

Brain dynamics associated with face-naming and the tip-of-the-tongue state

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Active brain areas and their temporal sequence of activation during the successful retrieval and naming of famous faces (KNOW) and during the tip-of-the-tongue (TOT) state were studied by means of low resolution electromagnetic tomographic analysis (LORETA) applied to event-related potentials. The results provide evidence that adequate activation of a neural network during the first 500 ms following presentation of the photograph —mainly involving the posterior temporal region, the insula, lateral and medial prefrontal areas and the medial temporal lobe— is associated with successful retrieval of lexical-phonological information about the person's name. Significant differences between conditions were observed in the 538-698-ms interval; specifically there was greater activation of the anterior cingulate gyrus (ACC) towards the supplementary motor area (SMA) in the KNOW than in the TOT condition, possibly in relation to the motor response and as a consequence of the successful retrieval of lexical-phonological information about the person.

Secuencia de actividad cerebral relacionada con la denominación de caras y el fenómeno de la punta de la lengua. Las áreas cerebrales más activas y su secuencia de activación durante el recuerdo y la denominación exitosa de caras (Condición SI) y durante el fenómeno de la punta de la lengua (Condición PDL) fueron estimadas a partir de potenciales evocados mediante tomografías electromagnéticas de baja resolución (LORETA). Los resultados muestran evidencia de que una adecuada activación de una red neural (estando principalmente implicadas áreas temporales posteriores, insula, áreas prefrontales mediales y laterales, y áreas temporales mediales) durante los primeros 500 ms después de la presentación de la cara está relacionada con la recuperación exitosa de información léxico-fonológica sobre el nombre de la persona. Además se obtuvieron diferencias significativas entre ambas condiciones en el intervalo 538-698 ms; concretamente, el giro cingulado anterior y el área motora suplementaria mostraron una mayor activación en la Condición SI que en la Condición PDL, posiblemente relacionada con la respuesta motora y como consecuencia de la recuperación exitosa de la información léxico-fonológica sobre la persona.

Naming faces is a complex process of important social relevance for human beings. This explains the interest in face processing and naming from a wide variety of branches in social sciences and neuroscience.

On the basis of the results of cognitive neuroscience studies, some authors have proposed neurophysiological models of face processing (Damasio, Tranel, Grabowski, Adolphs, & Damasio, 2004; Galdo-Álvarez, Lindín, & Díaz, 2009; Gobbini & Haxby, 2007; Ishai, 2008; Olivares & Iglesias, 2000). In general terms, these authors all agree in considering that a distributed brain network is involved in face processing (including face identification and name access). This brain network includes a visual processing core system that includes the inferior occipital areas, the face fusiform area (for invariant face features) and the

posterior superior temporal sulcus (for variable face features, such as eye gaze). According to Gobbini and Haxby (2007), an extended network of brain areas is involved in retrieval of information about that person, including the posterior superior temporal sulcus and the temporo-parietal junction (personal traits, intentions...), the precuneus (episodic memory retrieval) and anterior temporal areas (biographical information, including names).

However, few studies have focused on the temporal dynamics of activation of these regions during a face processing task, because of the limited temporal resolution of neuroimaging techniques. Studies involving intracranial recordings (Allison, Puce, Spencer, & McCarthy, 1999; Barbeau et al., 2008; McCarthy, Puce, Belger, & Allison, 1999; Puce, Allison, & McCarthy, 1999) have provided information about the time during which the different regions become active, showing that occipital, lateral ventral and medial temporal areas become active during the first 500 ms after the presentation of a face.

The intracranial recordings, however, have paid attention only on face recognition, and have ignored later stages of the face naming process, such as linguistic information access and articulation. Furthermore, most neuroimaging studies involving

faces and names (e.g. Kirwan & Stark, 2004; Zeineh, Engel, Thompson, & Bookheimer, 2003; Tsukiura et al., 2002) have focused on the encoding and retrieval of face-name associations rather than on the actual naming.

The tip-of-the-tongue (TOT) phenomenon constitutes a valuable tool for studying later stages of the process, such as phonological processing. The phenomenon consists of a transient failure in naming -even though this name has been retrieved several times before- and it is accompanied by the feeling of its imminent retrieval (Brown, 1991; Brown & McNeill, 1966). It has been proposed that a TOT state occurs when the activation of a lexical node (a name) is not able to send sufficient priming to activate all the phonological nodes of the target word (Burke, MacKay, Worthley, & Wade, 1991).

