002; Tanaka & Curran, 2001; Schendan et al., 1998) and attention (Eimer, 2000a), it is thought to reflect a relatively early stage of visual processing, being immune to the long-term familiarity of specific exemplar of faces and objects, and to semantic information (Curran et al., 2002; Eimer, 2000b; Rossion et al., 1999).

On the assumption that the N170 reflects a perceptual stage of processing where diagnostic visual information allowing efficient and fast face categorization is extracted, we targeted this electrophysiological process to test the hypothesis that the difference in N170 amplitude to diagnostic and antidiagnostic facial information should be larger and/or occur faster when diagnosticity is relevant to the categorization task at hand. This is because the presence of the particular salient information should yield a larger advantage over when that information is absent during the corresponding face classification task. This hypothesis follows our assumption

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<sup>1</sup> Taking into account the delayed response of the neurons in the human visual cortex as compared to the monkey.

that “Bubbles” reconstructs the perceptual representations used to perform a face categorization task.

The influence of top-down factors on visual processes reflected by the N170 has been tested previously, with moderate success. Previous studies have consistently failed to find any task-related modulation of the face-N170 when evoked by full-face photographs (e.g. Carmel & Bentin, 2002; Eimer, 2000b; Rossion et al., 1999). However, under certain conditions of stimulation, the amplitude of the N170 can be increased by attention (Eimer, 2000a), visual expertise (Rossion et al., in press; Tanaka & Curran, 2001) or perceptual priming (Bentin et al., 2002; Bentin & Golland, 2002). In addition, a recent ERP study has provided evidence that the task performed may modulate the processing of spatial frequency information on faces at the level of the N170 (Goffaux et al., 2003a), suggesting that this component may be a good candidate to test our hypotheses about the time course of diagnostic information selection.

Practically, we recorded scalp ERPs with a 64-channel system in 16 subjects presented with facial images that revealed only the diagnostic information used by normal subjects in previous behavioral studies to perform either a gender task or an expression judgment task (Schyns et al., 2002). We also presented subjects with anti-diagnostic information images, which contained all the information minus the diagnostic (Figure 1)<sup>2</sup>. Thus, subjects saw two types of images (diagnostic for expression vs. gender) each with two levels of diagnosticity (diagnostic, anti-diagnostic) while they performed two counterbalanced binary tasks: gender categorization (male/female) and expression (expressive or not). Independently of the task, we expected the N170 to be increased/decreased to the presence/absence of facial diagnostic information, given

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<sup>2</sup> A normalized condition was also presented to subjects in which the face information at each scale was multiplied by  $\sqrt{[\text{energy}_X(\text{scale}) / \text{energy}_{\text{FaceMask}}]}$ , where  $\text{energy}_{\text{FaceMask}}$  is the energy of the anti-diagnostic face mask. However, because there were no behavioural differences between diagnostic and normalized stimuli for this presentation duration (see Gosselin & Schyns, 2001), the latter were not included in the analyses.

that internal features are highlighted in these stimuli (see Schyns et al., 2003). Of primary interest was whether or not diagnostic images showed a larger advantage over anti-diagnostic images for their respective task. Thus, in order to isolate any potential effect of diagnosticity, latency and amplitude differences caused by the tasks themselves need to be factored out. To accomplish this, the differences between diagnostic and anti-diagnostic images (D-AD) for each task were analyzed with the factors *task* (expression vs. gender) and *stimulus* (expression vs. gender). Our hypothesis was that there would be an interaction between these two factors at the level of the N170.

## **RESULTS**

### **Behavioral data**

Accuracy rates and mean correct response times are reported in Table 1.

#### Accuracy

There was a significant *task x stimulus* interaction [ $F(1,60) = 22.24, p < 0.0001$ ], such that there was a larger D-AD difference for gender images during the gender task, than for those same images during the expression task ( $p < 0.05$ ); while there was a larger D-AD difference for expression images during the expression task than for those same images during the gender task ( $p < 0.005$ ; see Figure 3).

#### RTs

Mean response times are given in Table 1 for all conditions. There was a main effect of *task* [ $F(1,60)=18.24, p = 0.0001$ ], due to smaller overall D-AD differences for the gender task than for the expression task. Most importantly, as with accuracy, there was a significant *task x stimulus* interaction [ $F(1,60) = 25.33, p < 0.0001$ ] such that D-AD differences were larger when



the task matched the stimulus (Figure 3). Post-hoc t-tests showed that the speeding up for diagnostic information was larger for expression stimuli during the expression task than for the same stimuli during the gender task ( $p < 0.0001$ ), but the D-AD difference for gender stimuli during the gender task was not larger for the same stimuli than during the expression task ( $p > 0.9$ , see Figure 3).

## **ERP data**

Following the occipital P1 (80-120 ms), the occipito-temporal N170 (coupled with the centro-frontal VPP; see Rossion et al., 2003) was best observed between 140 and 180 ms for all categories of stimuli. The amplitude and latency values of the grand-average N170 are reported in Table 2. The location of the peak amplitude of the N170 for each hemisphere was exactly the same for all conditions (LLOC/RLOC electrodes, see Figures 2, 4), and the component was prominent in 4 occipito-temporal channels highlighted in Figure 2. The clearest observation in the grand-averages waves is a substantial increase of the N170 amplitude for diagnostic images compared to anti-diagnostic images, at both left and right hemisphere sites (Figure 4). Most importantly, there appears to be an interaction between diagnostic features and task performed. That is, the difference between the N170 elicited by diagnostic and anti-diagnostic face features when they match the task (A-C, Figure 4) appears larger than when they do not match the task (B- D, Figures 4 to 7), an interaction confirmed by the statistical analysis presented below.

### 1. Peak latency difference analysis

Peak values on right and left LOC electrodes for anti-diagnostic images were subtracted from those for diagnostic images within each category and repeated measures ANOVAS (factors: task, stimulus, hemisphere) were performed on the resulting differential latency values. Although there was a trend for a larger D-AD difference when the task matched the stimulus (interaction

task x stimuli:  $F(1,14)=3.56$ ,  $p < 0.08$ ), the slight latency delay of the N170 observed for anti-diagnostic stimuli did not differ across task, stimuli (expression of gender) or hemisphere (all  $p$  values  $> 0.2$ ). An analysis conducted on the preceding peak (P1) also failed to disclose any effect of *task*, *stimulus*, *hemisphere* or any significant interactions between these factors (all  $p$  values  $> 0.2$ ),

## 2. N170 amplitude difference analysis

Following the approach taken in the behavioral analysis, peak values for anti-diagnostic images were subtracted from those for diagnostic images within each category and analyses were performed on the resulting values (using the 4 occipito-temporal channels where N170 was prominent, see methods) Critically, there was a significant interaction of *task* with *stimulus* [ $F(1,416) = 11.83$ ,  $p = 0.0006$ ], reflecting the larger D-AD N170 amplitude difference when the task matched the stimulus (Figures 4 to 7). Post-hoc t-tests showed that the D-AD N170 amplitude was larger for gender stimuli during the gender task than for those same stimuli during the expression task ( $p < 0.01$ ), and than for expression stimuli during the gender task ( $p < 0.025$ ). Expression stimuli during the expression task, however, were not significantly larger than expression stimuli during the gender task ( $p > 0.3$ ) or than gender stimuli during the expression task ( $p > 0.2$ , See Figures 6 and 7). There was no main effect of hemisphere ( $p > 0.8$ ) or any interaction of hemisphere with the differences of interest (all  $p$ 's  $> 0.17$ ).

