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ORIGINAL PAPER

Attentional Modulation of Early ERP Components in Response to Faces: Evidence From the Attentional Blink Paradigm

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Abstract The attentional blink (AB) is a transient attentional deficit that occurs when two stimuli that must both be detected are presented within an interval of less than 500 ms. Event-related potential (ERP) investigations have suggested that the AB affects a specific component, the P3, which is suppressed when targets are blinked. In view of the link between the P3 and working memory, it has been suggested that the AB might be due to the inability of the blinked target to access working memory. Interestingly, it seems that faces, due to their saliency, might escape the AB effect when cross-category detection is required (i.e., when the targets are composed of faces versus other categories of stimuli). In the present study we investigated this phenomenon in an event-related potential (ERP) study using upright and inverted faces as targets. In a first task, the participants were asked to identify two successive targets, the first composed of geometric shapes and the second of upright or inverted faces. A second control task, identical to the first was also performed,

in which only the second targets had to be identified in order to compare ERPs. ERPs and scalp topographies of physically identical sequences of events, differing only by the attentional involvement, were thus compared. Behavioural results showed that faces indeed escape the AB while inverted faces do not. However, the electrophysiological findings showed that when attention was engaged in a previous stimulus (at the shortest lag times), both upright and inverted faces showed a decreased amplitude in the 150–260 ms time period, in addition to a lower P3. At longer lags, when the AB was no longer observed, no ERP differences were found. Our data demonstrate that, although faces escape the attentional blink, previous attentional involvement occurs much earlier than described for other categories of stimuli. This suggests that faces are subjected to an early selection which might allow rapid re-allocation of attention to the stimulus if it is deemed meaningful.

Keywords Awareness · ERP · RSVP · Attention

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Introduction

When large amounts of information are presented to the visual system, only a small selection actually gives rise to conscious processing. The selection of information involves attention, and if allocation of attentional resources is insufficient, “inattention blindness” can occur (see e.g., Mack et al. 2002). One task evidencing this phenomenon is the rapid serial visual presentation (RSVP) paradigm (Raymond et al. 1992; Shapiro et al. 1997). In this task, stimuli are presented serially in rapid visual succession at a single spatial location, at a rate of about 10 stimuli per second. In the RSVP stream, two targets, T1 and T2, are presented among a series of distracters, with

the second target (T2) presented at various time lags after the first (T1). Conscious report of T2 is impaired if it is presented approximately between 200 and 500 ms after T1. However, this effect is abolished when T1 is ignored demonstrating that T2 can be consciously perceived and explicitly reported if attention is not engaged on the previous stimulus. This phenomenon was named the “attentional blink” (AB).

The AB reflects the temporal limitation of the attentional selection necessary for information to reach consciousness. This limitation can be influenced by the significance of the items presented as T2. Indeed, past experiences and factors like emotions, motivations and social values might influence our perception. Consequently, in an RSVP task, a significant or relevant item presented as T2 can escape the AB effect and be explicitly detected by comparison with another non-relevant stimulus presented at same lag time (e.g., Jackson and Raymond 2006; Raymond and O’Brien 2009). As a consequence, the attentional resources devoted to the identification of a specific category of stimuli can be assessed using the AB paradigm.

AB is thought to reflect a transient impairment of post-perceptual attentional mechanisms active at a late stage (namely after complete identification of the stimulus), at the level of working memory (Vogel et al. 1998; Kranczioch et al. 2003; Sergent et al. 2005). Previous ERP studies on AB have suggested that its associated electrophysiological component is the P3 wave which reflects the electrical correlate of working memory updating (Kranczioch et al. 2003; Kok 2001). This component is maximal at central and parietal sites, about 300–500 ms after target presentation and its presence would provide evidence that the stimulus is present in working memory. The absence of a P300 in AB tasks is therefore taken as evidence that information does not gain access to working memory thereby suggesting that AB operates after stimulus identification, at a relatively late stage of information processing (Vogel et al. 1998; Sergent et al. 2005; Rolke et al. 2001; Kranczioch et al. 2003; Sergent and Dehaene 2004).

Previous ERP studies using the RSVP task have investigated alphanumeric stimuli and images, but rarely more complex stimuli such as faces. Yet faces are probably the most biologically and socially significant visual stimuli in the human environment and it has been claimed that they may be particularly efficient in capturing visuo-spatial attention (Mack et al. 2002; Vuilleumier 2000). In line with this suggestion, it appears that faces may be immune to the AB effect when they are to be detected amongst other non-face categories as T2.

Relative to others visual object, faces elicit an early enhanced negative component over the lateral-occipital scalp peaking about 170 ms after stimulus presentation which is thought to be face specific (but see Thierry et al. 2007a, b). The early stages of face processing are thought

to be automatic, and only subsequent stages would be amenable to attentional influence (Farah 1996; Farah et al. 1995; Lavie et al. 2003).

Contrasting with these views, a number of reports have found that face-specific processing is not automatic but requires the allocation of spatial attention. Early processing which differentiate faces from non-face objects thus strongly depends on endogenous factors such as the distribution of spatial attention (Crist et al. 2007). Along these lines, the N170 amplitude was found to be enhanced in response to attended faces, suggesting that spatial attention can modulate the structural encoding of faces (Holmes et al. 2003). In another study addressing the effect of spatial attention on face processing, Downing et al. (2001) used stimuli consisting of superimposed faces and houses presented at the same location. They found that the M170 (a magnetic counterpart of the N170) was significantly larger when subjects attended faces compared to houses. Thus, face processing was affected at a relatively early stage when attention was manipulated. By contrast, a second study (Furey et al. 2006) using the same paradigm reported no effect on the M170, although an effect was noted in fMRI.

Early visual processes therefore appear to be sensitive to directed attention, but the influence of attention on face encoding has not been investigated with attentional blink paradigms and EEG.

In the present study, we investigated whether faces and inverted nonfaces would show the same susceptibility to AB and investigated which electrical components were modified during the transitory impairment of attention.

We used faces and scrambled faces in which the internal features (eyes, nose, and mouth) were displaced and, after an initial behavioural study using four SOAs, retained two of these durations for a subsequent high density EEG experiment.

Method

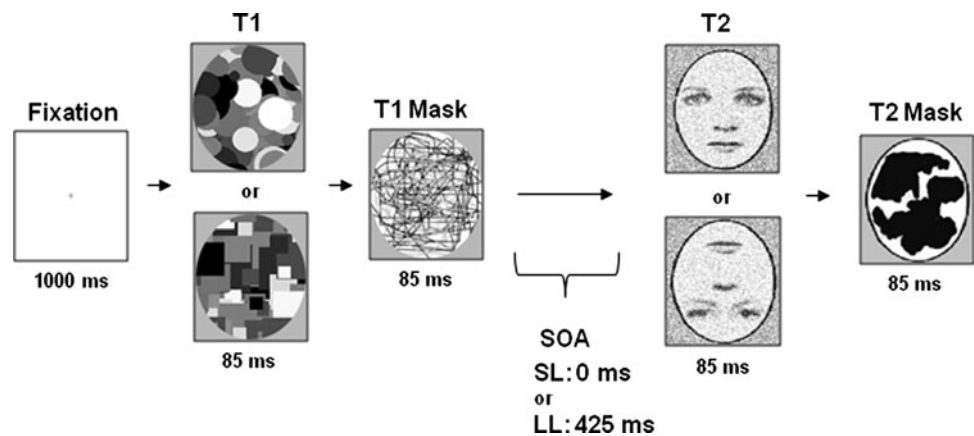
Participants

Seventeen right-handed (Oldfield 1971), 22–32 year-old, healthy students (8 males) with normal or corrected to normal vision took part in the experiment. One subject was rejected from the EEG analysis due to technical problems. Subjects were paid for their participation and informed consent was obtained prior to the beginning of the experiment.

Stimuli

The task required subjects to identify two targets appearing consecutively, called T1 and T2. T1 was a set of abstract

Fig. 1 Experimental procedure. Each trial proceeded in the following manner: an initial fixation point was followed by T1 composed of either *squares* or *circles* and followed by a mask. After a variable lag (0 ms or 425 ms), an *upright* or *inverted* face appeared, followed by another mask. In the dual task procedure two prompts followed asking participants to identify first T1, then T2. In the single task, the participants were asked only to identify T2



images (Fig. 1), previously used by Jackson and Raymond (2006). This set of targets was composed of computer-generated greyscale, abstract, elliptical patterns made up of either 20 small circles or 25 small squares, each element having a gray value randomly selected from 10 possible levels.