A previous study was aimed at determining the ERP components associated with successful face naming, and with the TOT state (Díaz, Lindín, Galdo-Álvarez, Facal, & Juncos-Rabadán, 2007). For this, the participants had to name the faces of famous people. Significant differences between the successful naming (KNOW) and the TOT conditions were observed in the interval between 550 and 750 ms, with larger amplitude in the former. This was interpreted as indicating division of the processing resources in the TOT state, between stimulus classification and the continued search for semantic and lexical information, because of the reduced activation of the lexical-phonological route (Díaz et al., 2007).

In a recent study (Lindín, Díaz, Capilla, Ortiz, & Maestú, 2010), the significant differences in brain activation between the response categories KNOW and TOT were analyzed by means of magnetoencephalography during a modified face-naming task (800 stimuli instead of 200; naming was delayed with respect to the manual response). The TOT state was characterized by lower activation, in the 300-500 ms post stimulus interval, of left temporal and frontal areas, bilateral parahippocampal gyrus, and right fusiform gyrus, which may underlie the genesis of TOT, and greater activation, in the 700-800 ms interval, of bilateral occipital, left temporal, and right frontal and parietal areas, corresponding with the unfruitful search for the name once the state has been produced.

In the present study, we attempted to go further in the characterization of the neural basis of the successful (or failed) face naming process. Concretely, we aimed to estimate the temporal sequence of activation of brain areas on each response category separately (KNOW and TOT), by application of low-resolution electromagnetic tomography (LORETA) to the ERP data from a preceding study (Díaz et al., 2007). As far as we are concerned, this is the first attempt to describe the temporal sequence of activation of brain areas during a face-naming task using the LORETA estimation from the ERP waveforms. The specific objectives were:

- 1) To characterize the temporal dynamics of the activation of brain areas participating in the neural network involved in retrieval of the names of faces. It is aimed to contrast if the brain areas estimated from ERP waveforms using LORETA are those reported by neuroimaging studies; in addition, it is aimed to determine the temporal pattern of activation of these areas, with a millisecond temporal resolution.
- 2) To determine the temporal intervals and brain areas in which the current density differs significantly between conditions.

Method

Participants

Twenty university students (10 women, age range 19-24 years) participated voluntarily in the study. All participants were healthy, with normal or corrected-to-normal visual acuity, self-reported right-handedness, with no history of neurological or psychiatric disorder, and no medication during the 4 weeks prior to the study. All participants were asked to refrain from smoking or drinking stimulant beverages for at least two hours before the session, and were not fatigued due to lack of sleep. None of the participants were familiar with the protocols used in the study. The study received prior approval from the local ethical review board, and informed consent was received from all the participants, in accordance with the Declaration of Helsinki.

Procedure

For a description of the experimental procedure, the reader is referred to a previous paper by Díaz et al. (2007).

Electroencephalographic (EEG) monitoring

Electroencephalographic activity was registered at 30 electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T3, C3, Cz, C4, T4, TP3, CP3, CPz, CP4, TP4, P7, P3, Pz, P4, P8, O1, Oz, O2) inserted in a cap with a nasal reference and frontopolar ground, in accordance with the extended International 10-20 System. The EEG signal was passed through a 0.1 - 50 Hz analogical band pass filter, and amplified at 22.5K before being sampled at 500 Hz. An ocular movement (EOG) recording was obtained -at the same time as the EEG recordings- with two electrodes located supra- and infraorbitally to the right eye (VEOG) and another two electrodes at the outer canthi of each eye (HEOG). All impedances were maintained less than 10 k Ω . Epochs of 2200 ms (200 pre-stimulus) were segmented separately for the KNOW and the TOT conditions. For each response condition, a minimum of 20 artefact-free epochs was averaged (see Díaz et al., 2007, for a more detailed description about the EEG monitoring).

Data analysis

To determine the most active brain areas in each condition (KNOW and TOT), and to estimate the temporal sequence of activation across the 2000 ms ERP epoch, low-resolution tomographic analyses (LORETA) were carried out.