## 3. P1 amplitude difference analysis

In the time window of the P1, the only comparison to reach significance was a main effect of *stimulus* [ $F(1,416) = 5.39$ ,  $p = 0.02$ ]: D-AD differences for gender stimuli were larger overall than D-AD differences for expression stimuli. However, there was no interaction of *stimulus* with

*task* ( $p > 0.7$ , all post-hoc  $p$ 's  $> 0.2$ ). There was no main effect of *hemisphere* ( $p > 0.08$ ) or any interactions of *hemisphere* with any other variables (all  $p$ 's  $> 0.07$ ).

#### 4. (N170 - P1) amplitude difference analysis

In order to ensure that the D-AD interaction with task at the level of the N170 is not a carryover effect from task differences observed at the earlier P1, an additional analysis was carried out on the same factors using the peak amplitude difference between the P1 and N170. When the peak amplitude of the D-AD difference for the P1 is subtracted from that of the N170, there is also a significant interaction of *task* with *stimulus* [ $F(1,416) = 7.7$ ,  $p = 0.0058$ ], again reflecting the larger D-AD N170 amplitude difference when the task matched the stimulus (Figures 4 to 7). Post-hoc t-tests showed that the D-AD N170-P1 peak differences were larger for gender stimuli during the gender task than for those same stimuli during the expression task ( $p < 0.025$ ), but non-significantly larger for expression stimuli during the expression task than those same stimuli during the gender task ( $p > 0.6$ ). There was no main effect of *hemisphere* ( $p > 0.15$ ) or any interaction of hemisphere with the differences of interest (all  $p$ 's  $> 0.3$ ).

## **DISCUSSION**

Our behavioral data (Tables 1 and 2) show clearly that providing human subjects with diagnostic facial information as extracted previously by *Bubbles* provides an advantage at categorizing faces, both in terms of performance and speed. This result indicates that the pre-selected information is really what matters for task performance. When this diagnostic information is selectively removed from the face pictures, performance drops significantly and the subjects are slower to perform the categorization tasks.

Irrespective of the task, the peak latency of the N170 was slightly delayed for anti-diagnostic stimuli compared to diagnostic pictures (see Table 3, Figures 5, 6). These effects at

both the electrophysiological and behavioral level suggest a slowing down taking place at face processing stages when the diagnostic facial information is removed. Note that a simple explanation, albeit not contradictory to our point, would be that removing internal face features delays the N170 component. Previous studies have indeed shown that removing or masking the eyes for instance, delays the N170 by around ~10 ms (Jemel et al., 1999; Eimer, 1998).

However, this simple explanation is not sufficient for our data. We also observed a clear overall increase in N170 amplitude for diagnostic over anti-diagnostic facial features. This result suggests that there is a larger part of early visual face-related processes that are tuned to specific feature information, regardless of the task at hand (see also Smith et al., in press; Schyns et al., 2003). Indeed, diagnostic images showed an enhanced N170 as compared to anti-diagnostic, regardless of whether the image was specifically diagnostic to the current task. This may be indicative of the somewhat automated nature of face processing (Langton & Bruce, 1999; Bruce & Young, 1998). In other words, certain features of the face may be relevant to many decisions that are regularly made about faces. Thus, extended experience with faces and judgments about them, has led to the automatic processing of certain facial features.

It may also be that the overall advantage of diagnostic images is related to the differential spatial frequency content of the images. The *Bubbles* technique extracted the spatial frequencies that were the most diagnostic for the face categorization tasks. Thus, by virtue of the methodology used, these stimuli were not equalized for spatial frequency power in all bands. Although diagnostic images contain less power in the low frequency range than anti-diagnostic images, and the N70 to faces is particularly sensitive to low spatial frequencies (Goffaux et al., 2003b), these differences in spatial frequencies may contribute to the larger N170 observed for diagnostic images.

Since *Bubbles* extracted from the facial images not only the 2D location of diagnostic information, but also the most diagnostic spatial frequencies, the present ERP result suggests that the increase of the N170 to diagnostic images is related to either the diagnostic spatial frequencies or the diagnostic face cues independently of their spatial frequency content, or possibly a combination of both. In any case, recent ERP investigations suggest that the relationship between the N170 amplitude and the spatial frequency content of the stimulus is not straightforward: there appears to be a general advantage of low spatial frequencies but this effect is not uniform across object categories (Goffaux et al., 2003b), and is modulated by the task at hand (Goffaux et al., 2003a). In addition, in the present study, the overall energy and the frequency distributions between conditions were the same (see methods). All stimuli showed maximal frequency content in the low frequency range, with very little difference in high frequency content. Anti-diagnostic images simply contained more *power* in the low frequency range than diagnostic images<sup>3</sup>.

Finally, while the behavioral data indicate that task difficulty differed between conditions, the diagnostic image advantage observed here cannot be simply related to changes in sustained attention. First, the experimental design was completely randomized within task so that subjects would be unable to predict what type of mask/stimulus was coming next. Second, sustained attentional processes would have most likely affected the preceding positivity, whereas our effects were observed with and without taking into account minor P1 differences at occipito-temporal sites.

### ***Task-Related Modulations of the N170***

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<sup>3</sup> The only modulations we observed that seemed to fall in line with the low spatial frequency power differences occurred pre-100ms focally at medial occipital sites on the P1 at OZ and PZ for instance, between 90 and 110 ms, shortly after the activation of the striate cortex between 50 and 80 ms (C1 or N70 component, see Jeffreys & Axford, 1972). These differences did not affect the preceding positivity at the occipito-temporal sites where we measured and analyzed our N170 task-related effects (Figures 5, 6).

Viewing diagnostic facial features for a given task causes better performance and speeded response times for both gender and expression judgments, but is perception of the stimuli influenced by these categorization tasks? Our main hypothesis was that the N170 should be (reduced)/enhanced particularly when the (anti-)diagnostic facial information matches the task at hand. The electrophysiological results support this hypothesis: the difference between diagnostic and anti-diagnostic facial features for gender and expression was larger when they were presented during the gender task and the expression task respectively. The amplitude modulation is relatively small (less than a microvolt) but the double dissociation between task and stimuli gives rise to a highly significant interaction.

