10

Neurofunctional Correlates of the Tip-of-the-Tongue State

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INTRODUCTION

Naming is the result of complex cognitive processes, as it involves remembering the verbal label associated with an object, action, place, animal, or person. Naming requires retrieval of a label and its spoken or written production. However, although we know the names of many people, animals, or things, in the course of daily life, the naming of known names can fail momentarily. A universal experience is the annoying feeling of wanting to say a word and not being able to, while being completely sure that we know it, that we have recalled it in the past, and that we are on the verge of retrieving it. This experience is, of course, the "tip-of-the-tongue state" (TOT).

One of the main features of the phenomenon lies in the temporary inability to access information that is undoubtedly registered in the memory stores of the person who presents a TOT. Understanding how this phenomenon occurs, therefore, may be helpful to understand how the mechanisms of accessing information stored in memory take place. We also think that TOTs can aid our understanding of memory retrieval disorders.

The vast majority of studies have focused on the behavioral (and therefore directly observable) characteristics of the TOT phenomenon. However, in recent decades, researchers have made important advances in the development of techniques that allow neuroscientists to study brain function in vivo and, therefore, to assess brain activity associated with cognitive

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processes and behavior in human beings. Consequently, these neuroscientific techniques may provide relevant information to understand *where*, *when*, and *how* the processes involved in successful name retrieval and the TOT phenomenon take place in the brain.

In this chapter, after a brief summary of the main cognitive models that explain the TOT phenomenon and the main contributions and limitations of behavioral studies on the characterization of this phenomenon, we analyze the contributions of neurophysiological techniques to study cognitive processes, beginning with the description of the basic features of such techniques, the information they provide, their limitations, and precautions that should be taken into account in the design of tasks, in recording brain activity, and in the interpretation of results obtained. Then, we present the main results of the study of the TOT phenomenon using such techniques, specifically the techniques of functional magnetic resonance imaging (fMRI), event-related potentials (ERP), and magnetoencephalography (MEG). Finally, an integration of neurocognitive results with cognitive models of the TOT is presented.

Cognitive Models Explaining the TOT

One aspect that has generated research on the TOT phenomenon is the study of the mechanisms through which it is generated, developed, and maintained. Several explanatory hypotheses seek to answer these questions, which may fall into three areas of psychology: psycholinguistics, memory, and metacognition. From these approaches, several models have been proposed that can be arranged, according to Brown (2012) and Schwartz and Metcalfe (2011), in two main types: direct access models and inferential models.

Direct access models propose that the TOT phenomenon reflects partial or incomplete activation of the stored information. Two main interpretations have been proposed from this perspective. The *hypothesis of blocking inhibition* (Woodworth, 1929; see Jones, 1989) suggests that the TOT phenomenon is due to the fact that name retrieval is inhibited or blocked by intrusive words. In contrast, the *transmission deficit hypothesis* (Burke, MacKay, Worthley, & Wade, 1991; MacKay & Burke, 1990), which has received substantial empirical support (Burke et al., 1991; James & Burke, 2000; White & Abrams, 2002; see Harley & MacAndrew, Chapter 6, this volume), argues that the TOTs occur when activation fails to be fully transmitted from the semantic to the phonological system, that is, when phonological activation of an unrecalled item is insufficient or partial. This transmission deficit is modulated by three variables: the frequency (how often a word is used) and recency (how recently a word has been used) of word usage and age of the person. Indeed, the incidence of TOTs seems to increase in less recent words (Bonin, Perret, Méot, Ferrand, & Mermillod, 2008; Burke et al., 1991; Cleary, 2006; Cleary & Reyes, 2009; Cleary & Specker, 2007) and low-frequency words (Brown & McNeill, 1966; Burke et al., 1991; Hanly & Vandenberg, 2010; Vitevitch & Sommers, 2003), as well as in older participants (Burke, Locantore, Austin, & Chase, 2004; Burke et al., 1991; Cohen & Faulkner, 1986; Cross & Burke, 2004; Evrard, 2002; Galdo-Álvarez, Lindín, & Díaz, 2009a, 2009b; Gollan & Brown, 2006; Heine, Ober, & Shenaut, 1999; James, 2006; James & Burke, 2000).

Inferential models maintain that TOT states reflect people's judgments about their knowledge (that is, aspects related to metamemory or metacognition), rather than the actual contents of memory (Schwartz, 1994). Within these models, two approaches can also be distinguished: First, the *cue familiarity hypothesis* (Metcalfe, Schwartz, & Joaquim, 1993) claims that TOT are based on the familiarity of the present cue information, predicting that the more knowledge you have of a particular issue, the more probability exists to present a TOT. Second, the *accessibility heuristic hypothesis* (Koriat, 1993) suggests that the TOT experience is the result of an assessment of the retrieval when only partial information (even if this information is not related to the current word) is recalled. In general, this perspective accepts that both hypotheses are complementary (Koriat & Levy-Sadot, 2001).

STUDIES ON THE TOT PHENOMENON

Behavioral Studies: Contributions and Limitations

In 1966, Brown and McNeill conducted the first systematic experimental study concerning the TOT phenomenon, which is defined as a failure to recall a word when you are sure you know it, and feel as if its recall is imminent (Brown & McNeill, 1966). Since this seminal work, scholars have conducted numerous behavioral studies to describe the characteristics of the phenomenon (see Brown, 2012). Two general approaches have been mainly used to characterize the TOT phenomenon: diary studies and experimental-naming tasks.