T1-mask was an elliptical pattern contains abstract scrawls (scrawls) of black lines.

T2 was either a face or an inverted face (Fig. 1). The faces were two greyscale images of a Caucasian adult, seen from a front view, with a neutral expression. A blank oval-shaped pattern was first created and the inner features (eyes, nose and mouth) were subsequently placed within the shape. For the inverted face, only the position of the eyes and mouth were inverted such that the eyes were presented at the bottom of the face and the mouth at the top.

The T2-mask was created with Adobe Photoshop and comprised the same oval shape with dark patches that occluded the features of the face.

All images (T1, T2 and theirs masks) were displayed against a grey rectangular uniform background that subtended approximately $3 \times 2.5^\circ$ visual angle when viewed at a distance of 100 cm.

Procedure

The AB procedure consisted in a series of 192 trials in which participants are asked to identify the two targets, T1 and T2. Each trial consisted of a sequence of four consecutive stimuli appearing at the centre of the screen. Trials started with the presentation of a central fixation cross that was shown for 1000 ms. This was followed by the first target, T1, for 85 ms, substituted immediately with a 0 ms delay by its mask (called the T1-mask) for 85 ms. Half of the T1 were squares and half were circles, appearing in a random order. Then, after a period of 0 or 425 ms (called

respectively the short and long lags—SL and LL),¹ the second target, T2, was presented for 85 ms, followed immediately (0 ms delay) by its associated mask (T2-mask) also for 85 ms. Half of the faces were in the upright position while half were upside down with the order of presentation randomized. Figure 1 summarises the sequence of events.

Short and long lags were used randomly in equal proportions. Each condition was repeated 48 times.

At the end of the trial, two questions appeared successively on the screen and remained visible until the participants had answered. The first question required them to identify T1 as circles or squares by pressing one of two keys with their index or middle finger on a dedicated response box. The second question pertained to the position of the eyes in T2, i.e., top or bottom part of the face. Participants again answered using a key press with their index or middle finger of the right hand. The response fingers were counterbalanced across subjects.

Visual stimuli were presented on a computer monitor placed at a distance of 100 cm in front of the subject.

In addition to the dual task, a control task was performed which was identical to the former with the exception of the instructions given to the subject, which were to detect only T2. Indeed, at the end of the trial, a single prompt requested the participant to respond only to the question whether the eyes were on top or on the bottom. This control task (*single task*), was performed in order to obtain ERPs from a physically identical sequence of stimulation, differing only in terms of attentional involvement. Differences between ERPs in the control and experimental situations could thus

¹ An initial behavioural experiment was carried out with 15 participants who were not involved in the current EEG experiment, using a procedure identical to the one described here, but with SOAs that varied between 0, 85, 170 and 425 ms. On the basis of this pre-test, SOAs of 0 and 425 ms were retained as producing the biggest and the smallest AB effects in our stimuli and the present EEG task was thus carried out with these values.

only reflect the subject's internal processing and not the effect of stimulus presentation.

The order in which the participants underwent the dual and the single task was counterbalanced with half the subjects carrying out the single task first.

Before beginning the experimental session, participants completed several practice trials that were similar to the task proper, but during which stimulus presentation was increased to 4000 ms per stimulus in order to ensure that the task was understood. Trials were then progressively decreased to 85 ms after which the session began.

EEG Recording

Subjects were seated in an electrically shielded room and a continuous EEG was acquired at 500 Hz using the Electrical Geodesic recording system (Electrical Geodesics, Inc., USA) with 109 equally-spaced scalp electrodes referenced to the vertex. Eye movements were monitored using three EOG leads. Impedances were kept below 50 k Ω throughout the experiment. The EEG was filtered offline from 1 to 30 Hz and recalculated against the average reference.

Epochs of 700 ms (–100 to 600 ms after T2 onset) were used to compute the ERPs in each of the four conditions (two stimulus types: upright and inverted faces; and two SOAs: 0 and 425 ms) in both the dual and single tasks. The 100 ms pre-stimulus period was used to establish baseline. Trials containing blinks, eye movement or electrical artefacts (amplitudes exceeding ± 100 μ V) were excluded during the averaging procedure, as were all trials in which T1 had not been correctly detected.

ERP Analysis

Waveforms

In order to test for unexpected effects, a time point by time point unpaired *t*-test was first carried out comparing the traces at each electrode in the dual and single task for the two stimuli and lags separately. Differences were considered meaningful if at least 10 neighbouring electrodes were significant at the .01 level (with no correction for repeated measures) over at least 10 consecutive time frames. Subsequently, mean amplitudes over significant time periods within groups of electrodes were selected for further statistical analyses using ANOVAs.

Temporal Segmentation

This analysis attempts to establish the sequence of stable scalp configurations across time between the conditions, by examining the spatio-temporal variations of the voltage distribution over time within and between conditions

(Brandeis and Lehmann 1986; Lehmann and Skrandies 1984; Michel et al. 1999; Michel et al. 2001). Since differences in map topographies measured at the surface of the scalp reflect differences in the underlying neuronal generators (Vaughan 1982), it is thought that the periods of stable map topographies, termed functional microstates (Lehmann et al. 2009), correspond to specific steps in information processing during which a given neural network configuration is active. The series of microstates composing the ERP map sequence are determined using a spatial k-means cluster analysis that identifies the dominant map topographies in the grand average ERPs of each experimental condition (Michel et al. 2001; Pascual-Marqui et al. 1995). The smallest set of maps that accounts for the greatest amount of variance is then selected using a cross validation criterion (Michel et al. 2001; Pascual-Marqui et al. 1995; Pegna et al. 1997; Pourtois et al. 2008). Next, the presence of a given ERP map, previously identified in the group-averaged data, is identified in the ERPs of the individual subjects. For each subject, at each time-point, a spatial correlation is computed between the momentary scalp topography and the template maps identified in the cluster analysis. Statistical analyses can then be carried out to compare the number of time frames (the total duration in ms) during which each map is present.

Source Localisation Analysis

In order to establish the cerebral areas responsible for the scalp topographies observed, a distributed linear inverse solution (LAURA; (Grave de Peralta Menendez et al. 2004) was used to estimate the putative sources in the brain that gave rise to the microstates established by the cluster analysis. The solution space was restricted to the grey matter of the MNI template brain. After applying a homogeneous transformation operation to the volume that rendered it to the best fitting sphere (SMAC model; (Spinelli et al. 2000), a 3-shell spherical head model was used to calculate the lead field for the 109 electrodes, and the LAURA inverse solution was determined (Michel et al. 2004).

Results

Behaviour

In the single task, hit rate was of 98.4, 99, 93.1 and 98.2% for faces SL and LL, and inverted faces SL and LL respectively.

In the dual task, results for T2 were analyzed only for the trials in which T1 was correctly detected. Consequently, the hit rate varied with respect to the total number of trials. The hit rate expressed as the percentage of correct

responses referred to the total number of trials is thus reported below.

Hit rate for T1 was 97.2 and 97.2% in the SL condition, and 97.5 and 97.4% in the LL condition for faces and inverted faces respectively.

For LL, performance is excellent for both faces and inverted faces with hit rates respectively of 95.4 and 91.4%. As can be observed in Fig. 2, faces are minimally affected by the AB.² For SL, performance is better when a face is presented upright (94.8%) than upside down (75%). Thus, in SL, only inverted faces appear to be affected.

A $2 \times 2 \times 2$ repeated measures ANOVA using task (dual vs. single), category (face vs. inverted face) and lag (short vs. long) as repeated measures was performed on the hit rates with a threshold set at .01. The 3-way interaction approached statistical significance ($F(1, 15) = 6.5, P = .02$), while all 2-way interactions were significant (category vs. lag: $F(1, 15) = 19.3, P < .001$; task vs. lag: $F(1, 15) = 8.8, P < .01$; task vs. category: $F(1, 15) = 10.1, P < .01$), as were the three main effects of lag, category and task (respectively: $F(1, 15) = 21.2, P < .001$; $F(1, 15) = 25.7, P < .001$; $F(1, 15) = 27.5, P = .0001$). It thus appeared that faces and non-faces produced different responses for SL and LL depending on the task. In view of these results and our hypotheses, we therefore performed repeated measures ANOVA for the dual and single tasks separately.

