

## Dissociable top-down anticipatory neural states for different linguistic dimensions

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### Abstract

When preparing to perform a task, the brain settles into task-set states which are relevant for the selection of the appropriate task-rules and stimulus-response mappings. The way this selection takes place within the Language domain is not well understood. We used high-density electrophysiological recordings while participants were engaged in a task in which cues directed their attention to the orthography, phonology or semantics of upcoming target words (or to the shape of novel symbols). To study the specificity of the brain preparatory states to different goals within the language domain, we contrasted the topographical maps associated with the cues for these different tasks, and explored whether the need of task-set reconfiguration modulated this preparatory activity. As a complement to the topographical analyses, we compared the amplitude of the cue-locked ERPs across task conditions. The topographical maps differed only at the end of the epoch. During this time window, each task-cue generated distinct topographical activity, which was also different depending on whether it involved a switch in task-set or not. These results suggest that, when the time of target onset approaches, the generators of anticipatory-biasing brain states for different language tasks vary depending on the nature of the task.

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The ability to guide our behavior according to the rules of the task at hand is a fundamental skill that allows humans to adapt to a changing environment. Attention mechanisms aid this function by prioritizing and enhancing those processes and/or representations that are relevant for the current goal, at the expense of competing information (see Itti, Rees, & Tsotsos, 2005; Posner, 2004). Attention can be focused on several different types of information, ranging from perceptual (e.g. Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1990; Coull, Frith, Buchel, & Nobre, 2000; Hillyard, Hink, Schwent, & Picton, 1973) to abstract representations (Cristescu, Devlin, & Nobre, 2006; see Posner, 2004 for an overview). On the other hand, the cognitive system of Language is a uniquely human, highly practiced skill, often claimed to be encapsulated from other cognitive systems (Fodor, 1983), and highly 'automatic' (Posner, 1978). However, while there are many examples showing that language can be influenced by task settings or attention (e.g. Bitan et al.,

2005; Cherry, 1953; Fuentes, Carmona, Agis, & Catena, 1994; Gitelman, Nobre, Sonty, Parrish, & Mesulam, 2005; McCarthy & Nobre, 1993; Ruz, Wolmetz, Tudela, & McCandliss, 2005), the mechanisms used to control language processing functions are not well understood. To advance our knowledge of this topic, the study presented in this paper used high-density electrophysiological methods to explore whether the preparatory activity generated by task cues varied depending on the nature of the task performed and on the need to reconfigure task settings from the previous trial. Such dissociation would suggest that cues directing attention to different language representations (or to non-linguistic symbols) are able to settle the brain into specific preparatory states even before the target is presented.

Different types of brain recordings have been used to explore the brain mechanisms engaged by attention cues while participants performed several kinds of tasks. Measurements explored both the preparation time prior to target presentation, as well as the modulations induced by the cue on subsequent stimuli processing (Chawla, Rees, & Friston, 1999). Currently in the literature, space or spatially laden attributes have been the most extensively explored. All cues, regardless of their

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nature, engage regions in a frontoparietal axis, including posterior parietal and frontal eye fields, together with other areas specific to the dimension signaled by the cue (Nobre, 2004). In some cases, attention generates a baseline shift or preparatory activity thought to be related to signal enhancement at the attended locations and/or suppression of ignored stimuli (Chelazzi, Miller, Duncan, & Desimone, 1993; Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999; Luck, Chelazzi, Hillyard, & Desimone, 1997; Serences, Yantis, Culbertson, & Awh, 2004; Thut, Nietzel, Brandt, & Pascual-Leone, 2006; Worden, Foxe, Wang, & Simpson, 2000). When the targets are presented, it is common to observe increased accuracy and faster reaction times to attended attributes compared to unattended ones, indicating that attended dimensions are processed more efficiently (Posner, 1980).

The excellent temporal resolution of the Event Related Potential (ERP) technique has been exploited to observe the timing of cue-generated shifts of attention to relevant spatial locations or tasks (see Luck, 2005 for a summary of the temporal profile of attention effects upon target processing). Symbolic cues directing attention to the location of visual, auditory or tactile spatial locations (Eimer & Van Velzen, 2002; Green & McDonald, 2006; Harter, Miller, Price, LaLonde, & Keyes, 1989; Nobre, Sebestyen, & Miniussi, 2000; van Velzen & Eimer, 2003; Yamaguchi, Tsuchiya, & Kobayashi, 1995) generate enhanced negativities in frontal electrodes, contralateral to the attended side, from about 300–500 ms (Anterior Directing Attention Negativity, ADAN). These cues also generate enhanced positivities in posterior contralateral electrodes starting at 500 ms (Late Directing Attention Positivity, LDAP). In addition, some of these studies reported additional modulations starting as early as 160 ms after cue presentation (Early Directing Attention Negativity, EDAN, Harter et al., 1989; Nobre et al., 2000; Talsma, Slagter, Nieuwenhuis, Hage, & Kok, 2005). These, however, could reflect spatial selection within the cue features rather than orienting of attention to the target location (van Velzen & Eimer, 2003). Other studies have used symbolic cues to provide advance information about the task that is to be performed on the target (Miniussi, Marzi, & Nobre, 2005). The authors found task modulations already in the N1 component, which was more negative for a cue predicting a verbal task (compared to a spatial task). Together, these data suggest that, at least under certain circumstances, task sets can affect brain activity from an early point in time after cue presentation.