In ***diary studies***, participants must record in a notebook TOTs that occur in everyday life. In addition to the TOT itself, participants are expected to include certain characteristics associated with the phenomenon (information they can retrieve, time and circumstances of the resolution of the phenomenon, etc.). This methodology allows researchers to contrast the incidence of TOTs in daily life, and provides qualitative information for the characterization of this phenomenon. However, it does not allow manipulating experimentally the characteristics of the stimuli that cause the TOT, thus limiting the predictive power of the causes of the phenomenon.

The ***experimental-naming task*** involves inducing TOTs in participants in the laboratory. The tasks and stimuli used are diverse: word definitions, pictures, photographs of faces, definitions associated with pictures, and paired associates (see Brown, 2012, for a review). The data obtained in these studies include, among others, the incidence (number or percentage of TOTs) and performance measures such as reaction times – both for initial recall and for how long people need to determine that they are in a TOT.

The results of the behavioral studies showed that the TOT appears to be a universal phenomenon; its presence has been found in virtually all cultures (Schwartz, 1999); in all age groups, from infancy (Hanly & Vandenberg, 2010) to old age (Burke et al., 1991). Moreover, in diary studies, TOTs seem to occur in everyday life around once a week (Burke et al., 1991; Cohen & Faulkner, 1986; Gollan, Montoya, & Bonainni, 2005; Heine et al., 1999; Reason & Lucas, 1984); in laboratory experimental tasks the average incidence to the different tasks used is around 15 percent, although the ratio changes using different types of stimuli (Brown, 2012). Research also finds that TOTs are more frequent for proper names, especially the names of people, than for common nouns (Brown, 1991; Burke et al., 1991, Cohen & Faulkner, 1986; Evrard, 2002; Gollan et al., 2005; Hanley, 2011; Rastle & Burke, 1996). Moreover, the experimental work shows that during a TOT, people can retrieve fairly accurate semantic information (Bock & Levelt, 1994; Hay, Young, & Ellis, 1991), syntactic information (Caramazza & Miozzo, 1997; Miozzo & Caramazza, 1997), and even partial phonological information (Brown & McNeill, 1966; Brown & Nix, 1996; Burke et al., 1991; Caramazza & Miozzo, 1997; Gollan et al., 2005; Hanley & Chapman, 2008; Yarmey, 1973).

Although the contributions of behavioral studies have allowed characterization of the TOT phenomenon and have provided evidence about its possible causes, such studies have important limitations. One such limitation is the difficulty of behavioral studies to delve into issues such as the differential mental chronometry of processes involved in successful retrieval and TOTs, or what cognitive control mechanisms are engaged once the problem of inaccessibility of information begins. The main difficulty in behavioral studies stems from the type of measures available, such as the ratio of TOTs to the number of correct names, or the reaction time of recall in different conditions. These measures, although they are readily available, are limited because they constitute the final result of the retrieval process, regardless of whether the retrieval is successful, and therefore they limit the exploration of processes involved, such as the smaller activation of phonological information than of other types of information, or the metacognitive process of deciding whether sufficient information is accessible to output a response. In these cases, differences in behavioral measures may not always be attributable to a particular process, complicating the interpretation of which factors may be a cause or a consequence of the TOT, that is, which factors trigger the TOT and which factors contribute to its maintenance over time.

To overcome these limitations, online measures are needed to distinguish what processes are affected during a TOT. In this sense, the discipline that can provide this type of measures, and thus elucidate the mechanisms underlying TOTs, is cognitive neuroscience.

Neurocognitive Studies

Cognitive neuroscience bridges cognitive science and cognitive psychology, on one hand, and biology and neuroscience, on the other. It has emerged as a distinct enterprise only recently and has been driven by methodological advances that enable the study of the human brain safely in the laboratory (Ward, 2010). Cognitive neuroscience is concerned with the scientific study of neural substrates of mental processes and their behavioral manifestations. To this aim, it has taken advantage of techniques from various scientific fields, such as neuroradiology, experimental psychology, psychobiology, bioengineering, physics, neurophysiology, and computer science, among others.

Research Techniques in Cognitive Neuroscience

In recent decades, researchers have developed a number of tools to study human brain activity during performance of cognitive tasks. These techniques include neuroimaging techniques, such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) and techniques to study the electromagnetic changes occurring in neuronal populations of the brain during cognitive processes, such as electroencephalography/event-related potentials (EEG/ERP) and magnetoencephalography (MEG). These techniques have in common that the signal and information that is gathered on brain function covary with the mental process of interest. They have revolutionized the study of the biological substrates of the behavior in humans, because of their remarkable spatial and/or temporal resolution and because of their noninvasive or minimally invasive nature.

Each of these techniques measures human brain activity in a different manner. Some of them record changes in electrical potentials (EEG/ERP) or magnetic fields (MEG) generated in the membranes of neurons, whereas others record changes in the level of blood oxygenation of the regional cerebral blood flow (fMRI), or metabolic changes (PET), derived from neuronal activity. Each technique uses specific procedures and recording devices, as well as methods of analysis of the obtained signal. These differences determine the differences of the degree of precision or the level of spatial and temporal resolution of each of the techniques.

Spatial resolution refers to the level of precision with which we can determine *where* in the brain functional changes are occurring, associated with a particular event. At present, the functional brain imaging technique with highest spatial resolution is the fMRI, with an accuracy in the order of 0.5 to 3 mm (Menon & Kim, 1999; Meyer-Lindenberger, 2010; Pfeuffer et al., 2002), which is followed by the MEG, multichannel EEG/ERP and PET, with accuracies between 3 and 10 mm (Hämäläinen, Hari, Ilmoniemi, Knuutila, & Lounasmaa, 1993; Meyer-Lindenberger, 2010; Yang, Wilke, Brinkmann, Worrell, & He, 2011).