In the dual task condition, a 2×2 repeated measures ANOVA was performed using category (face vs. inverted face) and lag (SL vs. LL) as repeated measures. A significant interaction was found ($F(1, 15) = 14.01, P < .01$) demonstrating that hit rates differed across conditions. An LSD post-hoc test showed that the interaction was due to a significantly lower hit rate for inverted faces in SL compared to all other conditions (all P 's $< .0001$), while upright faces in SL and LL, as well as inverted faces in LL did not differ.

In the single task, a repeated measures ANOVA was again carried out on the hit rates using category (face vs. inverted face) and Lag (SL vs. LL) as repeated measures in order to establish whether these values differed in statistical terms. The interaction did not reach the selected threshold ($F(1, 15) = 7.74, P > .01$), nor did the effect of lag alone ($F(1, 15) = 7.3, P > .01$). By contrast, the main effect of

² This result could at first view be attributed to a tendency of the participants to respond “eyes on top” when they were uncertain, i.e., a response bias, however this is unlikely. In our pilot study, 4 stimuli were used: a face, an inverted face, as well as two asymmetrical non-faces in which both eyes were placed in the upper part of the “face” or in the bottom half. At SL, subjects were good at detecting eyes on top in real faces, but not in asymmetric non-faces with the eyes on top. In line with this, the present results seem unlikely to be due to a bias towards the “top” response, but seem most likely linked to the fact that the “real” face escapes the AB.

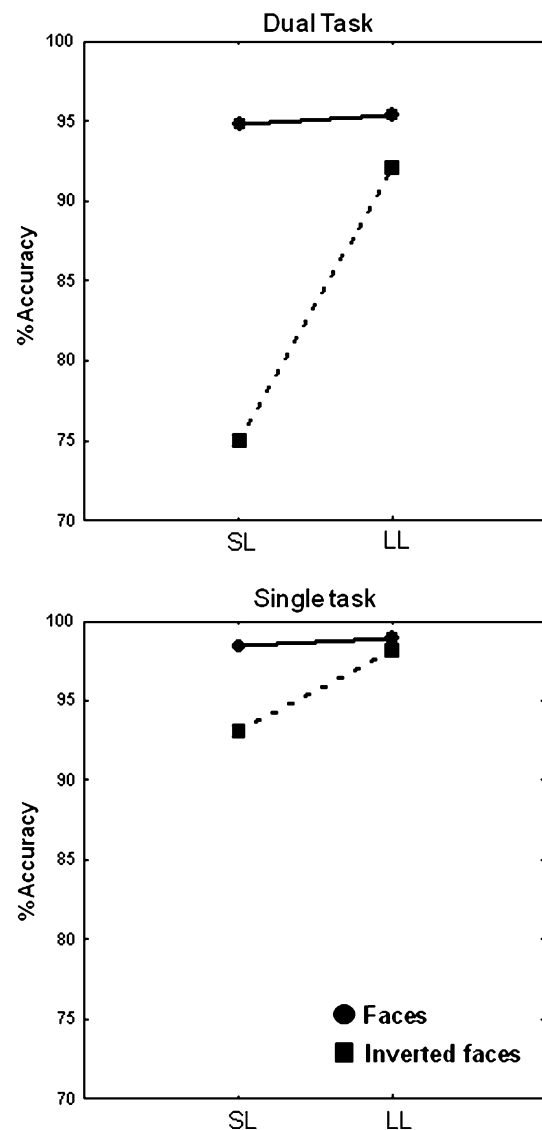


Fig. 2 Behavioural results. The number of correct identifications of T2 conditional on T1 detection is illustrated in percentages for faces (circles) and inverted faces (squares) for the short lag (SL = 0 ms) and the long lag L (LL = 425 ms). The top graph shows T2 identification in the dual task procedure whereas the lower graph depicts the percentage of correct responses in the single task condition where no response was required for T1

category was significant ($F(1, 15) = 9.3, P < .01$) due to a globally lower hit rate for inverted versus upright faces.

Electrophysiological Results: Waveform Analysis

The ERPs showed the most prominent responses over temporal and central leads (namely T5, T6 and Cz). Figure 3 illustrates the ERPs of the two areas of interest in the temporal region, namely T5 and T6 and their four neighbouring electrodes, labelled LTL (left temporal leads) and RTL (right temporal leads). In addition, the mean ERP

obtained for Cz and its six immediate neighbouring electrodes, labelled CL (central leads) are also depicted (see inset Fig. 3).

The traces are shown for each condition in the dual and single task conditions for faces and inverted faces for both SL and LL.

The ERPs represent the electrical response beginning –100 ms before the onset of T2. The superimposition of the ERPs in the dual and single task conditions, allows us to compare the differences between situations in which attention was or was not engaged by T1, the sequence of stimuli being otherwise identical in both conditions.

A point-wise *t*-test was performed in order to compare the ERPs in the dual and single task conditions. In LL, no differences were observed between dual and single task, either for faces or for inverted faces. For SL however, two periods differed significantly beyond 100 ms: one extending from 150 to 260 ms affecting temporo-occipital and frontal electrodes bilaterally, and a second extending from 380 ms to 570 ms and affecting a large group of electrodes over central and fronto-polar leads.

Amplitude Analysis Between 150 and 260 ms

The mean amplitudes of LTL and RTL in the 150–260 ms time window (highlighted in Fig. 3) were computed for upright and inverted faces, both in the dual and single task conditions in SL and LL. For upright faces on the left sites in SL amplitude was 0.54 μV (SEM: 0.39) for dual task and –1.32 μV (SEM: 0.41) for the single task condition. On the group of right electrodes, the mean amplitude was –0.11 μV (SEM:0.43) for dual task and –1.73 μV (SEM:0.56) for the single task condition. For inverted faces at SL, mean values over the five left sites were: 1.11 μV (SEM: 0.41) for dual task and –0.75 μV (SEM: 0.38) for single task condition. Over the right leads, these values were of 0.33 μV (SEM: 0.46) for dual task and –1.48 μV (SEM: 0.57) for single task conditions. For upright faces on the left, amplitude in LL was of –0.42 μV (SEM: 0.33) for the dual task and –0.52 μV (SEM:0.29) for the single task condition. On the group of right electrodes, the mean amplitude was 0.19 μV (SEM:0.37) for the dual task and –0.06 μV (SEM:0.45) for the single task condition. For inverted faces at LL, mean values over the five left sites were: –0.21 μV (SEM:0.28) for dual task and –0.36 μV (SEM:0.22) for single task conditions. Over the right leads, these values were of 0.28 μV (SEM:0.39) for dual task and –0.15 μV (SEM:0.39) for single task conditions. A $2 \times 2 \times 2 \times 2$ ANOVA using task, category, lag and lateralisation as repeated measures was computed. This revealed a significant main effect of task ($F(1, 15) = 15.4$, $P < .01$), with the dual task producing less negative amplitudes (0.21 μV) than the single task (–0.80 μV). In

addition, there was a significant interaction between task and lag ($F(1, 15) = 11.7$, $P < .01$) while all other main effects and interactions were non-significant (all P 's $> .01$). A post-hoc Tukey HSD test revealed that this was due to the fact that the amplitudes differed significantly between dual and single tasks in the SL ($P < .001$) but not in the LL conditions ($P < .1$).

Amplitude Analysis Between 380 and 570 ms

As for the previous time window, mean amplitudes were averaged within a period of interest, this time 380 to 570 ms, at electrodes Cz and its six nearest posterior neighbours (which included Pz). Similar results were obtained when analysing Cz alone but are not reported here.