Attention cues providing advance information about the upcoming task have also been used to explore the brain correlates of preparation for task switching. When participants are performing a given task and they have to switch to a different one, their responses are typically less accurate and slower than when the set is repeated (Allport, Styles, Hsieh, 1994). This behavioral cost remains even when participants are given advance information allowing them to prepare for an upcoming switch (Rogers & Monsell, 1995). Task-switching is one of most extensively used paradigms to study executive processes (Monsell, 2003). Despite being a very active area of research, currently there does not seem to be a general agreement about the nature of the so-called ‘switching-costs’. Proponents of ‘task-

set’ reconfiguration hypotheses state that such costs reflect the extra time needed by executive processes to reconfigure the system to engage in a new task (Meiran, 1996; Rogers and Monsell, 1995). In contrast, ‘task-set inertia’ models emphasize the persisting interference that the previous task exerts on the current one (Allport et al., 1994; Allport & Wylie, 1999). Neuroimaging results show that switch trials generate higher activation in several brain areas, including ventrolateral prefrontal cortex, anterior cingulate, supplementary motor area and inferior and superior portions of the parietal cortex, compared to repeat trials (Crone, Wendelken, Donohue, & Bunge, 2006; Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000; Rushworth, Hadland, Paus, & Sipila, 2002). When analyses are restricted to the brain activations generated by the preparatory cues, it has been often reported that there are no substantial differences in the pattern of brain activation that they generate (Brass & von Cramon, 2002, 2004; Gruber, Karch, Schlueter, Falkai, & Goschke, 2006; Ruge et al., 2005). This finding has been used to claim that the same set of preparation processes could be taking place regardless of whether the cue codes for a switch or a task repetition (although see Rushworth et al., 2002). In addition, the temporal profile of such processes has been uncovered using ERPs. Results have repeatedly shown cue-related switch modulations in frontal (Aistle, Jackson, & Swainson, 2006; Miniussi et al., 2005; Perianez et al., 2004; Rushworth, Passingham, & Nobre, 2005) and/or parietal electrodes (Swainson, Jackson, & Jackson, 2006; Wylie, Javitt, & Foxe, 2003), which in many cases were sustained until the presentation of the target (Wylie et al., 2003).

A few studies have explored task switching in the language domain, which employed changes in either the receptive or productive language of bilingual participants (e.g. Jackson, Swainson, Mullin, Cunningham, & Jackson, 2004; Price, Green, & von Studnitz, 1999). Studies have shown that switching the language strongly influences target-locked ERPs such as the N2 or the LPC (Jackson, Swainson, Cunningham, & Jackson, 2001). However, to date no experiment has studied the topographical dynamics of cue preparation for specific language tasks.

We aimed to explore the specificity of the brain activations related to different task-goals within the Language system, and the potential effect of task-reconfiguration mechanisms on these control functions. For this, we exploited the topographical information inherent in high-density electrophysiological data to obtain maps of the topographic distribution that allowed us to compare effects across tasks. This methodology can be used to infer whether two conditions engage differentiable brain generators (Lehmann, 1987) during specific time windows. We focused our comparisons to explore the possibility that task cues generated specific preparatory activity that differed across conditions. As mentioned above, attention may modulate brain activity according to task goals *before* the target stimuli appear (e.g. Chawla et al., 1999). Such preparatory activity might involve partially distinct brain generators depending on the nature of the upcoming task and the need to reconfigure the setting from the previous trial. Comparing the electrical field maps generated by the cues before target presentation, could reveal whether this pre-stimulus activity is the same across conditions or whether it differs depending on the task performed with the upcoming

target. This latter result would suggest that attention engages partially different brain regions during the expectation period. We also performed complementary analyses of modulations in the voltage amplitudes across conditions. These allowed us to explore the time course of task-set implementations that were not necessarily reflected in changes of brain generators uncovered by the topographical analyses.

With these goals in mind, we developed a paradigm that cued the task-set of participants to Orthographic, Phonological or Semantic representations of visually presented words. As a control condition, participants judged the shape of visually similar symbols. The paradigm held the perceptual nature of the cues constant, used the same words in all language conditions, and yielded equivalent behavioral measures across tasks.

## 1. Methods

### 1.1. Participants

Twenty-six students (19–27 years, 10 males) were recruited from the University of Oxford community. All were right-handed native English speakers with normal or corrected-to-normal vision. They all signed a consent form approved by the University of Oxford Research Ethics Committee and received payment in exchange for their participation.

### 1.2. Stimuli and procedure

Task-set cues were composed by the letters M,S,L and the symbol #, which appeared in a row at the centre of the screen. The position of the characters in the sequence was constant for each participant, but was counterbalanced across participants. Each character in the cue was colored either in red, blue, green or yellow (see Fig. 1). Participants were asked to use the instructions coded by the letter in a specific color in the cue (counterbalanced across participants) to direct their attention. The colors changed from trial to trial, and instructed participants about the task they had to perform on the upcoming target. When the L was presented in the color relevant for the participant, they prepared to perform a task with the Letters (decide whether the underlined letter is a consonant or a vowel). The character S prepared them to respond to the Sound of the word (judge whether the word has one or two syllables), and the M to their Meaning

(decide whether the word represents something natural or man-made). The # character indicated the Symbols task (decide whether the underlined symbol in the string has a symmetrical or asymmetrical shape).

Eighty 5-letter concrete words (526 average Familiarity and 43.8 average Kucera Frequency) were selected as targets for the language (Orthographic, Phonological and Semantic) tasks. A short bar underlined one of the letters in each word. For half of the words, the underlined letter was a consonant, and for the other half it was a vowel. Forty words were monosyllabic and the other 40 were bisyllabic. Half of the words represented a natural item and the other half corresponded to a man-made object. Such orthographic, phonological and semantic characteristics of the words were orthogonal. In order to create a set of symbols as similar as possible to words, we rearranged the different parts of individual letters to form 20 symbols with either a symmetrical or an asymmetrical shape (see Fig. 1). We then arranged these letter-sized symbols in 40 five-symbol strings, half of which had a symmetrical symbol underlined and the other half an asymmetrical one. All words were used twice in each language tasks. In total, participants saw each word six times and each symbol string four times. No word or symbol was repeated until all items had been presented once. Participants used the index finger of their right and left hands to press one of two buttons on the keyboard to make speeded choice responses for each of the tasks. The response assignment was counterbalanced across participants.