Temporal resolution refers to how accurately we can determine *when*, or at what time, there is a change in the brain function associated with a particular event. The higher temporal resolution techniques are the ERP and MEG, with an accuracy on the order of milliseconds, followed by the fMRI and PET with less precision, from several hundred milliseconds to seconds (Meyer-Lindenberger, 2010; Pfeuffer et al., 2002). Next, we briefly describe the techniques used to characterize the TOT phenomenon.

The MRI technique allows imaging of brain tissue by applying a magnetic field of high intensity, which orients the protons of some atoms in the same direction. When the protons are in the aligned state, a brief radio frequency pulse is applied that changes the orientation of the aligned protons by 90 degrees to their original orientation. As the protons spin in this state, they produce a change in the magnetic field. When the magnetic field is stopped, the protons return to their original positions, releasing energy. Depending on the nature of the tissue, the time taken to return to the initial situation is different, which forms the basis for measurement of this technique. Building on these physical bases, and using the same type of scanner, the functional MRI (fMRI) technique detects changes in the concentration of oxyhemoglobin/deoxyhemoglobin in blood flow in and out of different brain areas (that is, the blood oxygenation level dependent–BOLD signal).

Because blood flow and oxygen consumption increase in regions that are activated at a given task, this technique provides information on which areas have demanded increased blood supply and consumed more oxygen while a participant is performing a cognitive process. By correlating behavior with the changes in the BOLD signal in particular brain regions, we can infer the nature of the neural processes. Therefore, this technique allows us to map different neural networks in the brain (cortical and subcortical regions) associated with specific cognitive functions.

The potential of this technique is undeniable for the study of the TOT phenomenon. For example, to test the transmission deficit hypothesis (Burke et al., 1991), we might study which regions are involved in phonological processing, and then we could check if these regions are less activated in the TOT than in the successful naming condition (e.g., Shafto, Stamatakis, Tam, & Tyler, 2010).

Despite its high spatial resolution, the fMRI technique has limitations. First, its low temporal resolution is on the order of hundreds of milliseconds, so it is an imprecise technique to study the chronometry of mental processes that often take place in the range of milliseconds. Second, this limitation complicates the interpretation of results in experimental designs comparing conditions in which more than one component of cognitive processing differ. Third, the fMRI technique is very sensitive to technical artifacts. For example, the participant must refrain from making head movements for the fMRI to get a good signal. Fourth, the MRI scanner emits a loud noise that can interfere with auditory stimulation. Finally, for much research, the relatively high cost of fMRI prevents the carrying out of studies. Despite these limitations, fMRI has proven useful in the study of complex cognitive processes.

Other neuroimaging techniques, such as EEG/ERP and MEG, measure task-related changes that occur in the electromagnetic brain activity. The basic principle of both EEG and MEG is the same: the activity of the neurons consists in variations of the distribution of electrical charges within and outside neurons due to ion exchanges across plasmatic membranes. These current flows (or the magnetic fields produced by these flows) in large synchronously active populations of neurons can be detected by sensors attached on the scalp. These sensors are electrodes that record the electrical activity in the case of EEG, or magnetic field sensors (SQUID) in the case of MEG. The time resolution of these techniques is in the order of one millisecond, thus they are especially suitable for the study of the timing of cognitive processes.

ERPs (event-related potentials) are changes in EEG activity associated with certain events (physical stimuli, mental processes, or motor execution).

Because these changes are very small in voltage (relative to the spontaneous brain electrical activity, i.e., EEG), it is necessary to repeatedly present a stimulus so that, after averaging the EEG activity related to these events, the voltage changes associated therewith remain (that is, ERP), whereas the rest of the EEG activity, by its random nature, tends to cancel itself out.

ERPs are measured as positive and negative waves with different latencies with respect to the event of interest. For example, a repetitive visual flash is associated with a positive wave around 100 ms, called P1 or P100, which is related to the visual processing in the extrastriate visual cortex in the occipital lobe. Some of these waves or components (for a distinction between these concepts, and a deepening of the basis of this technique, see Luck, 2005; Luck & Kappenman, 2008) have been related to attention (N1, MMN, P3a), syntactic processing (ELAN, LAN, P600), and semantic processing (N400), or the preparation of the response (Readiness Potential, Lateralized Readiness Potential), among others.

Like each technique, the ERP technique has limitations. The ERP technique is very sensitive to artifacts such as eye or head movements, as well as muscle contractions, which present a greater magnitude than the EEG signal and mask the activity to be analyzed. For obtaining ERP waveforms, it is necessary to average a sufficient number of epochs (EEG segments related with the event of interest) free of artifacts, which means that the tasks are usually lengthy for the participants, especially under conditions that involve complex processes. So, to study the TOT phenomenon with ERP, researchers must evoke at least 20 or 30 TOT states free of such artifacts. Given that TOTs usually represent about 20 percent of presented stimuli in our experiments, it is necessary to provide 200 to 400 (or even more) stimuli (Buján, Galdo-Álvarez, Lindín, & Díaz, 2012; Díaz, Lindín, Galdo-Álvarez, Facal, & Juncos-Rabadán, 2007; Galdo-Álvarez et al., 2009a; Lindín & Díaz, 2010).

Another issue to consider is that many cognitive processes occur in parallel, so that an overlap occurs between the ERP components associated with each of the processes in progress, making it difficult to measure the ERP and disentangle the multiple cognitive processes. To differentiate these components, experimental designs are required for achieving a dissociation of the cognitive process under study, as well as analysis methods to isolate the components of interest. Finally, the spatial resolution of the ERP technique is limited, because EEG activity is recorded at the scalp and is the result of the sum of activity of large populations of neurons mostly in the cortex. In addition, the different tissues between the brain and the electrodes (meninges, skull, skin, etc.) act both as electrical conductors (so that the activity generated in a particular brain region is recorded by the various electrodes placed on the scalp) and as electric resistors that distort and attenuate the original activity.