The mean amplitude in the SL condition for upright faces was 0.23 μV (SEM: 0.41) for the dual task and 1.21 μV (SEM: 0.71) for the single task condition. For inverted faces, means were 0.1 μV (SEM: 0.25) for the dual task and 1.12 μV (SEM: 0.74) for the single task condition. In the LL condition, mean amplitudes were for upright faces, 0.71 μV (SEM: 0.25 in the dual task and 1.24 μV (SEM: 0.55) in the single task. For inverted faces, these values were of 0.67 μV (SEM: 0.53) in the dual task and 1.11 μV (SEM: 0.73) in the single task. The mean values of all subjects were used to compute a $2 \times 2 \times 2$ ANOVA using task, category, lag as repeated-measures. None of the interactions were significant (task X category X lag: $F(1, 15) = .2$, $P > .01$; category X task: $F(1, 15) = .02$, $P > .01$; lag X task: $F(1, 15) = 2.4$, $P > .01$; lag X category: $F(1, 15) = .01$, $P > .01$). The main effects of category and lag also failed to reach significance (respectively $F(1, 15) = 1.5$, $P > .01$ and $F(1, 15) = 3.8$, $P > .01$) while only that of task proved to be significant ($F(1, 15) = 12.8$, $P < .01$).

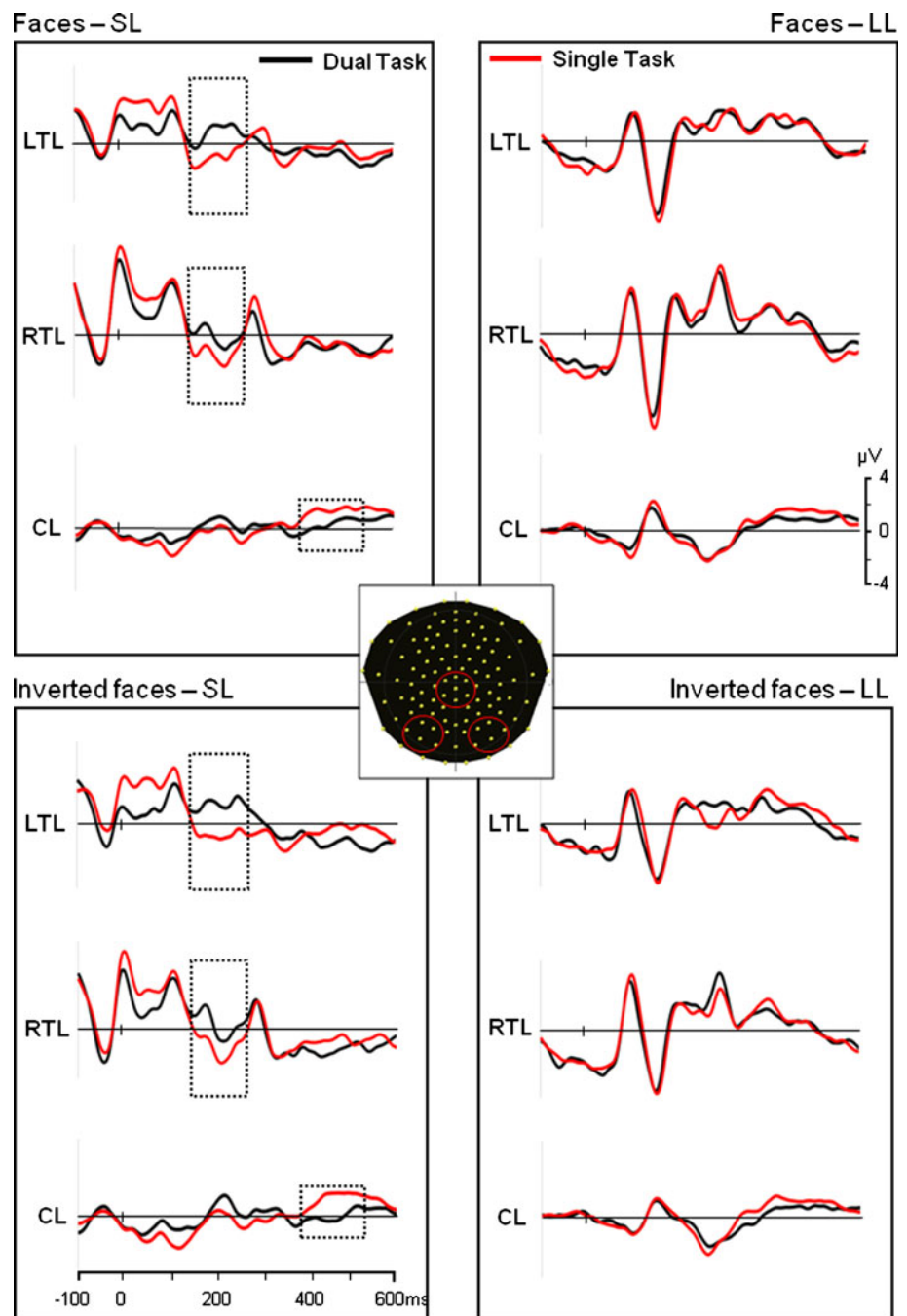
Segmentation Analysis

Segmentation was performed on the grand average ERP map series between 80 ms and 600 ms after T2 presentation. Microstates (MS) were discarded if they lasted < 10 time frames or explained $< 15\%$ of the total variance of the ERP map series. Similarly, microstates correlated at $> 85\%$ were merged.

SL-Faces

Dual task faces and single task faces were best explained by eight microstates. These were numbered MS1–MS8. However in order to distinguish microstates that were not common to both conditions, the latter were lettered in sequence of appearance (MSa–MSd) to allow them to be

Fig. 3 Waveforms analysis. Grand average ERP traces for clusters of neighbouring electrodes around T5, T6 and Cz in response to T2. The LTL (*left temporal leads*) and RTL (*right temporal leads*) traces (*right temporal leads*) illustrate the mean of electrodes T5 and T6 and their four immediate neighbours respectively. CL (*central leads*) show the ERP averaged over Cz and its six surrounding electrodes (see *inset* for electrodes placement). The *upper panels* show the ERPs when T2 were faces while the *lower panels* show the responses for T2 *inverted faces*. The panels on the *left* show the ERPs for the short lag (SL = 0 ms) and the panels on the *right* show the long lag (LL = 425 ms). For comparison purposes, the responses of the dual task condition (*black*) are superimposed on the responses of the single task (*red*) condition. The two conditions are strictly identical except for the instructions given to the participants to attend or not to a prior stimulus. Consequently, these differences can only reflect variations due to the distribution of attention



clearly distinguished. The two conditions shared four microstates (MS1, MS4, MS6 and MS8) while dual task showed two maps (MSb and MSc) that did not appear in the single task condition and two other maps (MSa and MSd) that were present in the single task but not the dual task condition. The onsets and offsets of these maps in the grand average ERPs are shown in Table 1A and in Fig. 3.

The periods showing divergences in microstates were approximately similar to the periods of differences in the waveform analysis, i.e., between ~150–270 ms and later between ~300–500 ms, demonstrating that the effects

found in the latter analysis were due to changes in topographies, rather than the strength of the maps.

The early differences were due to the presence of an N170-like map with bilateral posterior negativity in the single task, which was not observed in the dual task condition, but was replaced by a map showing a posterior positivity, albeit with a negativity extending into the temporal leads particularly on the right. During the second period of difference, the dual task condition was characterised by a map showing a posterior negativity more pronounced on the right (MSc followed by MS6), while the

Table 1 Microstate duration

	MS1	MSa*	MSb*	MS4	MSc*	MS6	MSd*	MS8		
(A) Faces (SL)—duration of microstates (ms)										
Dual task	80–156		158–256	258–306	308–408	410–484		486–		
Single task	80–148	150–282		284–332		334–396	398–512	514–		
	MS1	MSa*	MSb*	MSc*	MSd*	MS6	MS7	MSe*	MSf*	MS10
(B) Inverted faces (SL)—duration of microstates (ms)										
Dual task	80–172		174–200	202–244	246–280	282–316	318–488		490–588	588–
Single task	80–156	158–276				278–310	312–418	420–582		584–
	MS1	MS2	MS3	MS4	MS5	MS6	MS7	MS8		
(C) Faces (LL)—duration of microstates (ms)										
Dual task	80–118	120–176	178–224	226–278	280–340	342–442	444–514	516–		
Single task	80–120	122–182	184–226	228–282	284–332	334–384	386–510	512–		
	MS1	MS2	MS3	MS4	MS5	MS6	MS7	MS8		
(D) Inverted faces (LL)—duration of microstates (ms)										
Dual task	80–122	124–184	186–246	248–344	346–480	482–514	516–			
Single task	80–130	132–186	188–234	236–336	338–446	446–548	550–			

A–D: Onsets and offsets of the microstates (MS) explaining each of the grand average ERPs at short lags (SL) for faces (A, C) and inverted faces (C, D), as well as short (A, B) and long (C, D) lags are indicated in milliseconds for each map. MS that were significantly different in the participants' ERPs are indicated "*" (see text for details of analysis)

single task condition showed essentially a typical P3 map, with a vertex positive topography (MSd). Both conditions then led to a microstate with a central, but slightly more anterior positivity.