Stimuli were displayed on a PC controlled by Presentation 0.70. Each trial comprised the following events (see Fig. 1). After a fixation point (+; 0.3°) of variable duration (1500–2500 ms), a cue (1.7°) was flashed in the centre of the screen for 200 ms. During another variable interval (1300–2300 ms), the fixation point was displayed and then either an uppercase word or a symbol string (1.7°) was presented in the same position for 200 ms. Participants were allowed 3000 ms to respond, and received auditory feedback (50 ms) after incorrect responses or misses. On average, a trial lasted 7 s. Participants were asked to refrain from blinking and moving except during the intervals displaying the fixation point between trials. In total, there were 640 trials (160 per condition), grouped in blocks of 40 trials. Participants were allowed to rest between blocks. Before the main task, participants performed a short training session (10 min) to become familiar with the task. The whole EEG recording session lasted about 1 h and a half.

### 1.3. EEG acquisition and analyses

EEG data were collected over 128 electrodes with the Biosemi recording system, which uses active electrodes (Biosemi, Amsterdam, The Netherlands), at a 2048 Hz digitation rate (417 Hz bandwidth). Data were recorded relative to a common average. Vertical and horizontal oculoogram activity was additionally recorded by means of four electrodes: two above and below the left eye and two at the outer canthi of the eyes. EEG was transformed off-line with a 30 Hz lowpass filter (6 db/oct), referenced to Cz and epoched. Such epochs encompassed 200 ms before and 1500 ms after cue presentation (1501 ms was the earliest time point in which a target could be presented). Epochs containing blinks (thresholded at 70  $\mu$ V in the eye channels) or other artefacts (100  $\mu$ V threshold in all channels) were discarded. To explore the effects of task preparation generated by the cues, epochs were averaged according to the task cued (Orthographic, Phonological, Semantic or Symbol). As an additional analysis strategy, epochs were separately averaged according to whether the cued task was repeated or switched from the previous trial, collapsed across tasks. To prevent spurious effects in the ERPs related to different trial number across the switch and repeat conditions (task repetitions happened only in 1/4 of trials on average), only 1/3 of randomly chosen switch trials were included in each switch-average file. In all cases, after averaging, bad channels (containing excessive noise or drift) were interpolated using a spline-transformation (Perrin, Pernier, Bertrand, Giard, & Echallier, 1987) and then data were transformed to an average-reference.

We used two complementary approaches to analyze the data. First, the averaged files were submitted to a segmentation analysis performed with Cartool software, developed by Denis Brunet (<http://brainmapping.unige.ch/Cartool.php>). In a first step of this topographical analysis, we used a clustering method to find, at the level of the group-average data, the set of topographies which were predominant for each experimental condition as a function of time (see Foxe, Murray, & Javitt, 2005; Murray, Foxe, Javitt, & Foxe, 2004a,b; Murray et al., 2004a,b; Thierry, Martin, Downing, & Pegna, 2007). Scalp topographies

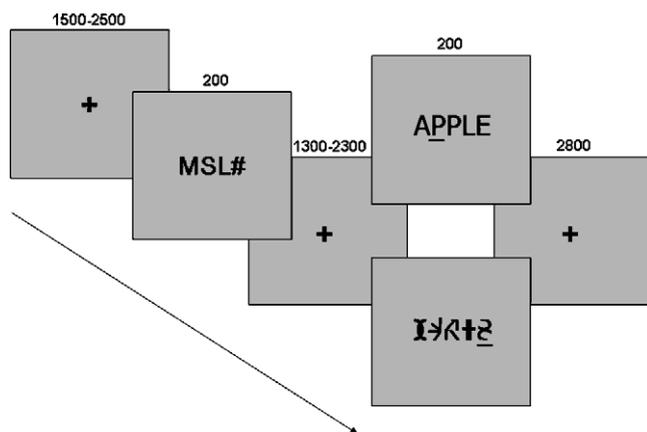


Fig. 1. Display of sequence of events during a trial. The task cue was briefly presented after a fixation point of variable duration. The color of the characters in the cue, M,S,L and #, was either red, blue, green or yellow and changed unpredictably from trial to trial, instructing the participants which task to perform on the target. After a variable 1300–2300 ms interval, the target was flashed for 200 ms. Participants had 3 s to respond. The arrow represents the direction of time.

do not vary randomly, but rather remain in a stable configuration for a period of time and then change to a different configuration. The segmentation approach finds such periods of stability in the map representation of the normalized ERPs (with the constraint that maps should remain stable for at least 20 ms and that the correlation between different maps should not be lower than 92%) and computes the average map for each of these stable periods. These stable maps are thought to represent computational stages of information processing, or functional microstates of the brain. Along the same lines, differences between maps indicate differences in the underlying brain sources (Lehmann, 1987). Variations in the amplitude of the signal between conditions do not affect results because data are normalized before comparisons. The number of maps that best explains the whole group-averaged data set is defined by a cross-validation criterion (Pascual-Marqui, Michel, & Lehmann, 1995). In a second step of the topographical analysis, we tested whether differences across conditions were significant at the single-subject level. To do so, we fitted the group-average maps results to the scalp topography of each participant. During this fitting procedure, data of each individual subject from each experimental condition are compared with the maps identified at the group-average level, using a spatial correlation. Each time point of the data of each participant is then labeled with the map with which it has the highest spatial correlation. This procedure thus allows a quantification of map presence per participant and task condition. These values were submitted to within-subject ANOVAS together with the experimental conditions of interest. An interaction involving the factor map would indicate that a certain task condition is better explained by one map vs. another, and hence that a different configuration of brain generators better explains the results (see Murray, Imber, Javitt, & Foxe, 2006 for a detailed description of the segmentation procedure).