Scholars have developed algorithms to estimate the neural sources of ERP, such as the low-resolution tomography algorithm: LORETA (Pascual-Marqui, 1999, 2002; Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002; Pascual-Marqui, Michel, & Lehmann, 1994). However, despite the promise of these algorithms, we should be cautious in interpreting these estimates and be aware of the low spatial resolution of the technique.

Magnetoencephalography (MEG) technique provides higher spatial resolution than the ERP, maintaining temporal resolution to the order of milliseconds. The sensors (SQUIDs) capture the magnetic fields generated by the flow of electric current of neurons. Magnetic fields are not distorted or attenuated by the tissues between the cortex and the sensors, which allows the technique to locate the brain sources of MEG components more accurately than with ERP. However, MEG does not achieve the spatial resolution level of fMRI technique.[1] MEG also has the disadvantage that the necessary equipment and its maintenance are expensive.

Therefore, each technique has distinct advantages and important limitations to consider when designing experimental tasks. Nonetheless, each of the techniques will be useful for understanding the TOT phenomenon. As outlined later in this chapter, different paradigms have been developed that have shed light on the neurofunctional characteristics of the TOT phenomenon, helping to clarify its genesis and maintenance.

Where? Spatial Information: What Brain Regions Are Involved in the TOT State?

The first studies using any imaging technique to describe brain activity in the TOT state used the fMRI technique (Kikyo, Ohki, & Sekihara, 2001; Maril, Simons, Weaver, & Schacter, 2005; Maril, Wagner, & Schacter, 2001).

Kikyo and colleagues (2001) asked participants questions about famous people (e.g., “Who established Sony?”), and the participants were required to recall the names as quickly and accurately as possible. When they retrieved the target name or they did not retrieve the target, they had to press either of two different buttons with the right hand. The authors differentiated the Retrieval phase (which followed the questions and lasted up until one second before the participants gave their responses) and “Hit-on” or “Give-up” phases, which extended for one second just before the participants gave their responses, when the target name was or was not retrieved, respectively. Finally, only TOT states were evaluated, and the only difference between them was that in some cases they were resolved (Hit-on)

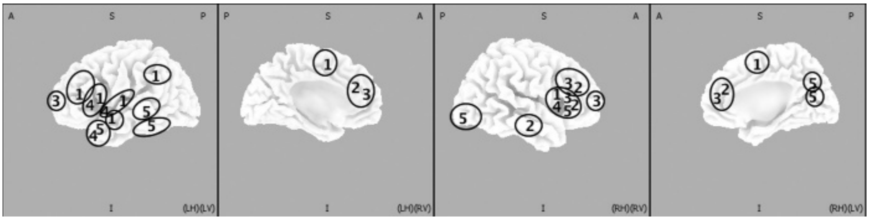


FIGURE 10.1. Schematic representation of the brain areas that showed greater activation in TOT than in K conditions in fMRI and MEG studies. Each number refers to the following study: 1- Kikyo and colleagues (2001), 2- Maril and colleagues (2001), 3- Maril and colleagues (2005), 4- Shafto and colleagues (2010), 5- Lindín and colleagues (2010).

and in other cases they were not (Give-up). Kikyo and colleagues observed bilateral activation of the dorsolateral prefrontal cortex, supramarginal gyrus, superior temporal gyrus, supplementary motor area and anterior cingulate cortex (ACC), as well as inferior frontal gyrus and motor/sensory area, during the Retrieval phase in those tests in which the name was retrieved. In addition, they noted activation of the left dorsolateral prefrontal cortex and of the ACC in the Hit-on phase (Figure 10.1). However, activation of these cortical areas was not observed in the Give-up phase. The study therefore provided interesting information on the neural correlates of the retrieval process when the TOT had already been produced, and of the resolution of the state, but did not provide any information about the spatial-temporal dynamics of the brain activity involved in genesis of the TOT state.

Maril and colleagues (2001) presented participants with general knowledge questions in the form of pairs of semantic cues (e.g., Iraq + capital) that converged on a target (e.g., Baghdad). The participants responded to each question by pressing one of the three response keys available to indicate their retrieval outcome: successful (KNOW), unsuccessful retrieval accompanied by a TOT, or unsuccessful retrieval not accompanied by a TOT (DON'T KNOW). On comparing trials, the authors obtained significantly greater activation for TOT than for the KNOW condition in the ACC, right inferior prefrontal cortex, and right dorsolateral prefrontal cortex (Figure 10.1).

In a later study involving a similar task (Maril et al., 2005), the authors observed significant TOT-related activation in the ACC and the right dorsolateral prefrontal cortex, as well as in the bilateral anterior frontal cortex (Figure 10.1), and interpreted the TOT-related activation in terms of cognitive processes that specifically characterize the TOT, such as retrieval and evaluation of partial information. They reported that some of this activation might also reflect a metacognitive process, such as evaluation by the subject of their level of knowledge on a topic, and evaluation of the probability of them getting the correct answer in time and deciding on a response.

Subsequently, Shafto, Burke, Stamatakis, Tam, and Tyler (2007) using structural magnetic resonance imaging technique (MRI), and Shafto and colleagues (2010) using fMRI, found that the left insula had a role in phonological retrieval, and therefore, it was especially responsible for the phonological deficits correlated with TOTs.