LORETA is a distributed source modelling method. The LORETA-KEY software package (<http://www.uzh.ch/keyinst/NewLORETA/Software/Software.htm>) calculates inverse solutions by identifying the smoothest of all possible 3-D current density distributions that would explain the surface potentials (Pascual-Marqui, 1999; Pascual-Marqui, Michel, & Lehmann, 1994). Solution space of LORETA is restricted to cortical and hippocampal grey matter, with grey matter defined via a reference brain, in accordance with the Talairach and Tournoux (1988) atlas. Several authors have reported the usefulness and validity of LORETA in localizing generators of scalp-recorded potentials (Carretié et al., 2004; Thatcher, North, & Biver, 2005; for reviews, see Pascual-Marqui, 1999; Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002).

Talairach coordinates, anatomical structures and Brodmann areas were determined with LORETA software.

Statistical analyses

Statistical analyses were performed by statistical non-parametric mapping (SnPM; see Holmes, Blair, Watson, & Ford, 1996; Mulert et al., 2001) implemented in the LORETA software. For assessment of significantly activated areas in relation to baseline, statistical non-parametric mapping tests (one sample *t*-tests, or *t*-test for single mean value zero) were performed separately for each condition over LORETA *xyz* tomographies, for 40 ms intervals, between 0 and 2000 ms, after presentation of the stimulus. Therefore, the areas showing significant differences with respect to mean value 0 represent the temporal sequence of brain areas activation along the entire stimulus epoch on each condition.

Differences between conditions were assessed by calculation of a TANOVA, which consists of comparison between the entire ERP waveforms in order to estimate the time points at which there is probably a difference in activation in the different brain areas. Therefore, the TANOVA analysis consists in a direct comparison between conditions along the entire ERP epoch. Map-by-map comparisons of the topographic ERP maps of scalp potentials between conditions were quantified by the map dissimilarity measure (Lehmann, 1987) implemented in the LORETA software. Statistical significance for each pair of maps was assessed nonparametrically with a randomization test, which also corrects for multiple testing (see procedure in Strik, Fallgater, Brandeis, & Pascual-Marqui, 1998).

The results of this type of analysis are therefore composed of the temporal intervals that differ significantly between two conditions in terms of topographical activation, in this case, KNOW and TOT. Paired-sample voxel-by-voxel *t*-tests of LORETA images between conditions were carried out on LORETA tomographies for the intervals indicated by the TANOVA to differ significantly. Statistical significance was assessed nonparametrically with a randomization test that corrects for multiple comparisons (see procedure in Mulert et al., 2001). Differences were considered significant at $p < 0.05$.

Results

Behavioural results

As reported in the previous study (Díaz et al., 2007), the responses were distributed as follows: 42% DON'T KNOW, 39% KNOW, and 19% TOT. Reaction times (RT) were significantly longer ($p < 0.001$) in TOT (1513 ms) than in both KNOW (1054 ms) and DON'T KNOW (1040 ms) response categories, but they did not differ significantly between KNOW and DON'T KNOW.

The time course of brain activity associated with face naming (KNOW) and the TOT state

The time course of activation of brain regions for both KNOW and TOT conditions, obtained by LORETA, is shown in Figure 1. The different estimated coordinates were clustered in different regions because of the limited spatial resolution of the technique (see Table 1 for the list of areas which each region included). The present analysis may provide data about the timing of activation

and possible interactions among the brain areas involved in the neural network associated with retrieval of people's names.

The brain areas in which activation differed significantly from the baseline (see Experimental Procedure) were similar in both conditions (Figure 2).

In both conditions, between 200 and 520 ms, the occipital region, the ventral pathway, the temporal-parietal-occipital (TPO) junction, the medial temporal region, the medial parietal areas, the ACC and the premotor areas were activated bilaterally in a similar way in both conditions, as well as the insula.