Additionally, we tested for differences in the amplitude of the ERPs across the four task conditions. For this, we selected symmetrical sets of contiguous electrodes in medial, left and right frontal and parietal regions of the scalp, which on an initial visual inspection seemed to reflect task effects on the amplitude of the voltage (see Fig. 5). We then calculated the average amplitude on the selected electrodes across conditions over the time windows revealed by the segmentation process, which represent periods of stability in the recorded electrophysiological signal. These average values were then compared across the relevant conditions. Where appropriate, the degrees of freedom were modified according to the Greenhouse–Geisser correction to compensate for the non-sphericity in the EEG data. Only results that fulfil the  $p \leq 0.05$  significance criterion are reported.

## 2. Results

### 2.1. Behavioral

Although only ERP data pertaining to the task cues are presented in this paper, we report the statistical analyses of the responses to the targets to give an estimate of main behavioural effects. Two participants were removed from the study, one due to chance performance in the phonological task and the other due to excessive eye blinks throughout the session. For the remaining 24 participants, Reaction Time (RT) and accuracy values were introduced into an ANOVA with the factors Task (Orthographic, Phonological, Semantic and Symbols) and Switch (Switch, Repeat). Tasks were equal in terms of RT (average 1095 ms,  $F_{3,21} = 1.29$ ;  $p = 0.3$ ) and Accuracy (mean 90%,  $F_{3,21} = 2.03$ ;  $p = 0.13$ ). Task switching slowed responses ( $F_{1,23} = 39.52$ ,  $p < 0.001$ ) and did not significantly affect accuracy ( $F_{1,23} = 3.79$ ,  $p = 0.064$ ). The interaction between Switch and Task was significant ( $F_{3,21} = 3.04$ ,  $p = 0.05$ ), as the switch costs were larger for the Orthographic task than for the Semantic, Phonological and Symbol tasks (138 ms vs. 72, 84 and 74 ms respectively; see Fig. 2).

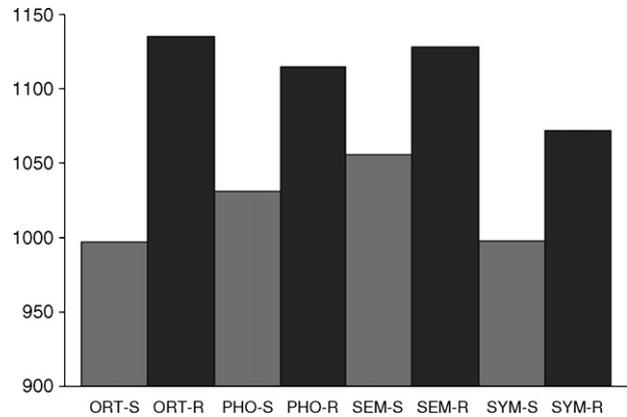


Fig. 2. Mean RT for all task switch (S) and repeat (R) trials. Ort stands for Orthography, Pho for Phonology, Sem for Semantics and Sym for Symbols.

## 3. Electrophysiological

### 3.1. Task effects

After data processing, the average number of trials per task condition was 93, and did not differ across cue types ( $F < 1$ ; see Fig. 3). The segmentation analysis showed that 11 different topographies explained the 95.9% variance of the ERP associated with the four task conditions (displayed and described in Fig. 4). Seven maps were common across cue types, and four of them were distinct to each of them. Maps elicited by all types of cues had a short duration at the beginning of the epoch, which increased gradually towards the end of the segment. All cues generated the same topographic maps until the latest phase before target appearance, starting around 1235 ms. During this late period of target expectancy, each of the cue types generated an electrical activity that was best represented by different maps. To test the reliability of the distinctness of topographies for each condition, the four maps in this late phase were introduced into a fitting procedure with each individual data. The estimation of map presence per condition per subject obtained from this fitting procedure from 1235 to 1500 ms was introduced into an ANOVA with the factors Task (4) and Map (4). The interaction between Task and Map was significant ( $F_{9,15} = 4.2$ ,  $p < 0.001$ ). To further test the differences between each possible pair of task conditions, the fitting data was introduced into 6 ANOVAS with the factors Task (2) and Map (2). All differences between paired conditions were reliable during this epoch, as shown by the significant interactions between these two factors (all  $F_s > 11$ ; all  $p_s < 0.005$ ; see Fig. 4). Data from the immediately preceding time window, from 1125 to 1235 ms showed no significant interaction between Task and Map ( $F_{9,15} = 1.86$ ,  $p > 0.13$ ).

In a second step, we explored whether task reconfiguration affected the topographical maps generated by the cues. Note that, as mentioned in Section 1, this task-switch analysis was performed over a different averaged data set, which only included 1/3 of randomly selected switch trials to equate the number of observations across switch and stay conditions. These ERPs had 108 trials on average, which were the same across conditions ( $F < 1$ ). The task-switch and repeat conditions, col-