Shafto and colleagues (2007) measured the volume of gray matter in brain structural MRI images in people between 19 and 88 years. In a separate session, participants performed two tests: the Raven's Progressive Matrices test (Raven, 1958) and a celebrity-naming task using stimuli consisting of photographs and descriptions of famous people. The authors found correlations between atrophy of the left insular region, which has been associated with phonological processing (Blank, Scott, Murphy, Warburton, & Wise, 2002) and the number of TOTs, even when the effects of age were controlled. Moreover, the atrophy was not related to performance on the Raven test, which does not involve phonological processing. According to the authors, this result supported the *transmission deficit hypothesis* (Burke et al., 1991) as an explanatory model of the TOT state. But the conclusions drawn from that study were inferences from correlations between behavioral and brain structural measures obtained at different times because no comparisons of insula activity were made during correct naming processes and TOT states. Furthermore, the results did not provide information about the possible role of prefrontal and anterior cingulate gyrus that were related to the TOT phenomenon in previous studies.

To overcome these limitations, in a second study, Shafto and colleagues (2010), using a celebrity-naming task similar to that used by Díaz and colleagues (2007), recorded brain activity with the fMRI technique. They compared the changes in brain activity of younger and older participants in three conditions: successful naming (K), not knowing the name (DK), and TOTs. The authors again found a relation between the insula and phonological processing, and that the greatest degree of atrophy of this region in older people could contribute to the age-related increase of TOT experiences. Furthermore, similar to Maril and colleagues' (2001, 2005) findings, they found higher activation in the anterior cingulate and inferior frontal cortex in the TOT condition than in the K condition, indicating that these regions are recruited when difficulties in access to the required information are observed (Figure 10.1).

In summary, studies with MRI and fMRI have shown that there are differences in brain activation between conditions of successful name retrieval and TOT state. The atrophy of the insula would be related to the unsuccessful access to names of people, whereas TOT states would be associated with the activation of brain areas such as the anterior cingulate cortex, the right prefrontal cortex, and bilateral anterior frontal cortex, which have been related to conflict resolution. Thus, the fMRI studies also support a metacognitive component of the TOT experience (Schwartz & Bacon, 2008; Schwartz & Metcalfe, 2011).

The When of TOTs: Electromagnetic Indexes of the Genesis and Maintenance of TOTs

Díaz and colleagues (2007) studied TOTs for the first time using ERPs in a face-naming task. They compared a condition of successful name retrieval with conditions in which the retrieval failed, either by not knowing the name or with a TOT. The experimental task consisted of the presentation of photographs of famous people to which participants responded by pressing a button if they were sure they knew the name of the famous person, and they pressed another button if they did not know. Immediately after the manual response, participants had to give a verbal response that could be classified into three categories: 1) K: he/she knew the name and said it correctly, 2) DK: he/she does not know the name of the character, and then said "I do not know," and 3) TOT: he/she was sure of knowing the name, was on the verge of retrieving it, but it was not accessible, and said "I can't retrieve it" (in Spanish: "*no me sale*") (see Figure 10.2).

When the response to a photo was "I can't retrieve it" (TOT response), the participant was then presented with a randomly ordered sequence of three words that s/he was required to read aloud. Each word remained on the screen until the participant had read it completely, and after one second, the next word of the series appeared. One of these three words, the cue word, shared with the target name two of the following characteristics: the same first syllable, the same last syllable, the same number of syllables, the same syllables stress pattern, or the same terminal vowel rhyme. The other two words (the foils) did not share any of these characteristics with the target name. Two seconds after the third word had been read, the participants were then presented again with the same photo (second presentation) and were required to respond again, following the same procedure as at the first presentation. The next photo in the series was then presented 2,500 ms after