Table 1
Correspondence between the cortical areas (including Brodmann Areas) and the clustered regions as referred in the present study

Clustered region	Area	BA
Occipital areas	Cuneus	17,18,19
	Inferior occipital gyrus	18,19
	Middle occipital gyrus	18,19
	Superior occipital gyrus	18,19
Ventral pathway	Lingual gyrus	17,18,19
	Fusiform gyrus	19,20,37
	Inferior temporal gyrus	20,37
TPO junction	Middle occipital gyrus	37
	Middle temporal gyrus	37,39
	Superior temporal gyrus	39
	Postcentral gyrus	40
	Angular gyrus	39
	Supramarginal gyrus	39,40
Posterior temporal areas	Middle temporal gyrus	21,22
	Superior temporal gyrus	21,22,29,42
	Transversal temporal gyri	41
Medial temporal lobe	Hippocampus	–
	Parahippocampal gyrus	27,28,30,34,35,36,37
Medial parietal lobe	Precuneus	7,19,31
	Posterior cingulate cortex	23,29,30,31
	Cingulate cortex	23,31
	Paracentral lobule	5,31
Superior parietal lobe	Superior parietal lobule	5,7
	Postcentral gyrus	5
Insula	Insula	13
Medial prefrontal areas	Superior frontal gyrus	10
	Middle frontal gyrus	10,11
	Medial frontal gyrus	10,11,25,47
	Rectal frontal gyrus	11
Anterior cingulate cortex	Anterior cingulate cortex	24,32,33
Lateral prefrontal areas	Superior frontal gyrus	10
	Middle frontal gyrus	10,46
	Inferior frontal gyrus	11,44,45,46,47
Premotor areas	Superior frontal gyrus	6,8
	Middle frontal gyrus	6,8
	Precentral gyrus	6
	Medial frontal gyrus	6,8
	Paracentral lobule	6
Primary sensory-motor areas	Postcentral gyrus	1,2,3
	Precentral gyrus	4

TPO junction: temporal-parietal-occipital junction

Between 500 and 1200 ms the regions mainly activated in both conditions were the bilateral medial temporal lobe, the bilateral medial parietal areas, and the superior parietal region, as well as premotor areas.

Finally, between 1600 and 2000 ms, the ventral region, the TPO junction, the insula and posterior temporal areas, predominantly in the right hemisphere, and also the bilateral premotor areas and the left medial parietal region were activated in both conditions.

TANOVA and T-tests

The Topographic ANOVA (TANOVA; see Experimental Procedure) revealed significant differences between conditions in the 538-598 ms and 622-698 ms intervals (Figure 1). T-tests for the first interval showed a significantly greater current density ($t= 4.14$; $p\leq 0.04$) for the KNOW condition than for the TOT condition, in the intersection between the left ACC (BA 24/32) and the left supplementary motor area (SMA, BA 6). In the second interval, ACC (BA 32) also showed significantly higher activity in the KNOW than in the TOT condition, in both the right ($t= 4.35$; $p\leq 0.03$) and left ($t= 4.31$; $p\leq 0.05$) hemispheres.

Discussion

In the present study, we explored the activation of brain areas during a face naming task by means of low-resolution tomographies applied

to ERP waveforms. The results have shown that a) the brain areas presenting activation according to LORETA estimation are those areas that has been related to face naming in neuroimaging studies; and b) successful naming and the TOT state share a similar brain network in the first stages of processing, including semantic and lexical retrieval.

According to the LORETA estimation of the temporal sequence of activation in the KNOW condition, the successful name retrieval and naming appears to be associated with the interaction, within the first 500 ms after the presentation of a face, of a distributed brain network involving occipital areas, occipital-temporal-parietal areas, medial temporal and parietal areas, the ACC and prefrontal cortex, the insula as well as premotor and sensoriomotor areas. These results, in spite of the low resolution of the LORETA solution, are fairly consistent with the networks involved in face processing and naming proposed in neuroimaging studies (Damasio et al., 2004; Gobbini & Haxby, 2007; Ishai et al., 2008).

The bilateral occipital and ventral occipital-temporal areas (the ventral pathway) have been considered as a face processing brain circuit in several neuroimaging studies (Allison et al., 1999; Gorno-Tempini et al., 1998; Halgren et al., 1999; Haxby et al., 1999; McCarthy et al., 1999; Puce et al., 1999). In addition, the bilateral TPO junction (posterior perisylvian region) has been associated with the visual processing of faces (Damasio et al., 2004) and, more specifically, with both semantic (Gobbini & Haxby, 2007; Gorno-Tempini et al., 1998; Kemeny et al., 2006) and lexical (Kemeny et al., 2006) information retrieval.