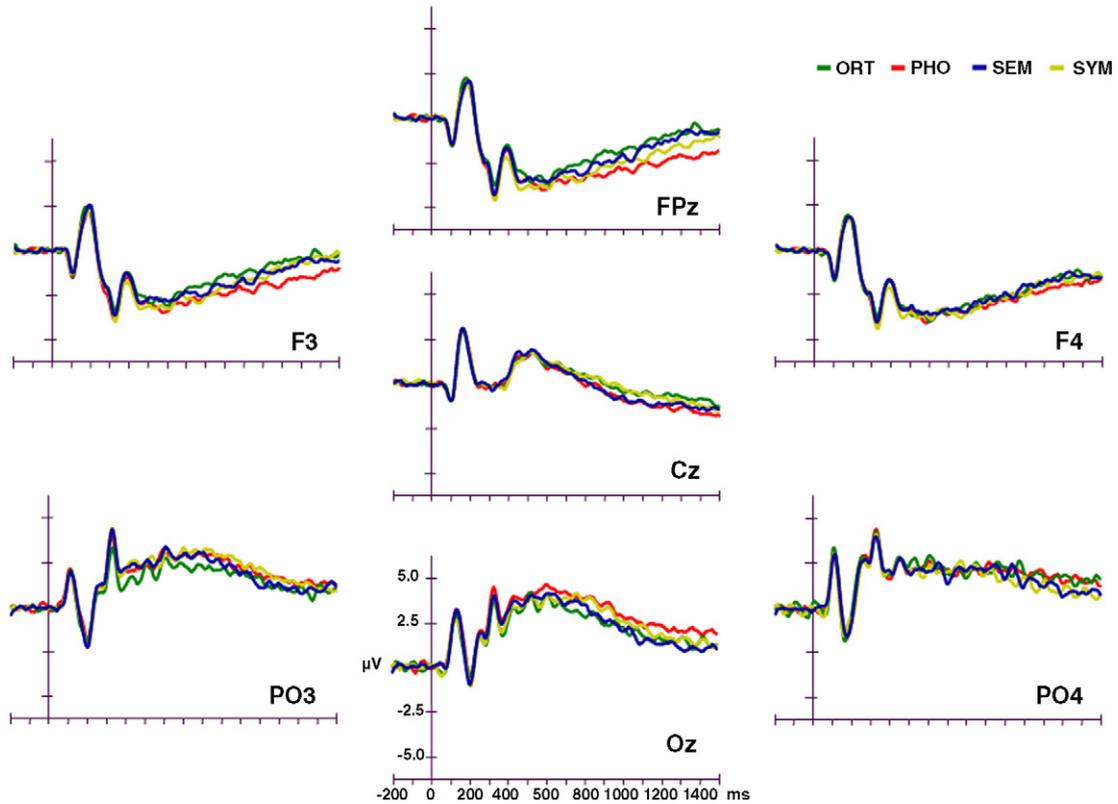


Fig. 3. Representative electrodes displaying the cue-locked ERPs for the four task conditions, from  $-200$  to  $1500$  ms. Zero represents the time of cue presentation.

lapsed across tasks, were described by 9 topographical maps explaining 95.4% of the global variance (see Fig. 5). As in the previous analysis, the duration of the maps was much shorter at the beginning of the epoch and extended for longer periods towards the end. Switch and repeat conditions shared the same maps throughout the epoch until approximately 1125 ms,

after which they were better explained by different maps. To test for differences between switch and repeat conditions, we introduced the fitting data of the two last intervals, from 1125 to 1235 ms and from 1235 to 1500 ms into two separate 2 (Switch vs. Repeat) by 2 (Maps) ANOVAs. The interactions of interest, between Switch and Map, were significant during both

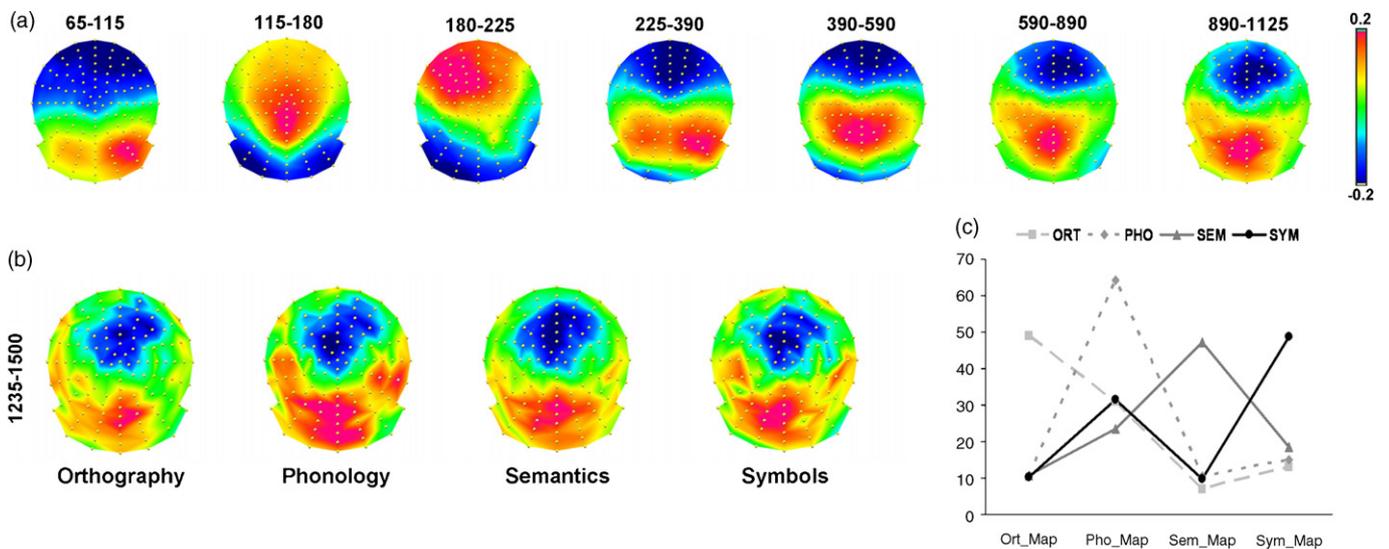


Fig. 4. 2D topographical maps explaining the whole epoch of the task-related ERPs generated by the cue. (a). Sequence of maps common to all conditions. The first map corresponds to the P1 window and presents a main positivity in the back and a negativity in anterior regions. This polarity is reversed in the following two maps. In all the remaining maps, posterior regions show positive voltages and anterior locations negative ones, although the distribution of these effects changes across maps. (b). Four different maps associated with the four task conditions at the end of the epoch. (c). Graphical display of the results of the fitting process. The Y-axis represents the percentage of times each of the maps was dominant in each of the four task conditions.