It should be noted that the hypothesis of task-diagnostic interactions before 200 ms following the presentation of the visual stimulus was particularly strong because of the absence of previous evidence for task modulations at this latency (e.g. Carmel & Bentin, 2002; Eimer, 2000b; Rossion et al., 1999), which fits the general hypothesis of the impenetrability of low and high-level perceptual stages by cognitive factors such as task constraints (Pylyshyn, 1999; Fodor, 1983; Pylyshyn, 1980). Yet, recent ERP studies have suggested that subject knowledge may indeed influence the N170 response (Goffaux et al., 2003a; Jemel et al., 2003; Bentin et al., 2002; Bentin & Golland, 2002). For instance, Bentin and colleagues (Bentin et al., 2002; Bentin & Golland, 2002) showed that the very same stimuli, either small round shapes (Bentin et al., 2002) or line drawings of scrambled faces (Bentin & Golland, 2002) evoked a conspicuous N170 only after the subject was provided hints that these stimuli were related to eyes and face pictures. More closely related to the present study, Goffaux et al. (2003a) showed a modulation of N170 amplitude to high and low spatial frequencies dependent on the task being performed. Precisely,

there was a larger N170 to low spatial frequencies compared to high-spatial frequencies but only when subjects had to categorize the gender of the faces, not for face familiarity decisions.

Compared to these recent studies, the present findings go several steps further in terms of reliability and theoretical significance. First, compared to the studies reported by Bentin and colleagues (Bentin et al., 2002; Bentin & Golland, 2002), we observed a task-related effect: the modulations of the visual responses are observed on line, depending on the subject's task, rather than his previous experience or knowledge. Secondly, contrary to these previous studies, including Goffaux et al. (2003a), our design was completely randomized across the types of stimuli presented. This additional methodological care prevents the effects from being attributed to any sustained attentional processes. Finally, the present findings suggest a task-related modulation of early visual processes by subtle variations in spatial frequencies and contrast at different locations of the facial image rather than to overall different spatial frequency contents for the face stimulus (Goffaux et al., 2003a).

An important theoretical consequence of this work is thus that perceptual processing of faces appears to be cognitively penetrable. How early these influences take place in terms of face processing stages and their neural correlates? As discussed in the introduction, functionally, the N170 reflects the earliest stage at which object categories appear to be distinguished. When evoked by faces, it has been related to the early structural encoding stage of Bruce & Young's architecture of face processing (1986), during which a complete viewpoint-dependent individual face representation is extracted from the visual stimulus, independently of any previous experience with this particular face (e.g. Eimer, 2000b; Bentin et al., 1996; see also Jeffreys, 1996). In response to foveally presented stimuli, the N170 is a lateral ERP response that usually follows the large posterior visual component P1 (Jeffreys & Axford, 1972) and starts at around

130 ms. At these latencies, given that visual information reaches the human primary visual cortex (V1) at around 60-80 ms (Bullier, 2001; Jeffreys & Axford, 1972), both the P1 and the N170 are assumed to be generated by multiple sources interlocked in time, in the visual extrastriate cortex (Regan, 1989). More specifically, evidence from electrophysiological studies and source localization of the scalp N170 (e.g. Itier & Taylor, 2004b; Rossion et al., 2003), intracranial recordings of field potentials (e.g. Allison et al., 1999) and combination of EEG and fMRI data (Horowitz et al., 2004; Henson et al., 2003) suggest that the N170 originates from a network of occipital and temporal regions including the middle fusiform gyrus, the inferior occipital cortex, and the inferior, middle and superior temporal gyri<sup>4</sup>. These localizations largely overlap with regions where face-sensitive responses have been described in functional neuroimaging studies (see Haxby et al., 2000 for a review) or in single-cell recordings in non-human primates (e.g. Tanaka, 1996; Perrett et al., 1992; Rolls, 1992; Perrett et al., 1982). Together with its functional response properties (see Rossion, Curran & Gauthier, 2002), these observations suggest that the N170 represents an early stage of visual processing of face that appears to be modulated by an interaction between task and the diagnosticity of the stimulus for the task.

### *Conclusions*

In the current work we show that brain electrophysiology is sensitive to the interaction between stimulus information and task requirements. Specifically, it appears that the task at hand primes the system to require certain types of stimulus information that, when provided, enhances N170 amplitude. We believe that the combination of this information with that of previous work showing N170 modulation to certain stimulus features (e.g. spatial frequency), and experience (e.g. expertise training) may lead us to a more comprehensive view of how information in the

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<sup>4</sup> In another experiment with the same subjects as in the present study (Rossion et al., 2003), we precisely localized the equivalent dipolar sources of the face (and object) N170 in the lateral parts of the inferior occipital lobe



brain is organized. In particular, it may give us insight as to how high-level object categorization interacts with lower level visual properties. Further, the *Bubbles* technique, in combination with electrophysiological recordings, is a useful tool in that investigation, providing ways to investigate how and when the level of experience with a particular category of stimulus affects the interaction of task demands with stimulus information.

## **METHODS**

### **Subjects**

Participants were 16 students (10 males, 6 females; all right handed; 21-39 years of age, mean = 27.5) from the University of California. Subjects were paid for participating in a single, two hour experimental session. One subject's data was removed for a poor SNR due to movement artefact.

### **Stimuli**

Our stimulus set is based on the results of Schyns, Bonnar & Gosselin (2002).

#### *The origin of diagnostic stimuli*

A subset of 20 grayscale faces from Schyns and Oliva (1999) (5 males, 5 females each of whom displayed two different expressions, neutral and happy, with normalized hairstyle, global orientation and lighting) were used. The faces subtended 5.72 x 5.72 deg of visual angle. To search for diagnostic information, the *Bubbles* technique (Gosselin & Schyns, 2001) was applied to an image generation space composed of three dimensions (the standard X and Y axes of the image plane, plus a third Z axis representing spatial frequencies). To compute each stimulus, an original face was first decomposed into 6 independent bands of spatial frequencies of one octave

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(Brodmann area 19).

each—with cutoffs at 90, 45, 22.5, 11.25, 5.62, and 2.81 cycles per face, from fine to coarse, respectively, using the Matlab Pyramid Toolbox (Simoncelli, 1997). The coarsest band was a constant background. The face represented at each band was then partly revealed by a mid-grey mask covering the face area of the image, and punctured by a number of randomly located Gaussian “bubbles”. The number of cycles per face that any bubble could reveal was normalized to 3 (i.e., the standard deviations of bubbles were .13, .27, .54, 1.08, and 2.15 deg of visual angle, from fine to coarse scales). The average total area of the face revealed across scales was also normalized. To generate a sparse face, the partial face information revealed at each scale was added together. To maintain categorization of sparse faces at 75% correct, the number of bubbles was adjusted online.