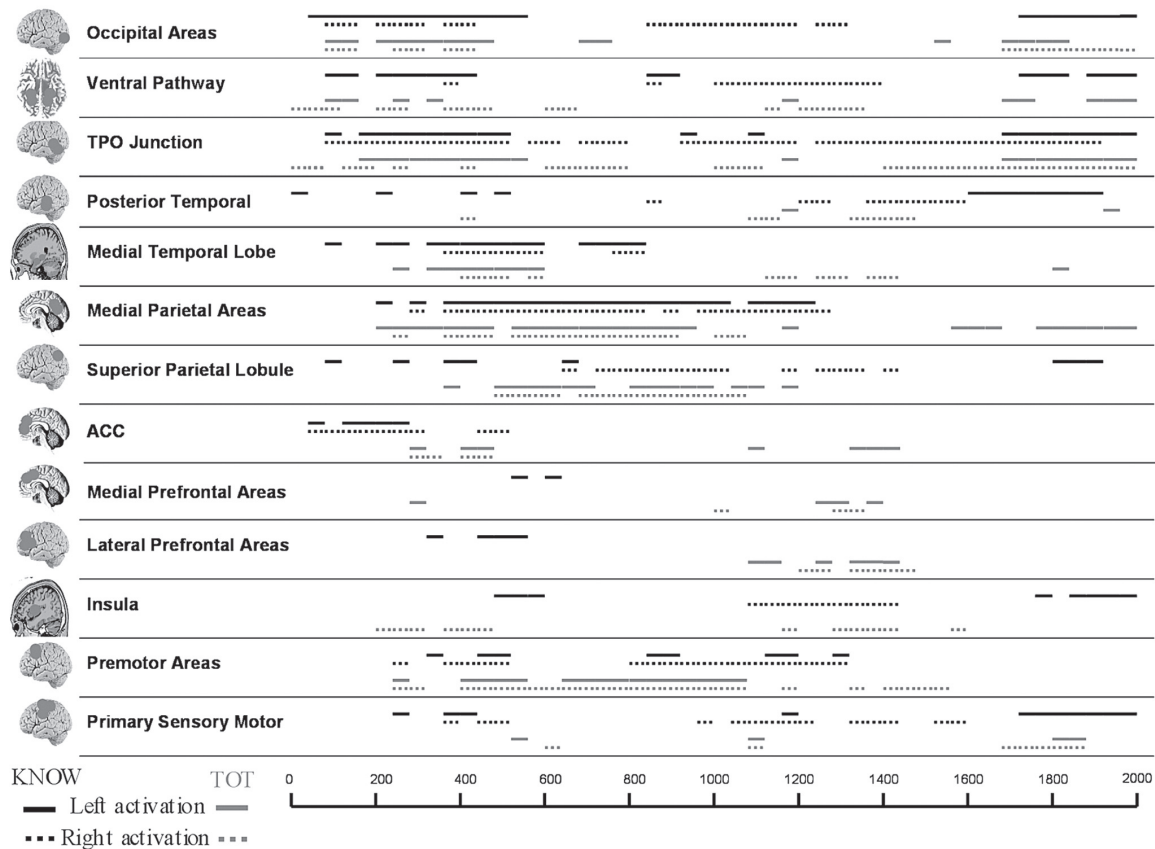


Figure 1. Temporal course of activation of brain areas for KNOW (black line) and TOT (grey line) conditions, as reflected by the t-test for single mean value zero analyses. Solid lines: left hemisphere activation; Dashed lines: right hemisphere activation