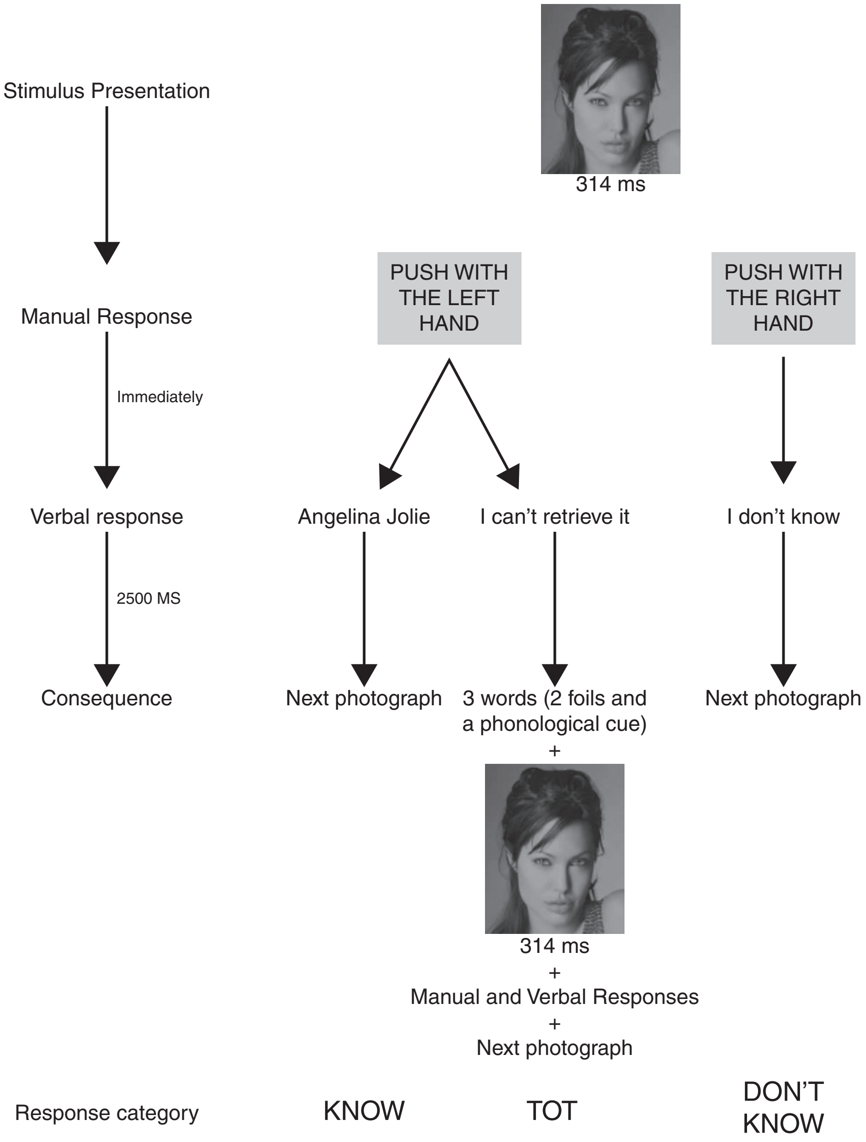


FIGURE 10.2. Face-naming task utilized in Díaz and colleagues' (2007) study.

the key press in response to this second presentation. Therefore, each photo was presented a first time (first presentation), and only faces receiving a TOT response were presented a second time (second presentation).

We used faces of famous people to produce TOT states for the following reasons: a) the faces could be homogenized regarding various physical characteristics such as luminance, color, size, and duration of stimulus presentation, which is more difficult to achieve with definitions or word pairs; b) by using celebrities across different decades, we expected to get a sufficient number of trials with K, DK, and TOT responses in participants of different ages; c) proper names result in a higher percentage of TOT states than common names, which facilitates producing enough TOT episodes to obtain ERP waveforms with a good signal-to-noise ratio; d) the faces are socially relevant stimuli; e) they have been frequently studied in neuroscience, thus various neuroimaging studies and intracranial ERP recordings have identified neural networks involved in face processing (Allison, Puce, Spencer, & McCarthy, 1999; Barbeau et al., 2008; Haxby, Hoffman, & Gobbini, 2000, 2002; Ishai, 2008; McCarthy, Puce, Belger, & Allison, 1999; Puce, Allison, & McCarthy, 1999). In addition, several studies have linked ERP components with phases of face processing (see a comprehensive review in Galdo-Álvarez, Lindín, & Díaz, 2009c). The N170 component, a negative with larger amplitude at lateral posterior electrode sites, has been related to the face structural coding; P2, a positive wave with maximum amplitude at posterior electrodes, has been associated with face recognition; and ERP components in the range between 300 and 600 ms (early P3, N400) have been associated with access to person-specific information, such as semantic, lexical, and phonological information.

In the first presentation of faces, Díaz and colleagues (2007) obtained no differences between K and TOT prior to 450 ms, confirming that processing during the initial stages of perception (P100), structural encoding (N170), face recognition (P2 and N2), and access to person-specific information (early P3) was similar between successful naming and TOT state conditions. Subsequently, another component called late-P3 (l-P3) with a peak around 676 ms and the maximum amplitude at parietal electrodes (which the authors associated with the P600 component or LPC identified in previous studies with faces), was associated with the categorization of the stimulus. The absence of differences in the l-P3 latency between response conditions led the authors to conclude that the time needed to classify the stimulus was similar between the successful name retrieval and the TOT state. The mean amplitude in the 550–750 ms interval, in which l-P3 was identified, was larger in the K condition than in TOT (Figure 10.3, top). It is likely that this difference was related to the different amount of processing resources dedicated to the categorization of the stimulus. We thought it was smaller in TOT than in K, because during TOTs, the participants' attention was divided between the categorization of the stimulus and the intense search for phonological information of the name.

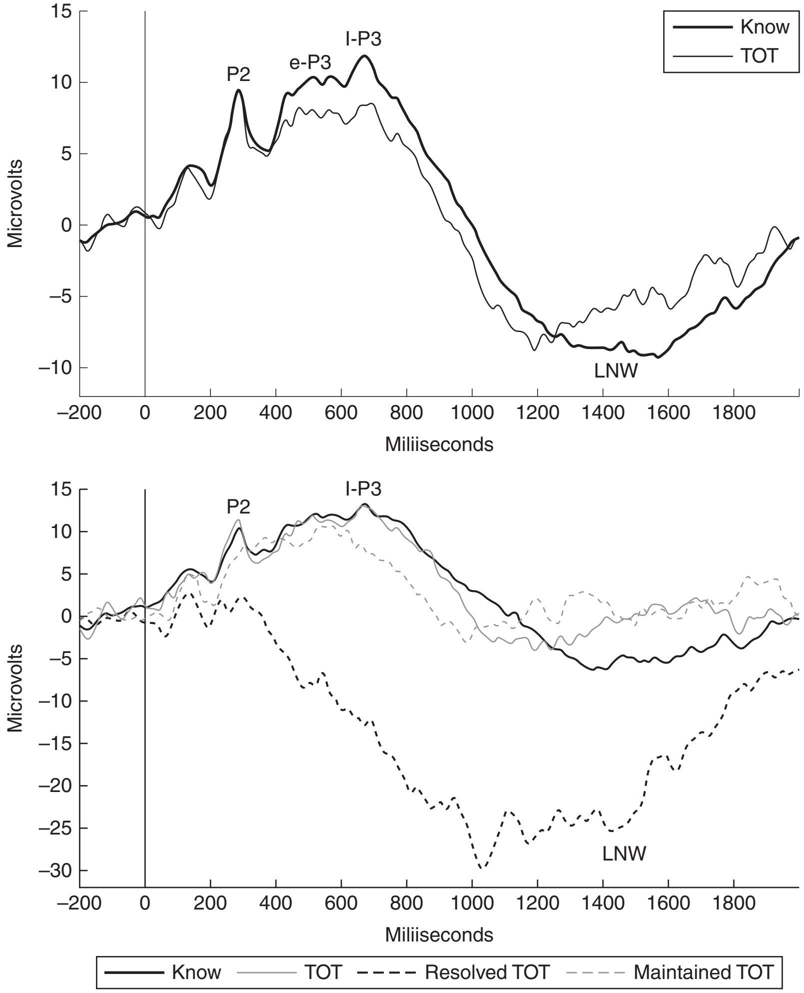


FIGURE 10.3. Grand-averaged ERP waveforms at Pz electrode site, for the first presentation of the face (top; N = 18), and for the first versus second presentation of the face after a TOT state (bottom; N = 9). (Modified from Díaz and colleagues, 2007).