Prior to experimentation, to normalize exposure to stimuli, all participants learned to criterion (perfect identification of all faces twice in a row) the gender, expression and the name attached to each face from printed pictures with corresponding name at the bottom. The experiment comprised two sessions of 500 trials (25 presentations of the 20 faces), but we only used the data of the last 500 trials, when subjects were really familiar with the faces and experimental procedure. In a trial, one sparse face computed as described earlier appeared on the screen. Participants in the GENDER group were instructed to decide whether the stimulus was male or female; those in the EXPRESSIVE OR NOT (EXNEX for short) group whether the sparse face was expressive or not (smiling or neutral); and those in the IDENTITY group the name of the individual sparsely revealed. The identity task is not relevant to the design of our stimulus set in the present ERP study.

Schyns, Bonnar & Gosselin created one CorrectPlane per group and per scale (henceforth,  $\text{CorrectPlane}_{\text{GENDER}}(\text{scale})$  and  $\text{CorrectPlane}_{\text{EXNEX}}(\text{scale})$ , for scale = 1 to 5, from fine to coarse) in which they added the masks of bubbles leading to correct categorizations. Similarly, they created

two TotalPlanes, TotalPlane<sub>GENDER</sub>(scale) and TotalPlane<sub>EXNEX</sub>(scale), the sum of all bubble masks in each group. They then derived two ProportionPlanes: ProportionPlane<sub>X</sub>(scale) = CorrectPlane<sub>X</sub>(scale) / TotalPlane<sub>X</sub>(scale), with X standing either for GENDER or for EXNEX. These ProportionPlanes give the ratio of the number of times a specific region of the input space has led to a successful categorization over the number of times this region has been presented. If all regions had equal diagnosticity, ProportionPlanes would be uniform. That is, the probability that any randomly chosen bubble of information led to a correct categorization of the input would be equal to the performance criterion—here, .75. To compute the DiagnosticPlanes, a confidence interval was built around the mean of the ProportionPlanes, for each proportion ( $p < .01$ ). The GENDER and EXNEX diagnostic stimuli used in this article were obtained by multiplying the face information of the 20 faces used by Schyns, Bonnar & Gosselin at each scale with the corresponding DiagnosticPlane<sub>X</sub>(scale). Figure 1a and 1c show the diagnostic information for the EXNEX and GENDER task, respectively.

*The making of anti-diagnostic stimuli*

To contrast the performance of subjects on a GENDER or an EXNEX recognition task with faces filtered with the DiagnosticPlanes, we created *anti-diagnostic* faces as well (Gosselin & Schyns, 2001), for a total of 80 face stimuli (20 original faces \* 2 DiagnosticPlanes \* 2 filtering conditions (i.e., diagnostic and anti-diagnostic). We used a subset of these stimuli, as described below.

The anti-diagnostic faces were obtained by multiplying the face information at each scale by the complement of (one minus) the DiagnosticPlane<sub>X</sub>(scale) within the face mask area depicted in Figure 1b (i.e., AntiDiagnosticPlane<sub>X</sub>(scale)) and by  $\sqrt{[\text{energy}_X(\text{scale}) / \text{energy}_{\text{ANTI-}}$

$x(\text{scale})]$ , where  $\text{energy}_{x(\text{scale})}$  is the energy<sup>5</sup> of the  $\text{DiagnosticPlane}_{x(\text{scale})}$  and  $\text{energy}_{\text{ANTI-}x(\text{scale})}$  is the energy of the  $\text{AntiDiagnosticPlane}_{x(\text{scale})}$ . The last factor equates the energy of the diagnostic and anti-diagnostic filters at each scale. Figure 1b and 1d show the anti-diagnostic information for the EXNEX and for the GENDER task, respectively.

#### *Stimuli as used during the ERP recordings*

Stimuli were grayscale, full frontal images of 8 different Caucasian individuals, 4 males (2 smiling, 2 with a neutral expression), and 4 females (2 smiling, 2 with a neutral expression) (see Figure 1). From these original images, 4 different images of each individual were used: one with the gender-diagnostic mask, one with the gender-anti-diagnostic mask, one with the expression-diagnostic mask, one with the expression-anti-diagnostic mask (see Figure 1). At a 100 cm distance from the monitor, face images (8.8 cm x 8.8cm) subtended  $\sim 5.04 \times 5.04$  degrees of visual angle.

#### **Procedure**

Following electrode application, participants were seated in a sound-attenuating, electrically-shielded chamber facing a computer monitor. They were told to fixate the centre of the screen during the presentation of 8 consecutive blocks ( $\sim$  one minute pause in between) of 96 trials each: 4 blocks during the gender decision task, and 4 blocks during the expression decision task. The order of task presentation was counterbalanced across subjects, and within a task, the order of the stimulus presentation was fully randomized. During a single trial, subjects were presented with a face picture for 200ms (ISI randomized between 1050-1550 ms). During the gender judgment task, subjects were asked to press a button with the index finger on their dominant hand if the

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<sup>5</sup> Values in the  $\text{DiagnosticPlanes}$  and face mask vary between 0 and 1, and can be interpreted as contrasts. Energy is defined as the sum of all squared contrasts.

face was male, and another button with the middle finger of their dominant hand if the face was a female. During the expression judgment, subjects were asked to press one button with the index finger of their dominant hand if the face was expressive, and another button with the middle finger of their dominant hand if the expression was neutral.

### **EEG recording**

Subjects were instructed to refrain from blinking and moving their eyes and bodies, as corresponding artefacts interfere with the recording of the electroencephalogram (EEG). Scalp recordings were made via 53 tin electrodes (10-20 system + additional sites) embedded in an elastic cap as shown in Figure 2. Four additional electrodes were used to monitor eye movement and blinks: one placed under each eye and one placed on the outer canthus of each eye. The online reference was an electrode placed on the left mastoid. Electrical activity was amplified with a bandpass filter of 0.01-100Hz and digitized at a rate of 500Hz.

### **EEG/ERP analyses**

EEG data was analyzed using Eeprobe (ANT, Inc.) running on Red Hat Linux 7.0. The EEG was filtered with a 201-point digital 30 Hz Hamming low-pass filter, with cut-off frequencies of 29 (-3dB point), and a stop-band attenuation of -63.3dB (50Hz and above). Then EEG and EOG artefacts were removed using a [-40; +40 V] deviation over 200 ms intervals on frontal electrodes and using a [-35; +35 V] deviation over 200 ms intervals on all other electrodes. In case of too many blink artefacts, they were corrected by a subtraction of VEOG propagation factors, based on PCA-transformed EOG components (Nowagk & Pfeifer, 1996). After VEOG correction and rejection of artefact-contaminated ERPs, the number of sweeps was equalized

across conditions for each subject. Averaged ERPs were re-referenced using a common average reference.