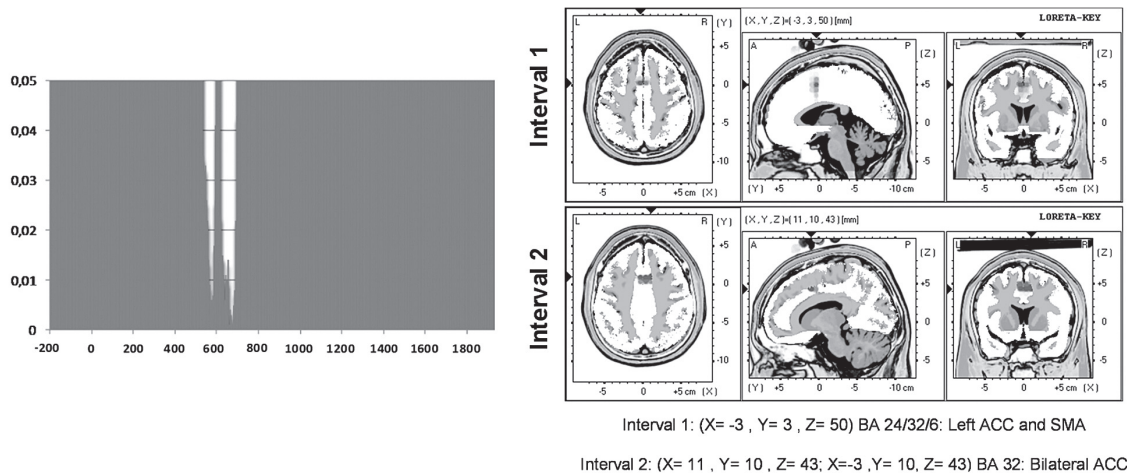


Figure 2. TANOVA results: *Left Panel:* *p* values of the comparison throughout the entire ERP waveforms between the KNOW and the TOT conditions; the graphical representation shows two time intervals presenting significant differences ($p < .05$). *Right panel:* LORETA *t*-tests images showing significantly more active brain areas in the KNOW condition than in the TOT condition for two time intervals. *Top:* Interval 1 (538-598 ms). *Bottom:* Interval 2 (622-698 ms)

The medial temporal and medial parietal areas have been related to memory retrieval processes. There is no doubt that the hippocampus and adjacent regions play a crucial role in memory retrieval (Wiggs, Weisberg, & Martin, 1998; Simons & Spiers, 2003), including face-name associations (Kirwan & Stark, 2004; Zeineh et al., 2003). Barbeau et al., (2008) reported differences in intracranial ERPs between famous and unfamiliar faces in different medial temporal areas between 200 and 500 ms, and related the result to the access to information in long-term memory. In addition, several studies have related the medial parietal areas to the face-name association (Shah et al., 2001), and the retrieval of lexical information (Kemeny et al., 2006). The interaction between the temporo-parieto-occipital junction, the medial temporal lobe and medial parietal areas in this interval may therefore reflect the search for the lexical-phonological information about the name corresponding to the face.

The left posterior temporal areas have been related to the lexical and phonological access (Damasio et al., 2004; Indefrey & Levelt, 2004; Kemeny et al., 2006). The ACC, the left prefrontal areas, and the left insula have been associated with successful retrieval of names. Kikyo, Oki and Sekihara (2001) observed greater activation of the ACC and the left dorsolateral prefrontal cortex in TOT resolution, i.e., at the moment at which the name was successfully retrieved. This is consistent with the role of the ACC and the prefrontal cortex in memory retrieval and monitoring of the retrieved information (Maril, Simons, Weaver, & Schacter, 2005; Maril, Wagner, & Schacter, 2001; Simons & Spiers, 2003). In addition, Shafto, Burke, Stamatakis, Tam, & Tyler (2007) considered that the activation of the left insula is necessary for achieving correct phonological access.

The premotor and primary sensorimotor areas, together with parietal and medial temporal regions were the main areas activated between 800 and 1400 ms in the KNOW condition; this may be related to response readiness and execution, as the RT is about 1050 ms. The premotor areas and the sensory-motor primary areas are involved in motor planning and execution, and have been related to the articulatory process in language production (Blank, Scott, Murphy, Warburton, & Wise, 2002; Damasio et al., 2004; Indefrey & Levelt, 2004; Kemeny et al., 2006).

Therefore, and in accordance with intracranial recordings (Barbeau et al., 2008), the areas involved in processing the face as well as accessing the semantic, lexical and phonological information become active during the first 500 ms from the presentation of a face.

The temporal sequence of brain areas activation is also congruent with the results reported in a recent study (Lindín et al., 2010), in which using a technique with a high spatial resolution, the magnetoencephalography, it was found that left temporal areas, the medial temporal lobe and prefrontal areas were less activated in the TOT condition than in the KNOW condition in the 310-520 ms interval after the presentation of a face. In the present study, although differences in brain activation not reached the significant level between KNOW and TOT in the first 500 ms, the temporal sequence of activation showed apparently a different pattern of activation in some of these nodes, concretely in lateral posterior temporal and prefrontal areas.