The last component identified in this study was a negative wave (late negative wave -LNW-) in the 1,350–1,550 ms interval. LNW showed a gradation in its amplitude, being larger in DK, followed by K, and the smallest in TOT (Figure 10.3, top), which led the authors to propose that this component could be related to a mechanism of reviewing the categorization of the stimulus and/or the selected response.

After a TOT, the presentation of phonetic cues facilitated resolution of TOTs on 35 percent of the trials. In such cases, the same face was presented again and ERP waveforms were obtained. In the ERP waveform to the second presentation of the face, the N2, e-P3, and l-P3 components were absent (Figure 10.3, bottom). The fact that these components were not identified supported the supposition that the phonetic cue presented after a TOT state facilitated its resolution, enabling access to the name even before the face was presented again. In consequence, it would be sufficient to compare the face with its structural pattern maintained in memory (the correlate of this comparison being the P2 component), to confirm the identity of the person's face and retrieve the corresponding name.

When the presentation of the phonetic cue did not facilitate TOT resolution (56% of the time), the ERP waveforms to the second presentation of the face were similar to those of the first presentation; thus, changes in the morphology and amplitude of ERPs were not detected, which the authors attributed to the stability of the TOT. A reduction in the latencies of N2, early P3, late P3, and LNW with respect to the first presentation of the face (Figure 10.3, bottom) was observed, however, which was interpreted as evidence that the repeated presentation of the face seems to give rise to a repetition priming effect, that is, a facilitation of information transmission.

In a second study, Galdo-Álvarez and colleagues (2009b) investigated the ERP correlates of correct naming and the TOT in young and old participants, using the same task Díaz and colleagues (2007) used. The authors found no age-related differences in the ERP correlates of the TOT, indicating that TOT is a stable phenomenon throughout life. However, they obtained smaller amplitudes in the old than in young participants for the successful naming condition. This result could indicate a lower basal activation of information in memory in the older participants, which would explain why the older participants have a higher incidence of failures in word recall (Burke et al., 1991; Shafto et al., 2010; Wierenga et al., 2008).

Lindín and Díaz (2010) used a variant of the face naming task Díaz and colleagues (2007) employed. They used a larger number of stimuli (800) for improving the signal-to-noise ratio in the ERP waveforms. Lindín and Díaz also changed the response mode; participants pushed three different buttons depending on the response, that is, one for K, one for TOT, and one for DK. The study also established a delay between pressing the button and the verbal response, beyond the two seconds of the EEG epoch evaluated, with the aim of avoiding modulation of the brain activity associated with the verbal response on the LNW. Furthermore, unlike the task Díaz and

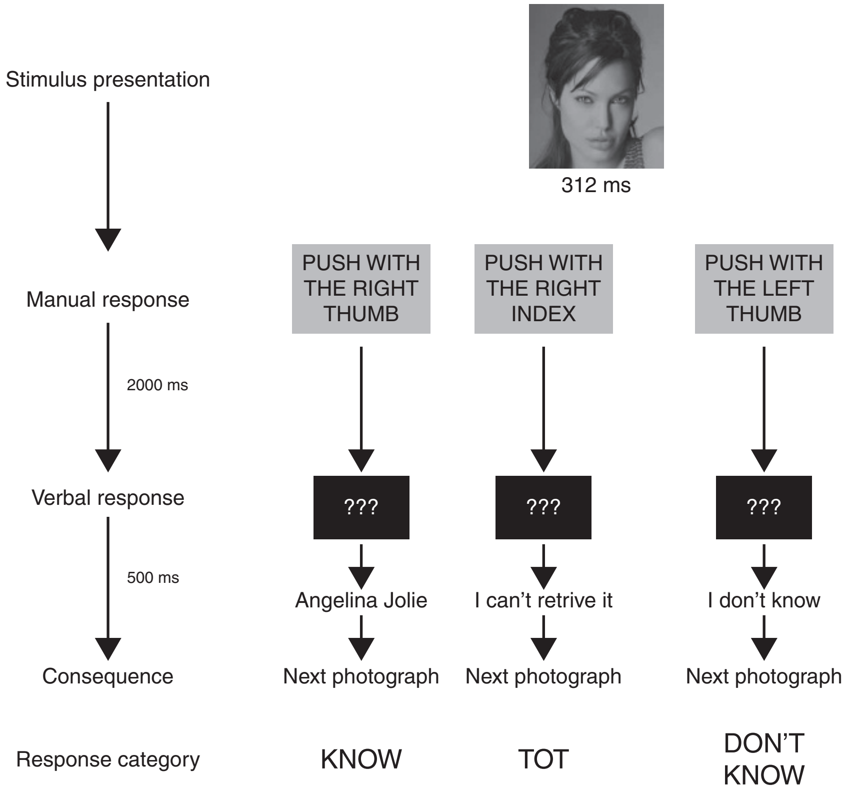


FIGURE 10.4. Face-naming task utilized in the Lindín and Díaz (2010) and Lindín and colleagues (2010) studies. The main differences regarding the task used in Díaz and colleagues' (2007) study were: the use of three response buttons (one for each response category), the time interval between the manual and the verbal responses (2000 ms), being the verbal response indicated by three question marks on the screen; and the short (about 500 ms) interval between the verbal response and the presentation of the next photograph.

colleagues (2007) used, there was not a second presentation of those faces that evoked a TOT state (Figure 10.4).