### **Statistical analysis**

After examination of the grand average topographies (see Figure 2), peak latency and amplitude values of the N170 were extracted automatically at the maximum (negative) amplitude value between 140 and 190 ms at a single occipito-temporal electrode site (LLOC/RLOC), 2 cm below T5 and T6 in the 10/20 system (Figure 2). It is also at this occipito-temporal electrode site that the N170 was found to be maximal to pictures of normal faces in the same group of subjects in an independent experiment (Rossion et al., 2003). At these sites, the peak amplitude and latency values of the preceding positivity (P1) were also extracted (80-140 ms). The choice of using a single site – where the N170 was maximum – for latency analysis was made because it was only at that electrode site that the components peaks could be reliably identified in all conditions for all subjects and thus that peak latency values could be extracted without errors (Picton et al., 2000). In addition, we performed an analysis on the average amplitudes computed between 140 and 190 ms at four occipito-temporal sites where the N170 was prominent. Repeated-measure ANOVAs were computed on differential (diagnostic – anti-diagnostic) peak amplitude of the N170 as measured at these sites. For the electrophysiological analyses on these differential values, the factors were *Task* (Expression/Gender), *Stimulus* (Expression/Gender) and *Laterality* (Left/Right hemisphere). Post-hocs t-tests were used when necessary to characterize the effects.

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## FIGURE CAPTIONS

Figure 1. (a) A face from the 20 greyscale face set from Schyns, Bonnar and Gosselin (2002). (a) and (b) pertain to the EXNEX condition: (a) diagnostic, (b) anti-diagnostic. (c) and (d) pertain to the GENDER condition: (c) diagnostic, (d) anti-diagnostic.

Figure 2. Electrode display.

Figure 3. Behavioral results in graphs: a) accuracy (%), b) response time (RTs).

Figure 4. Topographical maps showing the right hemisphere N170 in response to the pictures presented in Figure 1 when they match the task at hand (left column) or not (right column). Expression and Gender are averaged together. The topography is taken at peak values (Table 3) for each of the conditions.

Figure 5. Main diagnosticity effects at left (LLOC) and right (RLOC) occipito-temporal sites, separately by task.

Figure 6. Main diagnosticity effect at left (LLOC) and right (RLOC) occipito-temporal sites averaged across tasks.

Figure 7. Graphical representation of the D-AD N170 amplitude differences (collapsed across hemisphere) in each condition. Values are difference  $\mu$ Vs.

## TABLES

Table 1. Accuracy Means (% correct).

Table 2. Response Time Means (ms).

Table 3. Grand-average Latency values (ms) of the N170.

Table 4. Grand-average Amplitude values ( $\mu$ V) of the N170.

Accuracy (% correct)		Stimuli: Expression		Stimuli: Gender	
		Diagnostic	Anti-diagnostic	Diagnostic	Anti-diagnostic
Task	Expression	89	79	90	90
	Gender	78	83	93	82

**Table 1**

Correct RTs		Stimuli: Expression		Stimuli: Gender	
		Diagnostic	Anti-diagnostic	Diagnostic	Anti-diagnostic
Task	Expression	604	699	599	638
	Gender	670	656	628	664

**Table 2**

N170 latency (ms)		Stimuli: Expression		Stimuli: Gender		
		Diagnostic	Anti-diagnostic	Diagnostic	Anti-diagnostic	
Task	Expression	Left	166	166	164	166
		Right	164	166	156	166
Task	Gender	Left	164	168	164	168
		Right	164	166	158	164

**Table 3**



N170 mean amplitude ( $\mu V$ )

Stimuli: Expression

Stimuli: Gender

Task		Stimuli: Expression			Stimuli: Gender		
		Diagnostic	Anti-diagnostic	Difference	Diagnostic	Anti-diagnostic	Difference
Expression	Left	-2.43	-1.23	<b>-1.20</b>	-2.07	-0.90	-1.17
	Right	-3.05	-1.65	<b>-1.40</b>	-2.51	-1.60	-0.91
Gender	Left	-2.95	-1.98	-0.97	-2.56	-1.33	<b>-1.23</b>
	Right	-3.37	-2.18	-1.19	-3.25	-1.68	<b>-1.96</b>