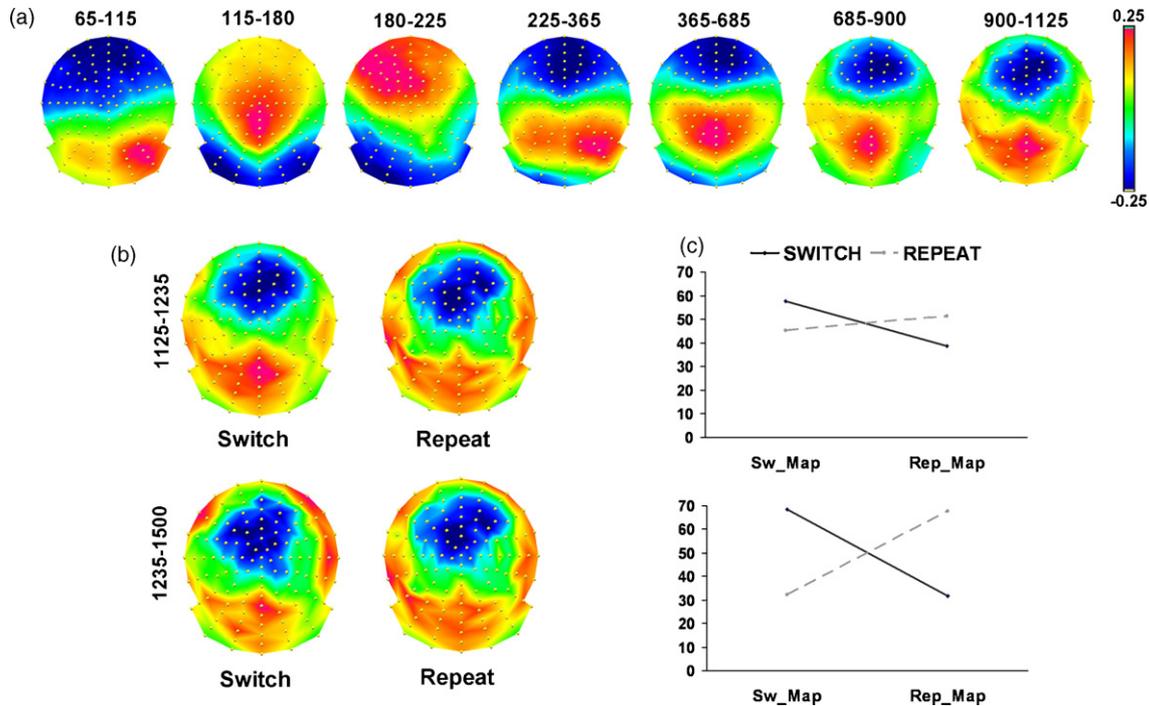


Fig. 5. 2D topographical maps explaining the ERPs generated by the cue according to the Repeat or Switch conditions during different time windows. (a). Sequence of maps common to all conditions. (b). Maps associated to the four task conditions at the two last windows of the epoch. (c). Graphical display of the results of the fitting process during both time windows. The Y-axes represent the percentage of times the maps were dominant in each of the Switch and Repeat conditions.

epochs, ( $F_{1,23} = 4.36, p < 0.05$  and  $F_{1,23} = 17.15, p < 0.001$ ; see Fig. 5).

Finally, to explore the time course of modulations in the voltage of task-cue waveforms, we analyzed the task-related effects in the ERPs during all the temporal windows revealed by the segmentation analyses. For this, we introduced the average voltage of the electrodes in left, central, right anterior and posterior locations into 4 (Task) by 6 (Electrode Group Location) ANOVAs (see Fig. 6). The first time window in which

the interaction of task and electrode location reached significance levels was from 1125 to 1235 ms, ( $F_{3,68,84.81} = 3.04, p < 0.05$ ). In left posterior regions (task effect  $F_{2,16,49.71} = 4.17, p < 0.05$ ), the voltages were more negative for the Orthographic than for the Phonological ( $F_{1,23} = 21.08, p < 0.001$ ), or Symbol ( $F_{1,23} = 7.77, p = 0.01$ ) tasks. In medial posterior regions (task effect  $F_{1,95,44.92} = 3.16, p < 0.05$ ), the voltage of the Semantic task was more negative than the Phonological ( $F_{1,23} = 6.67, p < 0.05$ ). In left frontal regions (task effect  $F_{2,37,54.63} = 3.27,$