The presence of maps MSa and MSb in the early period were established statistically as described in the Methods section, by searching for the number of time frames during which they were present (along with the preceding and successive maps MS1 and MS5) in the dual and single task conditions between 100 ms to 300 ms in each subject. MSa was found on average for 41 ms (standard error, SE = 9.4) in condition dual task and for 84 ms (SE = 11.4) in the single task condition across subjects. MSb was found for 47 ms (SE = 9.2) and 14 ms (SE = 6.9) in dual and single task conditions respectively. Thus, although MSa and MSb were only present in one of the two conditions in the grand average ERPs, they appeared nonetheless in the ERPs of each individual. As their mean durations differed across conditions, a 2×2 ANOVA was performed using Condition (dual and single task) and Map (MSa and MSb) as repeated measures, in order to establish statistical significance. A significant interaction was found between Condition and Map ($F(1, 16) = 28.8, P < .0001$). Condition alone was not significant ($F(1, 16) = 1.3, P > .05$). A Fisher post-hoc LSD test showed that MSa was significantly more present in the single task than the dual task condition ($P < .001$) while the opposite was true of MSb ($P < .01$).

For the late differences, the durations of maps MSc and MSd were established in the 300 to 500 ms time window (along with those of MS4, MS6 and MS8). On average, the durations of MSc was of 56 (SE = 12.2) and 14 (SE = 8) milliseconds for the dual and single task conditions respectively. Duration of MSd was of 20 (SE = 6.6) and 66 (SE = 9.2) milliseconds for the dual task and single task conditions respectively. A 2×2 repeated measures ANOVA was carried out using Condition (dual task, single task) and Map (MSd, MSe) as repeated measures. The results showed that the interaction was significant ($F(1, 16) = 34.9, P < .0001$). The effect of Condition was not significant ($F(1, 16) = 0.1, P > .5$). Post-hoc analyses comparing the duration of each MS in the dual and single task condition confirmed that the presence of MSc was significantly longer in the dual task than the single task condition ($P < .005$) and was longer for MSd in the single task than the dual task condition ($P < .0005$).

SL-Inverted Faces

For dual task non-faces and single task non-faces, the map series was explained by nine microstates, three of which were common to both conditions (see Table 1; Fig. 4 for onsets and offsets of the maps). From 80 ms to about 160 ms, a common MS (MS1) was found. Subsequently, separate maps explained the ERPs until ~ 280 ms (MSa to MSd) at which point two common topographies (MS6 and MS7) were again observed.

Subsequent differences were seen again after 420 ms for the single task (MSe) and 490 in dual task (MSf). These findings were thus similar to faces although the differences were shifted slightly later in time. As in the Face condition, the differences in topographies showed up mainly as a more marked posterior negativity in the 170 ms time period in the single task condition while the dual task condition gave rise to a strong central posterior positivity. The later period showed, in the case of the single task condition, a MS characterised by a central positivity, consistent with a P3 topography. In the dual task condition, the maximum positivity was more anterior and maintained a posterior negativity.

The presence of maps MSa to MSd in the early period were again determined by establishing the number of time frames during which these maps (in addition to the preceding and successive ones, MS1 and MS6) were present in the dual and single task conditions between 150 ms to 300 ms in the ERPs of each subject. MSa, MSb, MSc and MSd were present on average for respectively 38 ms (SE = 13.2), 40 ms (SE = 10.2), 26 ms (SE = 7.5) and 32 ms (SE = 10) in the dual task condition; and for 96 ms (SE = 13.1), 22 ms (SE = 9.3), 6 ms (SE = 3.8), 14 ms (SE = 6.0) in the single task condition. The statistical validity of these differences was established by performing a 2×4 ANOVA using experimental Condition (dual task, single task) and Map (MSa, MSb, MSc and MSd) as repeated measures. A highly significant interaction was found ($F(3, 48) = 9.2, P < .0001$). Condition alone was not significant ($F(1, 16) = .004, P > .5$). A post-hoc Fisher LSD test showed that the difference across map duration in the two conditions was present only for MSa that was longer in the single task than the dual task condition ($P < 0.0001$). None of the other maps differed across conditions (all P 's $> .05$).

The late differences in the ERP map series for inverted faces affected maps MSe and MSf that occurred roughly between 400 and 600 ms in the grand averages. We again verified the statistical validity of these findings by searching for these two maps (as well as MS7 and MS10) in this time window in the individuals' ERPs. MSe was present for respectively 22 (SE = 9) and 98 (SE = 15) milliseconds in the dual and single task conditions, while MSf was present for 62 (SE = 10.4) and 50 ms (SE = 10.6). This yielded a significant interaction ($F(1, 16) = 9.3, P < .01$) as well as an effect of experimental condition alone ($F(1, 16) = 23.6, P < .001$). A Fisher post-hoc LSD test showed that MSe, i.e., the P3 map, was present statistically longer in the single task than the dual task ($P < .01$). By contrast, MSf showed no significant difference between condition dual and single task ($P > .1$).

LL-Faces and Inverted Faces

Segmentation of the ERPs for AB faces and control faces showed that eight identical microstates explained the whole

series for both conditions. Their onsets and offsets can be seen in Fig. 4 and Table 1. The segmentation for inverted faces in the dual and single task conditions showed the existence of seven maps explaining both conditions (Fig. 4). As expected in view of the lack of any behavioural AB effect and any difference in the waveform analysis, no divergence in map topographies was noted between the single and dual task conditions for either stimulus category.

Source Localisation

Faces-SL

The sources generating the MS of interest were estimated using the LAURA inverse solution (see Fig. 5). For SL, faces in the dual task (MSb) and in the single task condition (MSa) gave rise to an activation situated in the primary visual areas with maxima in Brodmann's area (BA) 17 bilaterally for both conditions. The single task condition (MSa) produced an additional activation in the right temporal region corresponding to the superior and middle temporal gyri corresponding to BA 22 and 39, as well as a weaker mirror activity in the left temporal region.

The later MSc in the dual task condition showed an activation that was similar to MSa, although the right middle temporal maximum of activation extended slightly more posteriorly.

Finally, the P3 map (SMe) showed a large activation in the right anterior temporal area which included the ventral, lateral and medial portions of the temporal pole including BA 20, 21 and 38.