Table 4

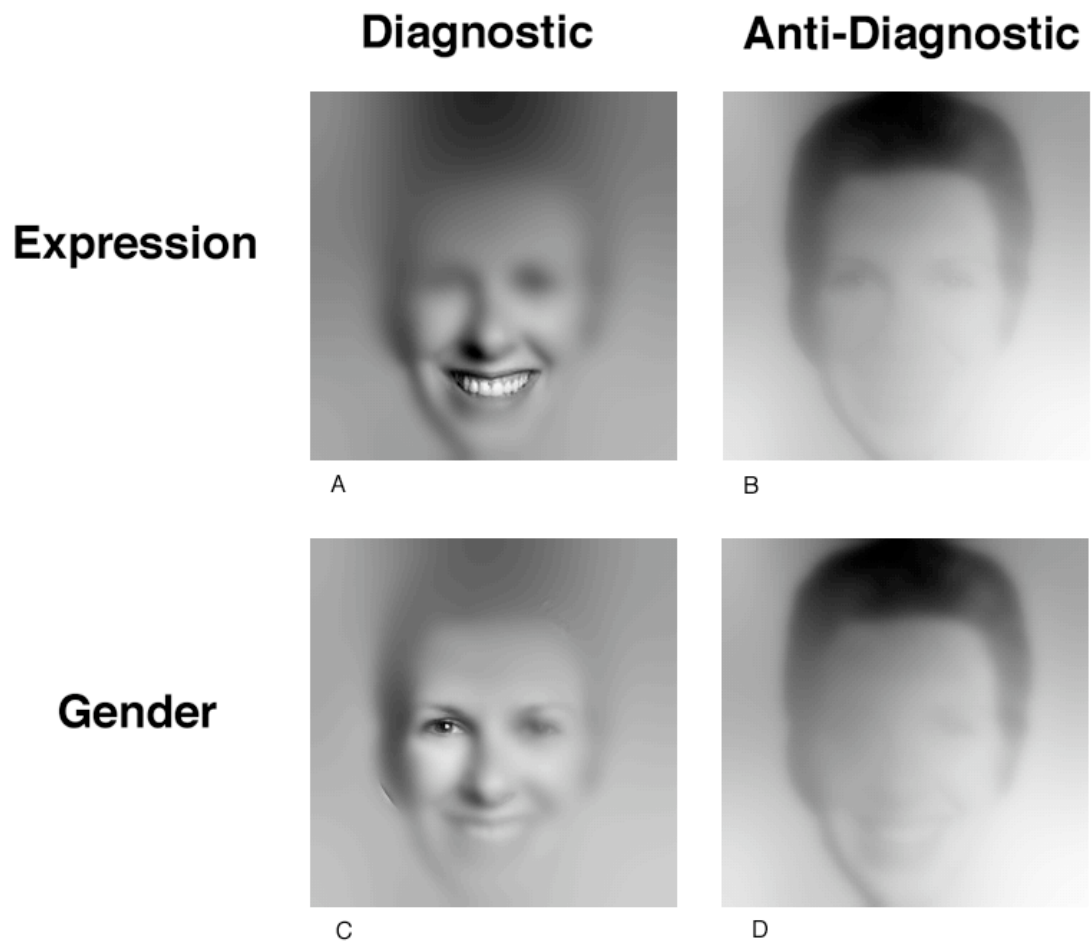
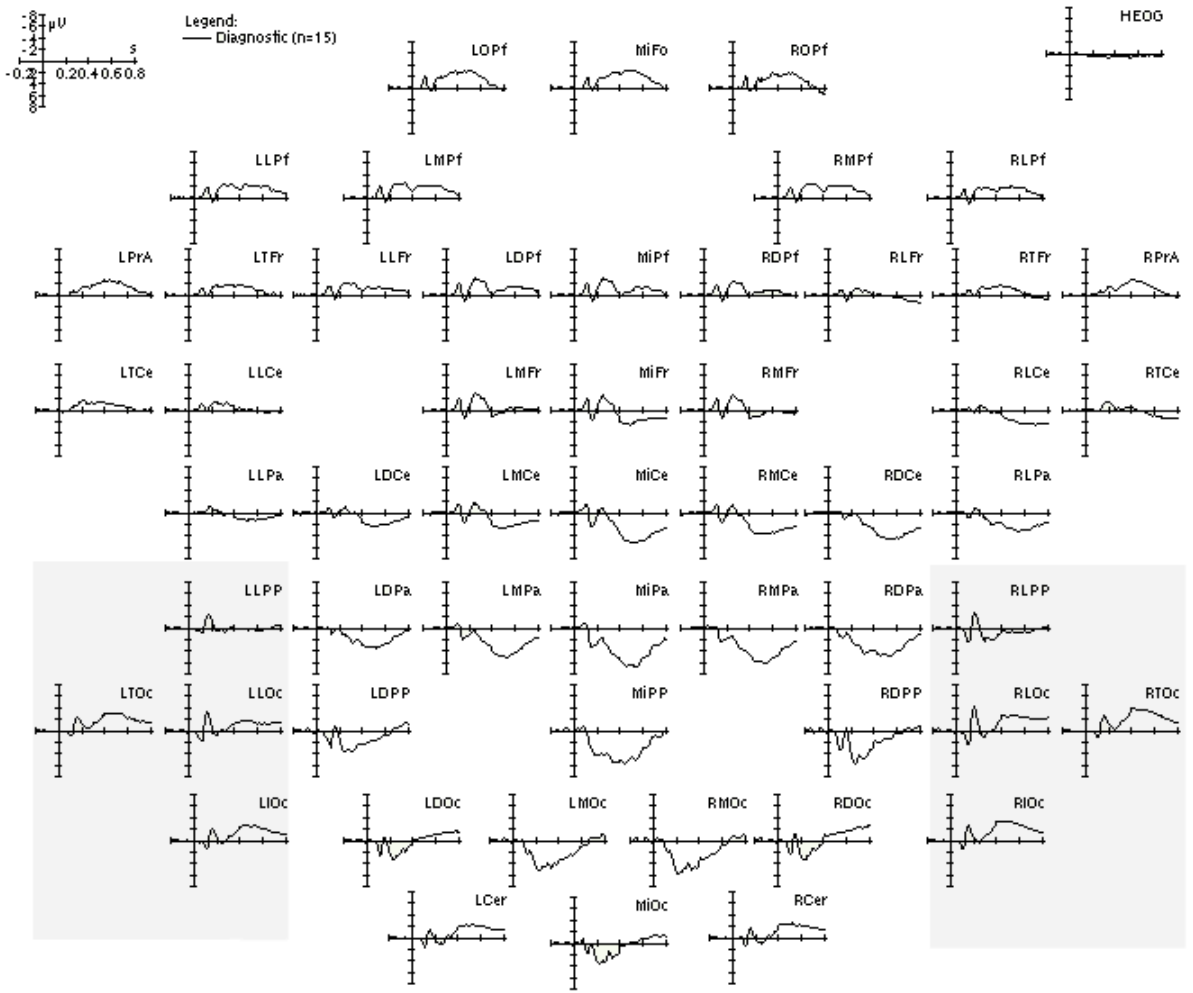
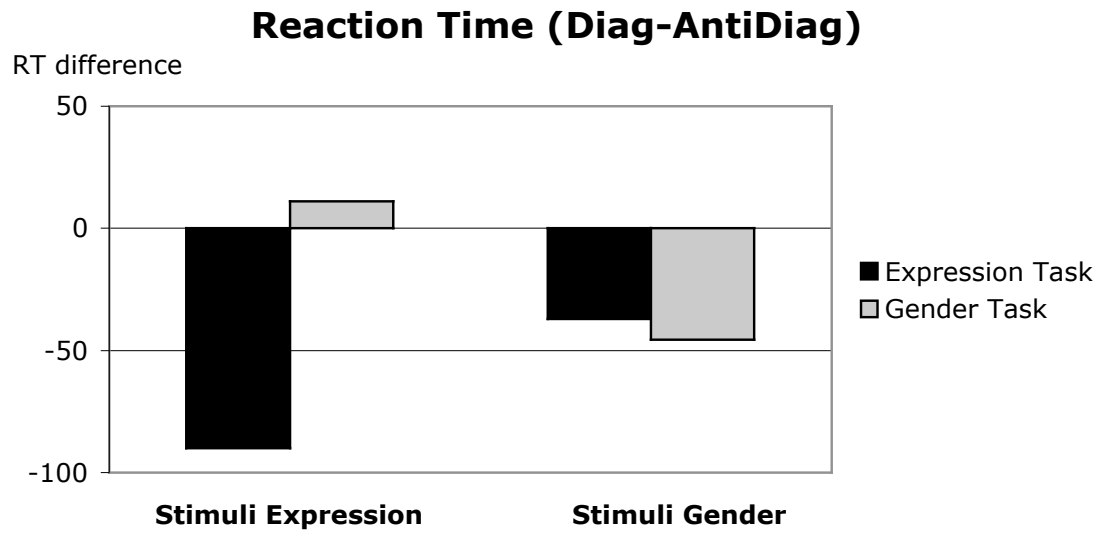
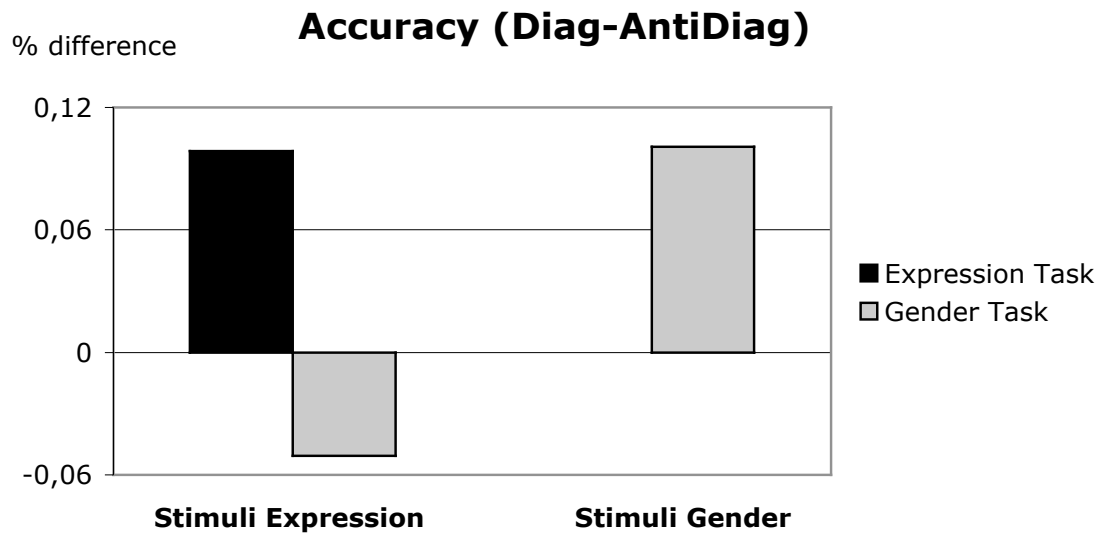