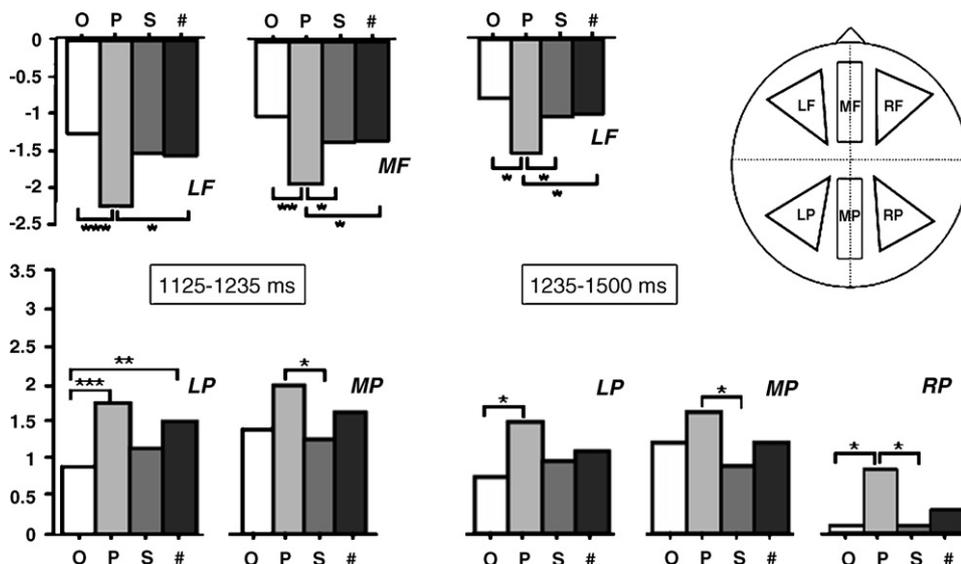


Fig. 6. Summary of the voltage ( $\mu V$ ) differences in the ERPs associated with the different types of cues (O: orthographic, P: phonological, S: semantic, #: symbols) in different regions of the scalp (LP: left posterior; MP: medial posterior; RP: right posterior; LF: left frontal; MF: medial frontal, RF: right frontal). The model head depicts the location of the electrodes entered into the ANOVA analyses.

$p < 0.05$ ), the ERP of the Phonological task was more negative than that of the Orthographic ( $F_{1,23} = 19.17, p < 0.001$ ), or the Symbol ( $F_{1,23} = 5.76, p < 0.05$ ) tasks. In medial frontal areas (task effect  $F_{2,79,64.19} = 4.71, p < 0.01$ ), the ERP of the Phonological task was more negative than the Orthographic ( $F_{1,23} = 14.31, p = 0.005$ ), Semantic ( $F_{1,23} = 6.30, p < 0.05$ ) or Symbol ( $F_{1,23} = 6.11, p < 0.05$ ) conditions. During the last interval, from 1235 to 1500 ms, task and electrode location interacted again ( $F_{5,29,121.68} = 2.64, p < 0.05$ ). The task was significant in left ( $F_{2,23,51.31} = 3.15, p < 0.05$ ), medial ( $F_{2,68,61.79} = 2.84, p = 0.05$ ), and right posterior ( $F_{2,78,64.06} = 2.84, p = 0.05$ ) areas, and left frontal ( $F_{2,86,65.92} = 4.84, p < 0.005$ ) electrodes. The voltage of the Orthographic task was more negative than that of the Phonological in left posterior electrodes ( $F_{1,23} = 17.34, p < 0.001$ ), the Semantic more negative than the Phonological in medial posterior areas ( $F_{1,23} = 7.19, p = 0.01$ ), the Phonological more positive than the Orthographic ( $F_{1,23} = 5.19, p < 0.05$ ), and Semantic ( $F_{1,23} = 6.61, p < 0.05$ ) conditions in right posterior regions, and also the Phonological more negative than the Orthographic ( $F_{1,23} = 12.73, p = 0.001$ ), Semantic ( $F_{1,23} = 6.59, p < 0.05$ ), or Symbol ( $F_{1,23} = 8.28, p < 0.01$ ) tasks in left frontal electrodes (see Fig. 4 for a summary of the results).

#### 4. Discussion

Our study aimed to explore the preparatory brain activity related to attentional control for different language functions, compared to novel symbol processing. We contrasted the top-down task sets used by the brain to prepare for different upcoming language tasks and explored how switching between tasks affected this preparation. We measured electrophysiological brain activity while participants were engaged by cues directing their attention to the Orthographic, Phonological and Semantic dimensions of upcoming words (or the shape of novel symbols). We analyzed the topographic distribution generated by cues inducing the different task sets and also investigated how task-reconfiguration affected these topographies. In addition, the amplitude analysis of the ERP waveforms offered information about the time-course of task-set configuration processes.

##### 4.1. Task-related preparatory brain activity

In our study, cues instructing participants to prepare for different tasks with words or novel symbols generated a series of brain activations reflected in topographical maps that were dissociable during the latest part of the epoch. During this late time window, from 1235 to 1500 ms, the segmentation analysis showed that differences in the waveforms corresponded to separable topographical maps, which were further dissociable between each pair of tasks.

Cues were perceptually equated across participants, both in terms of the color of the different characters (i.e. which color the participants used to direct their attention) and also in terms of the spatial location of the cue elements. While the character position remained constant for each person, across participants they all were presented in all possible spatial positions. This is a relevant control for ERP studies of attention as it has been

previously reported that minor differences in the spatial location of relevant cue elements may lead to cue-selection effects that could, in principle, be confounded with early attentional orienting processes (van Velzen & Eimer, 2003). In addition, the effects cannot be explained in terms of the general preparation for tasks that entail different levels of difficulty, as tasks were equal both in terms of accuracy and RT<sup>1</sup>. Therefore, the results are likely to reflect differences in the intrinsic characteristics of the tasks employed, rather than cue perceptual factors or unspecific differences in difficulty.

Overall, the findings suggest that the brain prepares in advance, in a manner specific to each condition, for the different upcoming word tasks, in the absence of visual stimulation. It is not clear, however, which processes are actually being initiated by the cue. As we have argued, cues may direct attention to different levels of linguistic representations, in preparation for the upcoming target. In addition, cues could also activate the appropriate stimulus to response associations. In the domain of spatial attention, preparatory processes have been interpreted to reflect a top-down signal that feeds back from higher order to lower order brain areas (e.g. Kastner & Pinsk, 2004). For example, Kastner, De Weerd, Desimone, & Ungerleider (1998) directed the attention of participants to either left or right regions of space in expectation for checkerboards over which they had to perform subtle detections. Before the target was presented, BOLD activity increased in striate and extrastriate visual areas, and this activation was further increased by the presentation of the target stimuli. Such modulations during the baseline period have also been shown with single-cell recordings (Chelazzi et al., 1993; Luck et al., 1997). The function of this preparatory activity is unclear, but some reports show that it may actually be related to the efficiency with which participants perform the task. For example, Stern and Mangels (2006) measured the preparatory activity generated by a cue that instructed participants about the interfering dimension (word meaning or space) in a Stroop task. They found that preparatory activity in right frontal and central parietal regions was correlated with fast correct responses to Stroop word stimuli, an effect that was interpreted to reflect the more successful implementation of control processes in those trials (see also Serences et al., 2004). Unfortunately, the present paradigm was not designed to explore the relationship between preparatory activity and later task performance. However, given previous results and also the fact that different kinds of task cues generated differentiable preparatory activity, it is likely that such effects are somehow linked to task success. In addition, when we examined the ERPs linked to target processing in this paradigm, we observed that attention modulates the initial stages of word processing according to the task cue (Ruz & Nobre, *in press*). Attention to orthography enhances the N200 component,