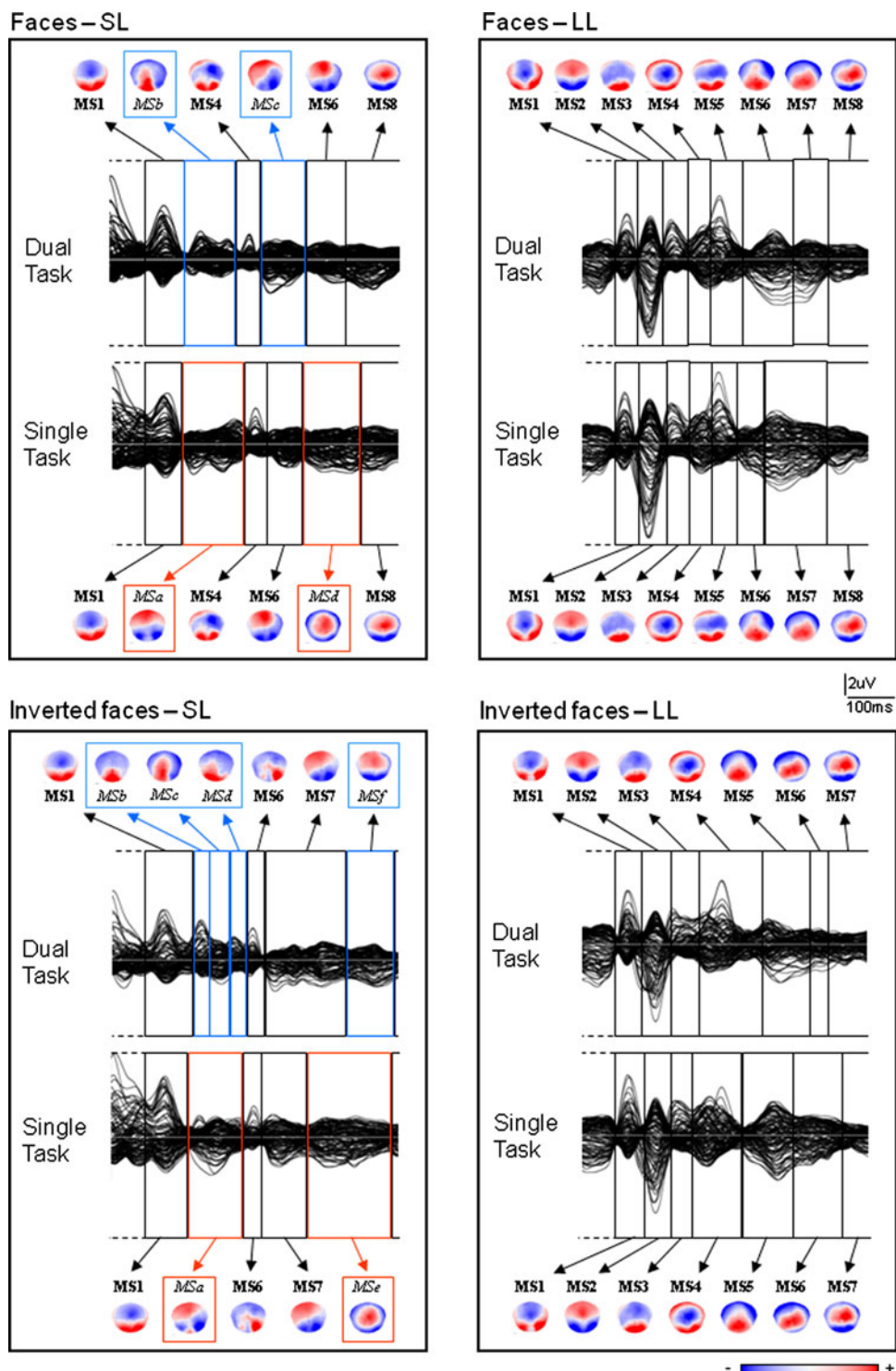
Inverted Faces-SL

The strong resemblance between the MS found for faces and inverted faces was also found in the inverse solutions. Indeed, the initial map for dual task condition of inverted faces (MSb) and the initial map of the single task condition (MSa) again differed in that the dual task condition showed little if any lateral temporal activation compared to single task. The two subsequent MS in the dual task condition (MSc, MSd) produced some lateral temporal activation in the superior and middle temporal gyri (BA 22 and 39) as was the case for upright faces. However, MSd yielded a maximum over the left temporal area, a pattern not observed for faces.

Faces-LL

For illustrative purposes, the solutions for MS1 and MS2 for faces (LL) are shown in Fig. 5. As can be observed,

Fig. 4 Topographic segmentation analysis. A topographic segmentation was performed on the grand average ERP map series between 80 and 600 ms for faces (*top panels*) and inverted faces (*lower panels*) for the short lag (SL—*left column*) and long lag (LL—*right column*). The 600 ms epochs beginning at T2 onset are presented for each of these conditions with the 109 electrodes superimposed. The dual and single task of every condition are represented one above the other in the same panel. The segmentation procedure yielded a different set of maps explaining each of the grand average ERPs. *Boxes* indicate the temporal boundaries of these maps on the ERPs. Within each panel, the microstates common to both the dual and single task conditions are numbered (MS1, MS2, ..., MSn). Maps that differentiated the dual task from its control, the single task, are highlighted (*red* for maps specific to dual task and *blue* for maps specific to single task) and are lettered (MSa, MSb, ... MSz) to distinguish them. Note that for LL, dual and single task conditions were explained by the same maps



when attention is unhindered either because of the long lag or because the initial stimulus is discounted, the initial map (MS1) coincides with activation in the primary visual cortex as well as the right middle temporal area (BA39). The subsequent N170 map (MS2) is produced by bilateral middle temporal activation (with a maximum also coinciding with BA39).

Discussion

The behavioural results in our study showed that faces escape the attentional blink phenomenon and were rarely missed by the participants. This occurred despite a decrease in attentional resources suggested by the lower N170 amplitudes for both categories of stimuli. Indeed, a

decrease in amplitude in this time window was found in the dual task independently of whether the stimuli were upright or inverted faces even though behavioural responses showed that upright faces remained detectable. In addition, the dual task produced modifications of the N170 segment map in which posterior negativity disappeared in the SL/dual task condition, as well as the disappearance of the typical P3 map although hit rate was practically unchanged for faces. Interestingly, for inverted faces, the dual task/SL condition showed an increased number of short-duration maps compared to the corresponding single task, which could be taken to mean that the dual task gives rise to multiple attempts at information processing that are interrupted or incomplete due to attentional engagement by T1. This interpretation is of course highly tentative, since the precise functional significance of the topography maps is unclear at this point. Nevertheless, these observations, along with the decrease in amplitudes of the ERP components, are consistent with lowered attentional resources whose effects are less disruptive for faces.

The participants' performances are in line with three other studies that have explored the attentional resources necessary for face processing using an attentional blink paradigm (Jackson and Raymond 2006; Landau and Bentin 2008; Awh et al. 2004).

The findings of Awh et al. (2004) had suggested that faces escape the AB effect due to the existence of specific attentional mechanisms dedicated to featural and configural processing. Indeed, they carried out a number of AB procedures using different SOAs and T1-T2 stimuli including digits and faces and observed most notably that the AB effect failed to arise unless both T1 and T2 were faces or face-like stimuli. They concluded that numerous channels must be available for processing during the AB period, thus precluding AB when T1 and T2 were accessible through different channels. When both stimuli require the same channel for processing, AB appears. This could apply to tasks involving both identification (Awh et al. 2004) and detection (Landau and Bentin 2008). Since faces are thought to be processed configurally, AB would appear for T2 faces only when T1 also requires configural processing. In contradiction with this hypothesis, Jackson and Raymond (2006) used a featural T1 task, yet found an AB effect for T2 faces. In their case, an identification task was used in which T2 was composed of famous or unknown faces whose gender had to be determined. Famous faces were less susceptible to the AB effect than unknown faces in their study; a finding that the authors suggested was due to the fact that higher familiarity required less attention for processing. They concluded that face identification used the same attentional resources as featural processing and consequently that separate channels were unlikely.

The immunity of faces induced by previous processing of other stimulus categories, but not of faces, was also explored by Landau and Bentin (2008). The authors were capable of producing an AB effect across faces and watches when the attentional demands of the task were sufficiently high, thus also calling into question the idea of multiple channels of processing. Their conclusions concur with those of Jackson and Raymond (2006), suggesting that the immunity from the AB effect is due to the perceptual salience of these stimuli which reduces the amount of resources needed for their detection.

In our experiment, T1 detection was feature-based, while T2 explicitly required participants to respond to features (eyes). However, since an AB was observed for upside down T2 faces but not upright ones, either the participants were incapable of adopting a featural mode of processing for the upright faces, or the perceptual salience was such that faces could not be ignored.

In our study, an effect of stimulus familiarity cannot be rejected. Indeed, since humans are highly familiar with upright faces but not with inverted ones, it could be argued that the lack of AB in the former simply reflects the fact that more familiar stimuli require less attentional resources. One partial answer to this argument has been given by Mack et al. (2002). If familiarity were sufficient to explain the capture of attention, then similar observations should be made with other categories of stimuli. However, in an inattention blindness task, these authors showed that highly familiar words such as “the” and “and” are affected in a similar manner as words like “tie” and “ant”, that are visually similar but less familiar. Thus familiarity is unlikely to be the only factor explaining attentional capture, at least as far as verbal stimuli are concerned. Since the authors also observed that happy face icons do not blink compared to upside down versions, they consequently attributed this absence of an AB to the meaningfulness of the face stimulus rather than its familiarity.