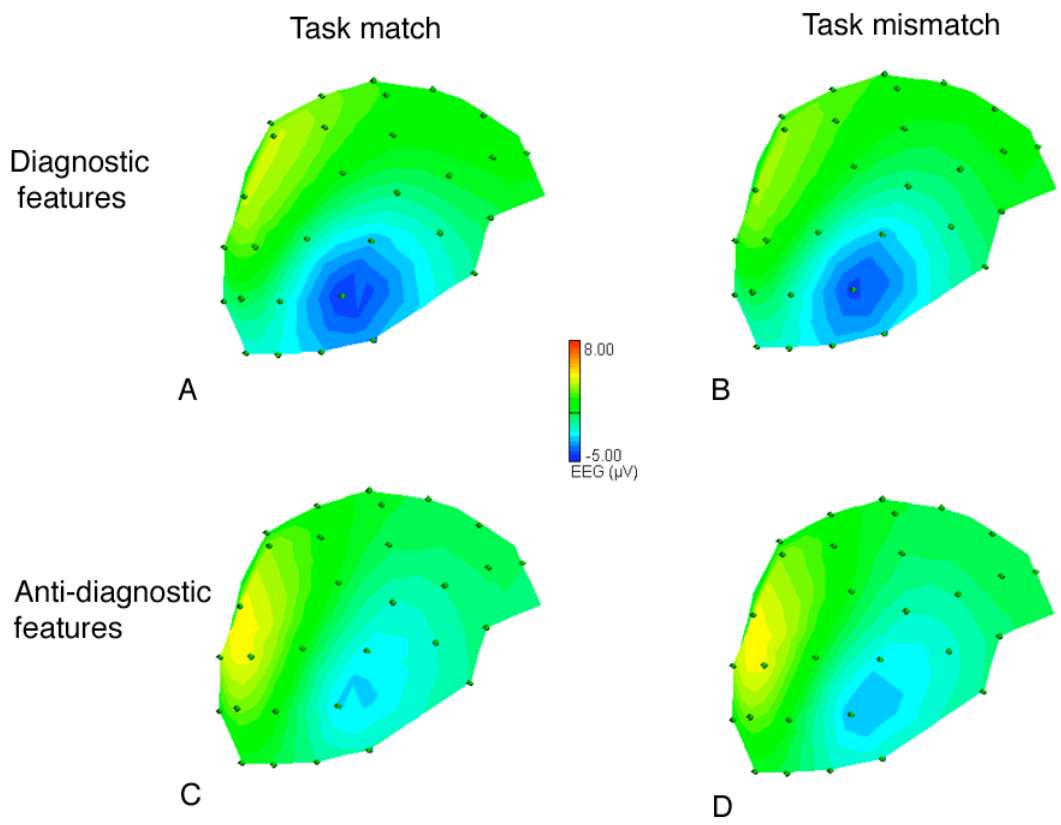
Figure 1



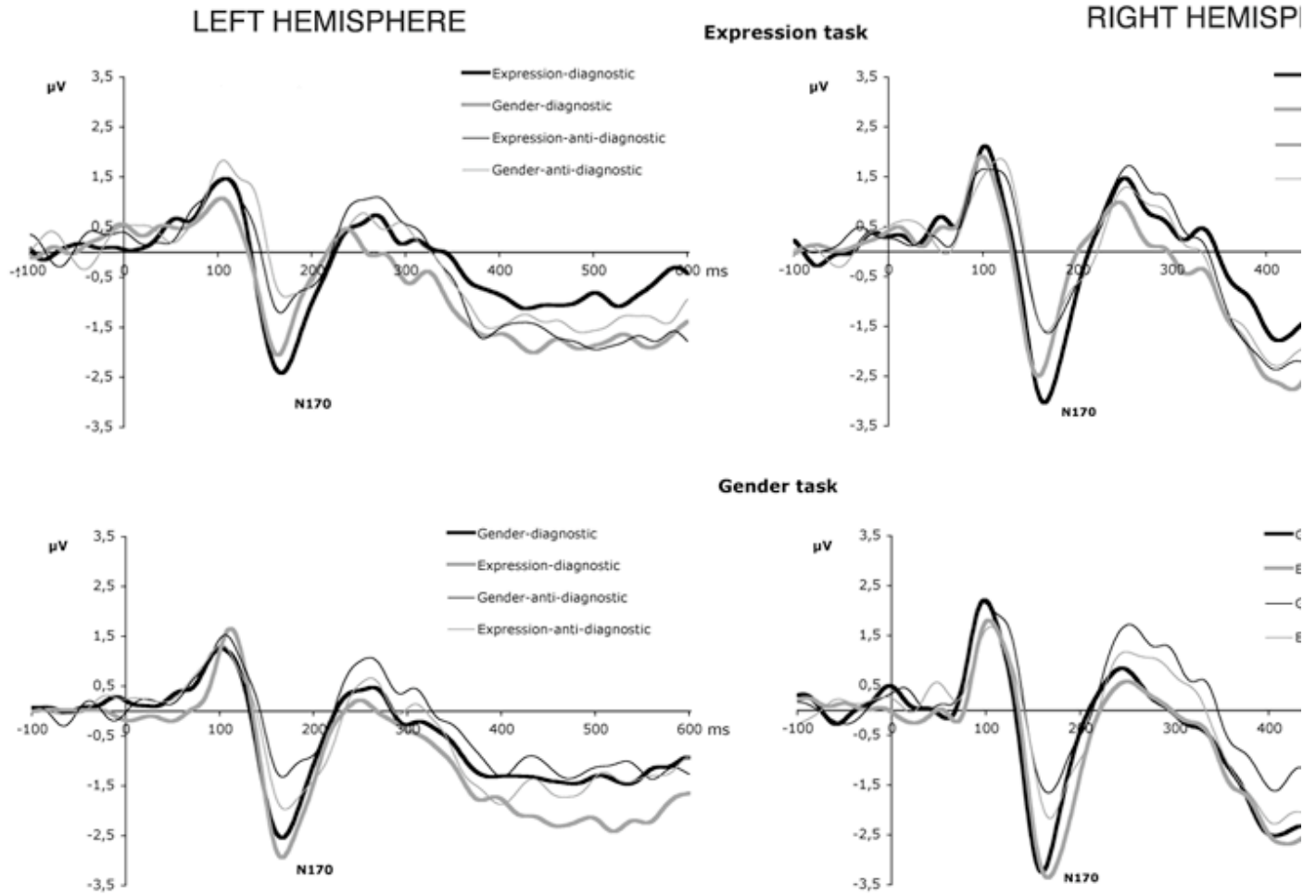
**Figure 2**



**Figure 3**



**Figure 4**