Significant differences between KNOW and TOT conditions have been found from 540 to 700 ms, specifically in the intersection between ACC and premotor areas. Kikyo et al., (2001) also described greater activation of the ACC (as well as in the left dorsolateral prefrontal cortex) during TOT resolution, and thus, in a successful retrieval stage. The greater activation of the ACC in the KNOW than in the TOT condition therefore appears to be related to the retrieval of semantic and lexical-phonological information about the person.

The ACC and the prefrontal cortex have been associated with the retrieval process (Simons & Spiers, 2003) and monitoring of the retrieved information (Allan, Wolf, Rosenthal, & Rugg, 2001; Maril et al., 2005; Rugg, Fletcher, Frith, Frackowiak, & Dolan, 1996). In the present study, as well as in studies by Maril et al. (2001, 2005) the participants had to press a button once they were sure they knew the target name; thus, the transient higher activation of the ACC at 500 and 700 ms, together to premotor areas may correspond to readiness for the motor responses, indicating success in retrieving the required information (in this case, the famous person's name).

The opposite was found in other studies, i.e. greater activation of the ACC during the TOT state than during a successful naming condition (Maril et al., 2005; Maril et al., 2001). In our opinion, these discrepancies can be explained by the different recording techniques used. The fMRI technique provides indirect information about the neural activity, as it measures the haemodynamic changes that are related to particular neural activity. Although these changes are slow (maximum activity about 4-6 seconds after the presentation of a stimulus), the bioelectrical response to the stimulus follows a rapid (milliseconds) temporal sequence of changes in the neurons engaged in the different brain networks. The limited temporal resolution of the neuroimaging techniques does not allow detection of the exact moment at which the brain areas become active, the time interval that these areas remain active, or the temporal dynamics of activation of the different areas contributing to the neural network for retrieval of the information from the semantic and lexical-phonological memory stores. To overcome this problem, we can take advantage of the high temporal resolution of the ERP technique, together with the estimation of the brain areas involved, with LORETA tomographies, although we must be careful in interpreting the results because of the limited spatial resolution of these tools.

Thus, the differences between the results of the present study and previous neuroimaging studies regarding the ACC activation during the TOT state may be related to different levels of activation of the ACC depending on the results of the memory search or the moment of activation. If the information is correctly retrieved, the ACC, together with premotor areas, may transiently present greater activation in relation to the successful search and the response preparation, as reflected by the differences between conditions observed in the present study or those observed by Kikyo et al. (2001) during TOT resolution, as compared with an unsolved condition. However, if the lexical-phonological information is not correctly activated, the ACC activation, together with prefrontal areas, may reflect the subsequent attempts to retrieve the information from the semantic memory, as suggested by Maril et al., (2001, 2005).

Concluding remarks

In the present study, the time course of activation of a possible neural network dedicated to the face naming process was described by means of the estimation of discrete sources of brain activity generating ERPs in a task involving the naming of famous faces.

Taking into account the differences in the pattern of activation in the KNOW and TOT conditions, the present results provide evidence that adequate activation of a neural network during the first 500 ms following presentation of the photograph, involving the posterior temporal region, the insula, lateral and medial prefrontal areas and the medial temporal lobe, is associated with successful retrieval of lexical-phonological information about the person's name. On the contrary, a deficit in activation of this network, or of some of the nodes, may be the neural substrate of the deficit in the lexical-phonological route proposed by Burke et al., (1991) as the genesis of TOT.

Finally, significant differences between conditions were observed in the 538-698 ms interval; specifically the results indicated greater activation of the ACC towards the SMA in the KNOW than in the TOT condition, possibly in relation to the motor response and as a consequence of the successful retrieval of semantic and lexical-phonological information about the person, in accordance with the results of Kikyo et al., (2001). However, the temporal sequence of activation revealed activation of the ACC, towards several prefrontal areas, between 1000 and 1500 ms only in the TOT condition, possibly in relation to the continued search for the phonology of the name in memory, in accordance with the results of Maril et al., (2001, 2005).

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