If meaning is necessary for attentional capture, it ensues that sufficient processing must occur for meaning to be extracted before attentional selection takes place. Thus, the AB effect should occur relatively late in the stream of processing. Indeed, the most common account of the AB effect is that it occurs at a post-perceptual stage of stimulus processing (e.g., Awh et al. 2004; Jolicoeur 1999). As pointed out above, evidence of this has arisen from ERP measures of AB suggesting that, while the earlier P1, N1 components are left unaffected, the blink is associated with modifications of the P3 component which has been linked to consolidation of the stimulus representation in working memory (Vogel et al. 1998; Sergent et al. 2005). Our results are in agreement with these previous studies since a decrease in P3 amplitude for ‘blinked’ stimuli was also observed and the topographic analysis showed a

disappearance of the P3 map as is generally expected (and was observed in the single task condition).

However, one striking difference in our task is the effect observed on the early components notably the N170 topography during the SL. Previous studies have shown that components earlier than the P3 can also be modulated by the AB. For example, using a dual stream paradigm, Dell'Acqua et al. (2006) and Jolicoeur et al. (2006) found that the N2pc component, a marker reflecting the spatial deployment of attention, was suppressed during the AB. These findings suggested commonalities between the mechanisms engaged in spatial attention and those involved in the AB, pointing to the possibility of a processing bottleneck occurring prior to working memory. However, a more recent investigation found that the N2pc was sensitive to both lag and working memory load (Akyürek et al. 2010), showing that working memory load affects an earlier stage of processing than the P3 and thus maintaining its possible involvement in AB. Nevertheless, the striking difference in our task is the effect observed on an even earlier component, notably the N170 topography. The N170 component is thought to reflect the pre-categorical perceptual encoding of a face and is generally observed over temporal electrodes (usually T5 and T6), seemingly reflecting activity in ventral visual areas specific for faces such as the FFA (Eimer 1998), although more lateral temporal areas such as STS may also be involved (Itier and Taylor 2004). These areas provide a structural representation of faces used in subsequent stages of processing (Bentin et al. 1996; Eimer 2000; 1998).

However, although it may reflect early feedforward perceptual processing, other studies have shown that the N170 is capable of being modulated by top-down influence. Eimer (2000) described no change in N170 amplitude in response to faces when attention was directed towards or away from the stimuli. Similarly, as noted above, Furey et al. (2006) failed to find an M170 modulation when superimposed faces and houses were presented with attention directed to the latter. This is in contradiction with our results showing a decrease in the N170 when less attention is available for stimulus processing. The fact that the N170 might be modulated by attentional or top-down control is not altogether surprising and has been demonstrated in other situations. For example, Bentin and Golland (2002) showed that schematic, scrambled non-faces failed to produce an N170 until the subjects were exposed to schematic non-scrambled faces. Once participants were aware of the link between the scrambled and non-scrambled version of the faces, a normal N170 was then observed for all items, demonstrating the extent of top-down modulation of the N170.

In the attentional domain, Luo et al. (2009) used an RSVP task with emotional faces as T2 targets. The authors

Fig. 5 Source localisation. The sources generating the main maps MS were estimated using the LAURA inverse solution. The scalp topography and source current density (SCD) maps differentiating dual and single task conditions for faces in at the short lag (SL) are shown in the *upper* panel. Those differentiating dual and single task conditions for *inverted* faces in SL appear in the *middle* panel. Finally, for illustrative purposes, the inverse solution is given for MS1 and MS2 in the long lag condition for faces (Faces—LL). The maps were similar to the *inverted* faces in the long lag condition and are thus not illustrated

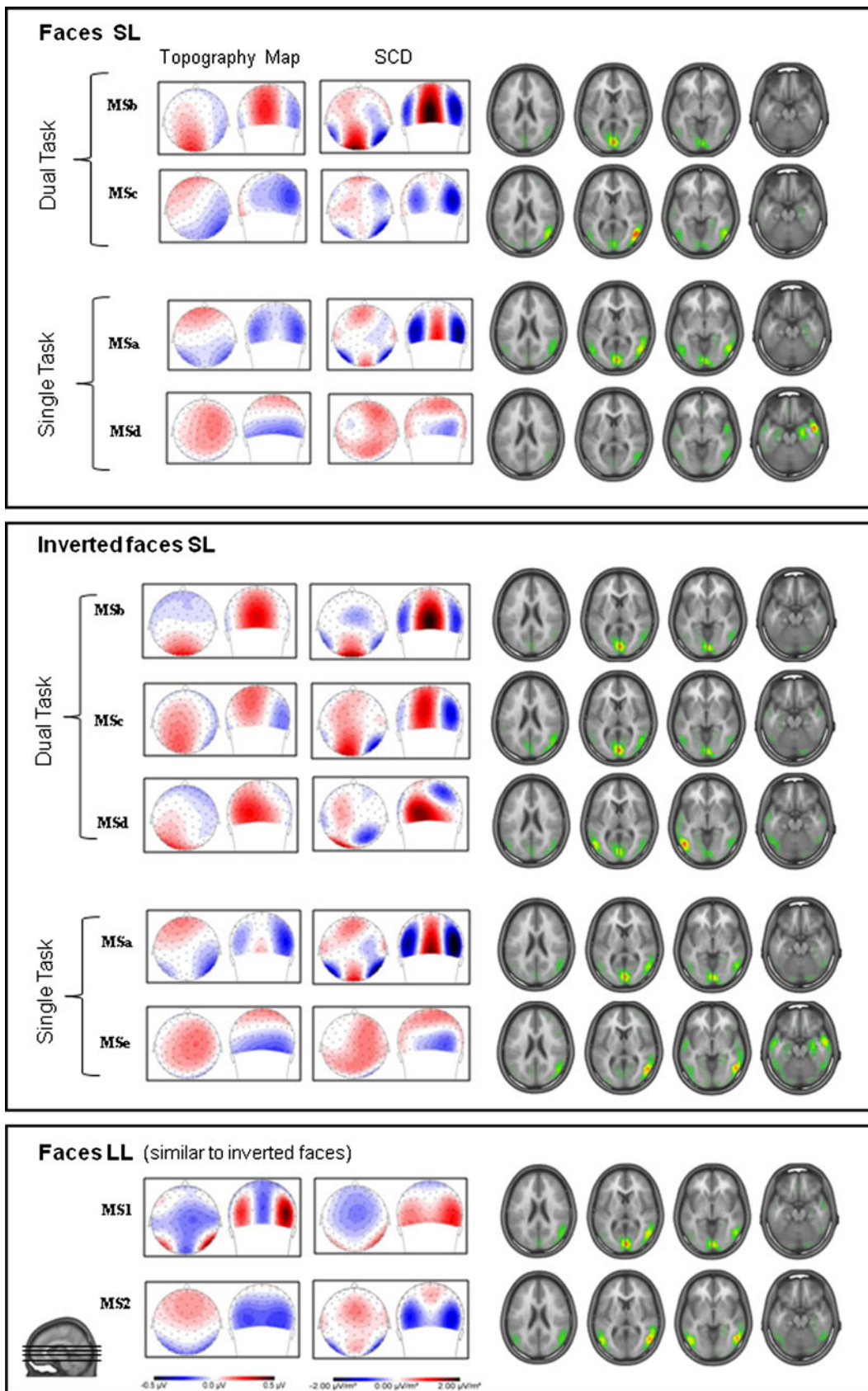
found that accuracy rate for T2 detection decreased when attention was engaged in a previous (T1) target and, interestingly, observed a concurrent decrease in several ERP components among which the P1 and N170, showing that facial features may impinge on earlier components in line with our findings. Our data thus provide further evidence that attention can modulate this early component. However, interestingly, although a modification of the early electrical response was seen in our experiment for faces and inverted faces, the former nevertheless escaped the AB phenomenon proving once more their capacity to capture attention (Mack et al. 2002).

Notwithstanding these observations, it remains that, contrary to other ERP reports investigating the AB, the temporal locus of the AB for faces or face-like stimuli arises much earlier than for other types of stimuli such as alphanumeric characters (e.g., Vogel et al. 1998; Sergent et al. 2005).

On the basis of our findings, we would hypothesise that because of their relevance, faces must be subjected to an early attentional selection and subsequent capture, reason for which they escape the AB. Faces or face-like stimuli would undergo an attentional selection at the perceptual level, which might then lead, or not, to further processing in working memory depending on whether the stimulus is meaningful (i.e., if it is a face) and on the availability of resources.