**Figure 5**

All tasks confounded

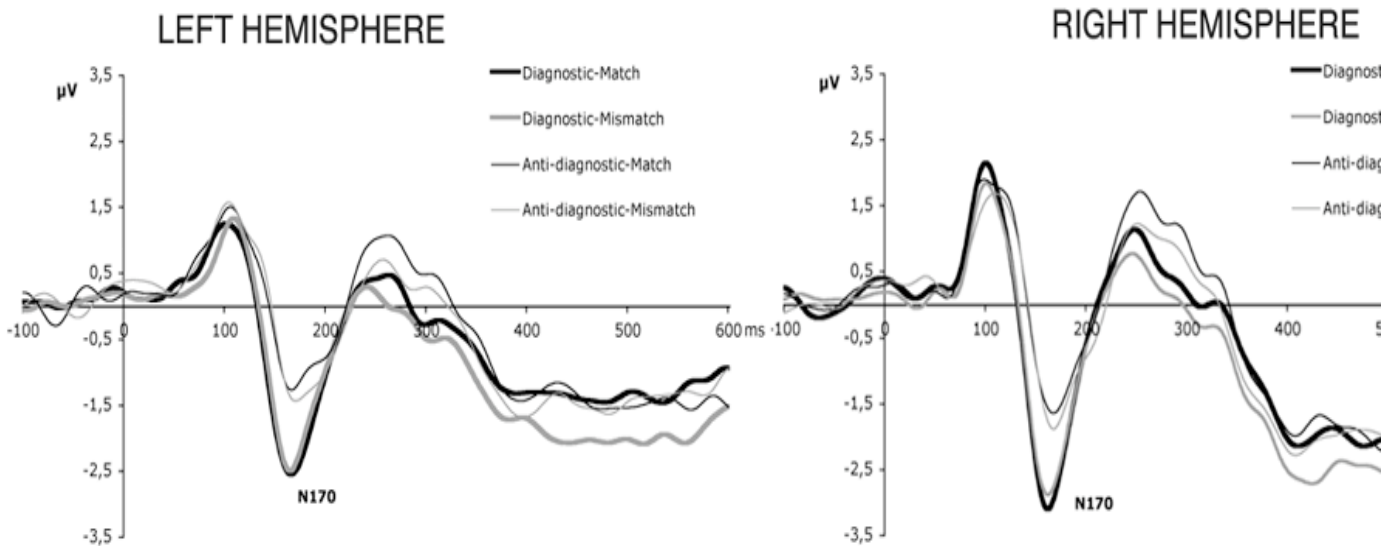


Figure 6

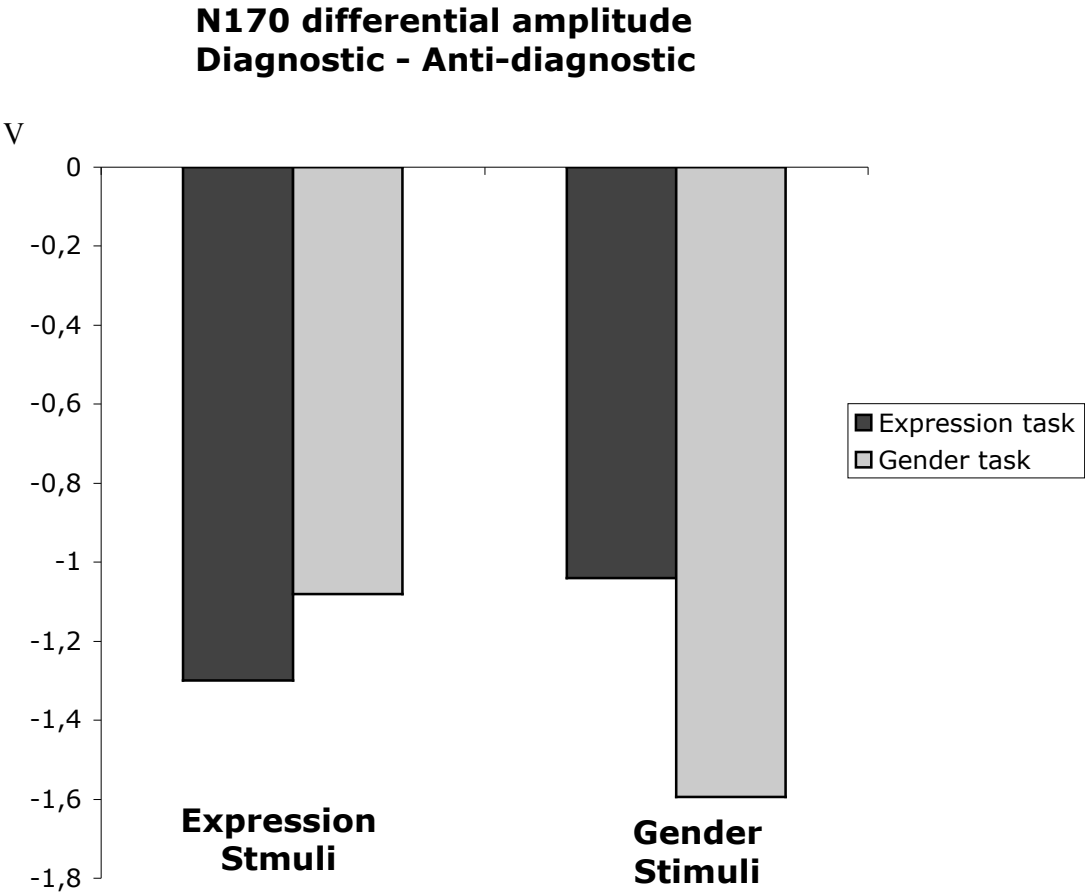


Figure 7