<sup>1</sup> From an information processing point of view, it would seem reasonable that RTs to the Orthographic task were shorter than those of the Semantic, as the first is a prerequisite to the latter. Note, however, that the consonant-vowel judgement in the Orthographic task required the selection of the underlined letter, which was surrounded by distracters (i.e. the other letters in the word). This additional requirement may have slowed responses to make them equal to the other language conditions.

thought to reflect initial stages of orthographic analyses. Attention to phonology, on the other hand, modulates electrodes in left temporo-parietal regions around 200 ms, whereas semantic analyses enhance the N400 component. These early results suggest that the differential preparatory activity generated by the cues is not limited to selection of the appropriate stimulus-response mappings, but also influences early stages of visual word processing.

The brain activations generated by the cues in our study possibly reflect the combination of general preparatory and arousal mechanisms, common to all tasks, and specific settings for each of them. It is noteworthy that all cues generated statistically indistinguishable topographies at the beginning of the epoch. Such activations may reflect general processes of character selection within the cue and other decoding and unspecific preparatory processes. The statistically distinct cue-related topographies that take place at a later stage reflect both the brain activity which is shared across tasks and the activations specific to each of the conditions. In contrast to research that uses techniques with a good spatial resolution, such as fMRI, our electrophysiological analysis strategy is not well suited to compute reliable subtractions between conditions, or to point at possible neural substrates generating the differences. However, our results are highly informative regarding the *time* at which differential neural substrates are engaged. Topographical differences only arise by the time target onset approaches, which suggests that neural regions specific to each language (and symbol) set are engaged at this stage. Interestingly, the need to reconfigure the task settings from the previous trial only affects this later specific preparation stage. Starting at 1125 ms, the segmentation analysis showed that the topographical distribution of the effects was different for the switch and repeat condition. This result seems to support the involvement of different preparation processes in switch and stay conditions, but only in the late part of the epoch. As mentioned in the introduction, several fMRI studies have not found differential cue modulations in similar cue-target intervals using fMRI (i.e. Brass & von Cramon, 2004; Gruber & Goschke, 2004; Ruge et al., 2005). This stands in contrast to our results, which suggest differential brain activations for the switch and stay trials. This discrepancy could be related to the differences between paradigms used across the studies, or to the sensitivity of the different brain imaging techniques and/or analyses approaches. Our results support the notion that the preparatory brain states for performing an upcoming task are modulated depending on whether the task is the same or different from the previous trial, in agreement with other reports (Rushworth et al., 2002; Slagter et al., 2006). This would add support to models that propose that when relevant information is given, task reconfiguration processes can be brought into play before the target for the particular task is presented (e.g. Meiran, 1996). Moreover, the fact that the switch-related modulation in neural generators takes place during the pre-target preparatory period, and not during initial cue-decoding, is consistent with the idea that endogenous control processes can be initiated with task cues and need not to wait until target onset (Monsell, 2003).

In addition, we analyzed task-related modulations in the amplitude of the voltage of the ERPs which can be compared

with previous studies manipulating attention to spatial locations (e.g. Nobre et al., 2000; van Velzen & Eimer, 2003) or to space vs. language (Miniussi et al., 2005; Stern & Mangels, 2006). ERP amplitudes only differed across tasks in the late part of the epochs, during the same time window in which the segmentation analyses showed differences in topographies across conditions. Cues directing attention to a region of space show reliable modulations at 300 ms in anterior regions (ADAN), and starting at 500 ms in posterior electrodes contralateral to the cued side (LDAP). Furthermore, cues instructing participants to perform either a verbal or spatial task modulate the N1 component (Miniussi et al., 2005). The lack of early differences in our study could be due to the nature of the tasks used. Rather than focusing attention on spatial locations, our cues instructed participants to focus on abstract attributes of words (or the shape of symbols). Another relevant factor might be the long cue-target SOA (average 2000 ms) used in our study. This long interval may have not required a fast set-reconfiguration after cue onset. Instead these processes may have been delayed until the end of the epoch, when the probability of target appearance started to rise. In any case, late differences show modulation of preparatory brain activity according to the task at anterior and posterior regions, which is consistent with the results of the topographical analysis.

## 5. Conclusions

Results from the present study suggest that the brain enters dissociable preparatory states in a time window just a few hundred milliseconds prior to presentation of the particular task targets. This preparatory activity seems to vary according to the particular type of task that is to be performed upon the target and also depends on whether task settings need to be switched from the previous trial. Additional analyses show that task-settings affect the voltage of the ERPs at the same point in time. Currently, the functional role and location of the dissociable neural generators activated during the preparatory interval remain unclear. Such preparation signals are likely to reflect the activation of a common general arousal and vigilance system (which should be common across the different task-maps) plus the additional involvement of specific regions tuned to the different tasks employed. The modulation of pre-target activity according to the task cued, and its switch or repeat nature, suggests that part of the preparatory signals engages regions which are specific to the different task goals. These brain regions generating such specific activity could be related simply to preparation or biasing processes (such as working-memory subcomponents, for example) or could also be involved in actual target processing. More insights into this disjunctive will arise from the use of other brain recording techniques with a better spatial resolution than ERPs, such as fMRI.

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