Conclusion

Our behavioural results showed that faces were immune to the attentional blink phenomenon and were always detected whatever the lag time between the two targets. On the other hand, highly similar stimuli, in our case inverted faces, were not reported at shortest lags and their detection rate increased with lag time. Of particular interest, the extent of attentional availability was found to modulate early electrophysiological periods including the N170, in addition to the P3 which has been described for other categories of stimuli.



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References

- Akyürek EG, Leszczynski M, Schubö A (2010) The temporal locus of the interaction between working memory consolidation and the attentional blink. *Psychophysiology* 47:1134–1141
- Awh E, Serences J, Laurey P, Dhaliwal H, van der Jagt T, Dassonville P (2004) Evidence against a central bottleneck during the attentional blink: multiple channels for configural and featural processing. *Cogn Psychol* 48(1):95–126
- Bentin S, Golland Y (2002) Meaningful processing of meaningless stimuli: the influence of perceptual experience on early visual processing of faces. *Cognition* 86(1):B1–B14
- Bentin S, Allison T, Puce A, Perez E, McCarthy G (1996) Electrophysiological studies of face perception in humans. *J Cogn Neurosci* 8:551–565
- Brandeis D, Lehmann D (1986) Event-related potentials of the brain and cognitive processes: approaches and applications. *Neuropsychologia* 24(1):151–168
- Crist RE, Wu CT, Karp C, Woldorff MG (2007) Face processing is gated by visual spatial attention. *Front Hum Neurosci* 1:10
- Dell'Acqua R, Sessa P, Jolicoeur P, Robitaille N (2006) Spatial attention freezes during the attention blink. *Psychophysiology* 43:394–400
- Downing P, Liu J, Kanwisher N (2001) Testing cognitive models of visual attention with fMRI and MEG. *Neuropsychologia* 39(12):1329–1342
- Eimer M (1998) Does the face-specific N170 component reflect the activity of a specialized eye processor? *Neuroreport* 9:2945–2948
- Eimer M (2000) The face-specific N170 component reflects late stages in the structural encoding of faces. *Neuroreport* 11:2319–2324
- Farah MJ (1996) Is face recognition 'special'? Evidence from neuropsychology. *Behav Brain Res* 76(1–2):181–189
- Farah MJ, Wilson KD, Drain HM, Tanaka JR (1995) The inverted face inversion effect in prosopagnosia: evidence for mandatory, face-specific perceptual mechanisms. *Vision Res* 35(14):2089–2093
- Furey ML, Tanskanen T, Beauchamp MS, Avikainen S, Uutela K, Hari R, Haxby JV (2006) Dissociation of face-selective cortical responses by attention. *Proc Natl Acad Sci USA* (103)4:1065–1070
- Grave de Peralta Menendez R, Murray MM, Michel CM, Martuzzi R, Gonzalez Andino SL (2004) Electrical neuroimaging based on biophysical constraints. *Neuroimage* 21(2):527–539
- Holmes A, Vuilleumier P, Eimer M (2003) The processing of emotional facial expression is gated by spatial attention: evidence from event-related brain potentials. *Brain Res Cogn Brain Res* Apr 16(2):174–184
- Itier RJ, Taylor MJ (2004) Source analysis of the N170 to faces and objects. *Neuroreport* 15(8):1261–1265
- Jackson MC, Raymond JE (2006) The role of attention and familiarity in face identification. *Percept Psychophys* 68(4):543–557
- Jolicoeur P (1999) Concurrent response-selection demands modulate the attentional blink. *J Exp Psych: HPP* 25:1097–1113
- Jolicoeur P, Sessa P, Robitaille N (2006) On the control of visual spatial attention: evidence from human electrophysiology. *Psychol Res* 70:414–424
- Kok A (2001) On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology* 38(3):557–577
- Kranczioch C, Debener S, Engel AK (2003) Event-related potential correlates of the attentional blink phenomenon. *Brain Res Cogn Brain Res* 17(1):177–187
- Landau AN, Bentin S (2008) Attentional and perceptual factors affecting the attentional blink for faces and objects. *J Exp Psychol Hum Percept Perform* Aug 34(4):818–830
- Lavie N, Ro T, Russell C (2003) The role of perceptual load in processing distractor faces. *Psychol Sci* 14(5):510–515
- Lehmann D, Skrandies W (1984) Spatial analysis of evoked potentials in man—a review. *Prog Neurobiol* 23:227–250
- Lehmann D, Pascual-Marqui RD, Michel CM (2009) EEG microstates. *Scholarpedia* 4(3):7632
- Luo W, Feng W, He W, Wang N, Luo Y (2009) Three stages of facial expression processing: ERP study with rapid serial visual presentation. *Neuroimage* 49:1857–1867
- Mack A, Pappas Z, Silverman M, Gay R (2002) What we see: inattention and the capture of attention by meaning. *Conscious Cogn* 11:488–506
- Michel CM, Seeck M, Landis T (1999) Spatiotemporal dynamics of human cognition. *News Physiol Sci* 14:206–214
- Michel CM, Thut G, Morand S, Khateb A, Pegna AJ, Grave de Peralta R (2001) Electric source imaging of human brain functions. *Brain Res Brain Res Rev* 36(2–3):108–118
- Michel CM, Murray MM, Lantz G, Gonzalez S, Spinelli L, Grave de Peralta R (2004) EEG source imaging. *Clin Neurophysiol* 115(10):2195–2222
- Oldfield RC (1971) The assessment and analysis of handedness: the Edinburgh Inventory. *Neuropsychologia* 9:97–113
- Pascual-Marqui RD, Michel CM, Lehmann D (1995) Segmentation of brain electrical activity into microstates: model estimation and validation. *IEEE Trans Biomed Eng* 42(7):658–665
- Pegna AJ, Khateb A, Spinelli L, Seeck M, Landis T, Michel CM (1997) Unraveling the cerebral dynamics of mental imagery. *Human Brain Mapp* 5:410–421
- Pourtois G, Delplanque S, Michel C, Vuilleumier P (2008) Beyond conventional event-related brain potential (ERP): exploring the time-course of visual emotion processing using topographic and principal component analyses. *Brain Topogr* 20(4):265–277
- Raymond JE, O'Brien JL (2009) Selective visual attention and motivation: the consequences of value learning in an attentional blink task. *Psychol Sci* 20(8):981–988
- Raymond JE, Shapiro KL, Arnell KM (1992) Temporary suppression of visual processing in an RSVP task: an attentional blink? *J Exp Psychol Hum Percept Perform* 18(3):849–860
- Rolke B, Heil M, Streb J, Hennighausen E (2001) Missed prime words within the attentional blink evoke an N400 semantic priming effect. *Psychophysiology* 38(2):165–174
- Sergent C, Dehaene S (2004) Is consciousness a gradual phenomenon? Evidence for an all-or-none bifurcation during the attentional blink. *Psychol Sci* 15(11):720–728
- Sergent C, Baillet S, Dehaene S (2005) Timing of the brain events underlying access to consciousness during the attentional blink. *Nat Neurosci* 8(10):1391–1400
- Shapiro KL, Arnell KM, Raymond JE (1997) The attentional blink. *Trends Cogn Sci* 1(8):291–296
- Spinelli L, Andino SG, Seeck M, Michel CM (2000) Electromagnetic inverse solutions in anatomically constrained spherical head models. *Brain Topogr* 13(2):115–125
- Thierry G, Martin CD, Downing P, Pegna AJ (2007a) Controlling for interstimulus perceptual variance abolishes N170 face selectivity. *Nat Neurosci* 10:505–511

- Thierry G, Martin CD, Downing P, Pegna AJ (2007b) Controlling for interstimulus perceptual variance abolishes N170 face selectivity. *Nat Neurosci* 10(4):505–511
- Vaughan HG Jr (1982) The neural origins of human event-related potentials. *Ann N Y Acad Sci* 388:125–138
- Vogel EK, Luck SJ, Shapiro K (1998) Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. *J Exp Psychol Hum Percept Perform* 24:1656–1674
- Vuilleumier P (2000) Faces call for attention: evidence from patients with visual extinction. *Neuropsychologia* 38:693–700