Lindín and Díaz (2010) partially replicated the results Díaz and colleagues (2007) obtained, although they obtained differences between response conditions for early P3 (300–460 ms interval) and N450 (a component of the N400 family, into the 370–560 ms interval) latencies, both of which were longer in TOT than in the K condition (Figure 10.5). From these results, they concluded that access to semantic and lexical information occurred later in TOT than in K when greater specificity is required

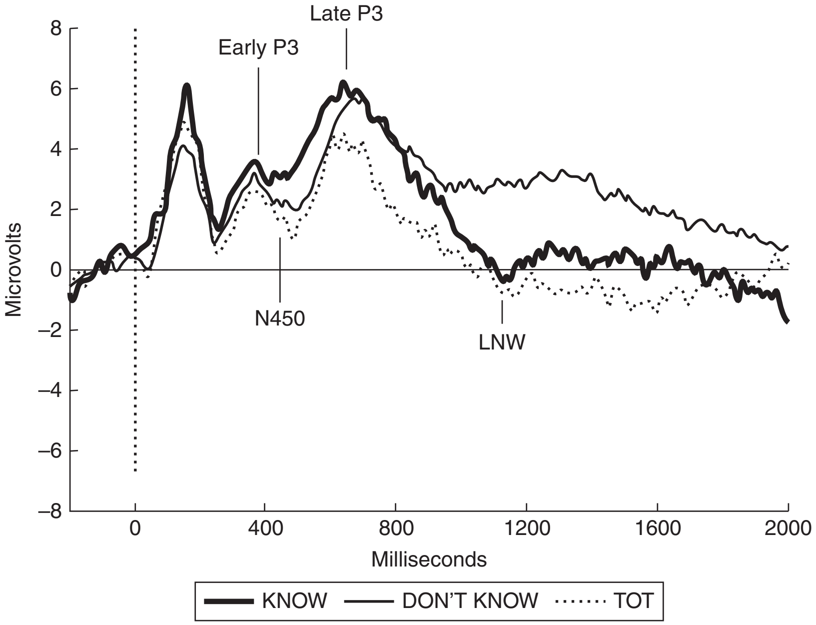


FIGURE 10.5. Grand-averaged ERP waveforms at Pz electrode site, for the K, DK, and TOT response categories. (Modified from Lindín & Díaz, 2010).

when categorizing the stimulus. Unlike the previous study (Díaz et al., 2007), Lindín and Díaz required participants to press a specific button for K and one for TOT (not the same button for both categories), so participants should have accessed the phonological information of the name before making the manual response.

The second major difference regarding Díaz and colleagues' study (2007) was that differences in the LNW amplitude among response categories were not obtained (Figure 10.5), which Lindín and Díaz interpreted as meaning that the differences observed in this component in Díaz and colleagues' (2007) study could be due to a modulation of the ERP waveform by motor components associated with the preparation and/or execution of verbal responses, as Buján, Lindín, and Díaz (2009) had confirmed.

Buján and colleagues (2009) evaluated the manual and speech Movement-Related Cortical Potentials (MRCP) in a subsample of the young participants involved in the previous study (Díaz et al., 2007). The results indicated that the LNW occurred in TOT at the same time as the negative slope of the MRCP, but in the K and DK conditions, LNW coincided with the interval corresponding to the speech-related motor potential

(Figure 10.6). The authors concluded that the differences Díaz and colleagues (2007) obtained in LNW amplitude among response categories (DK > K > TOT) might have been partly caused by the larger amplitude of the speech-related motor potential than the negative slope, and the different modulation of both motor components on the stimulus-related LNW component in K and DK regarding TOT conditions. Thus, this overlap of motor potentials might have masked the ERP correlates of the TOT experience and its consequences in the previous studies.

Furthermore, Buján and colleagues (2009) observed that while in the DK and K categories, a general mobilization of necessary resources was produced to preprogram the motor action (as is reflected in the adequate development of the first component of the readiness potential -1st-RP-). In the TOT, a temporal blockage of this mechanism is produced until completing categorization of the stimulus (whose ERP correlate is the late-P3 component). This blockage was considered the result of the division of processing resources between the fruitless search for semantic and lexical-phonological information about the famous person and the motor programming in the TOT.

Buján, Lindín, and Díaz (2010) showed with older adults a blockage in the development of 1st-RP in the TOT condition, but in a different time than the young participants. Thus, in older adults, more motor resources were allocated at the beginning of motor programming. Furthermore, the division of the processing resources started from the most demanding processing stages (stimulus categorization and review of the categorization and/or of the selected response), when the participant tries unsuccessfully to resolve the conflict between recognizing the famous person and knowing his/her name, but being unable to recall the complete phonology of the name. Buján and colleagues (2010) concluded that the interruption in the progression of the 1st-RP, in both young and older participants, could explain the specific behavioral slowing in TOT category with respect to the other response categories (K and DK).

Although the previous studies shed light about the electrophysiological characterization of face processing and the TOT phenomenon, several relevant aspects about the causes and consequences of the TOT remained unanswered. First, it was necessary to establish clearly if TOTs are due to a transmission deficit in earlier stages of processing (recognition, semantic, and/or lemma access). To achieve this goal, it would be necessary to compare this condition with a category in which no recognition and access to person-specific information take place. Comparison between ERP components associated with processes prior to the response decision was not

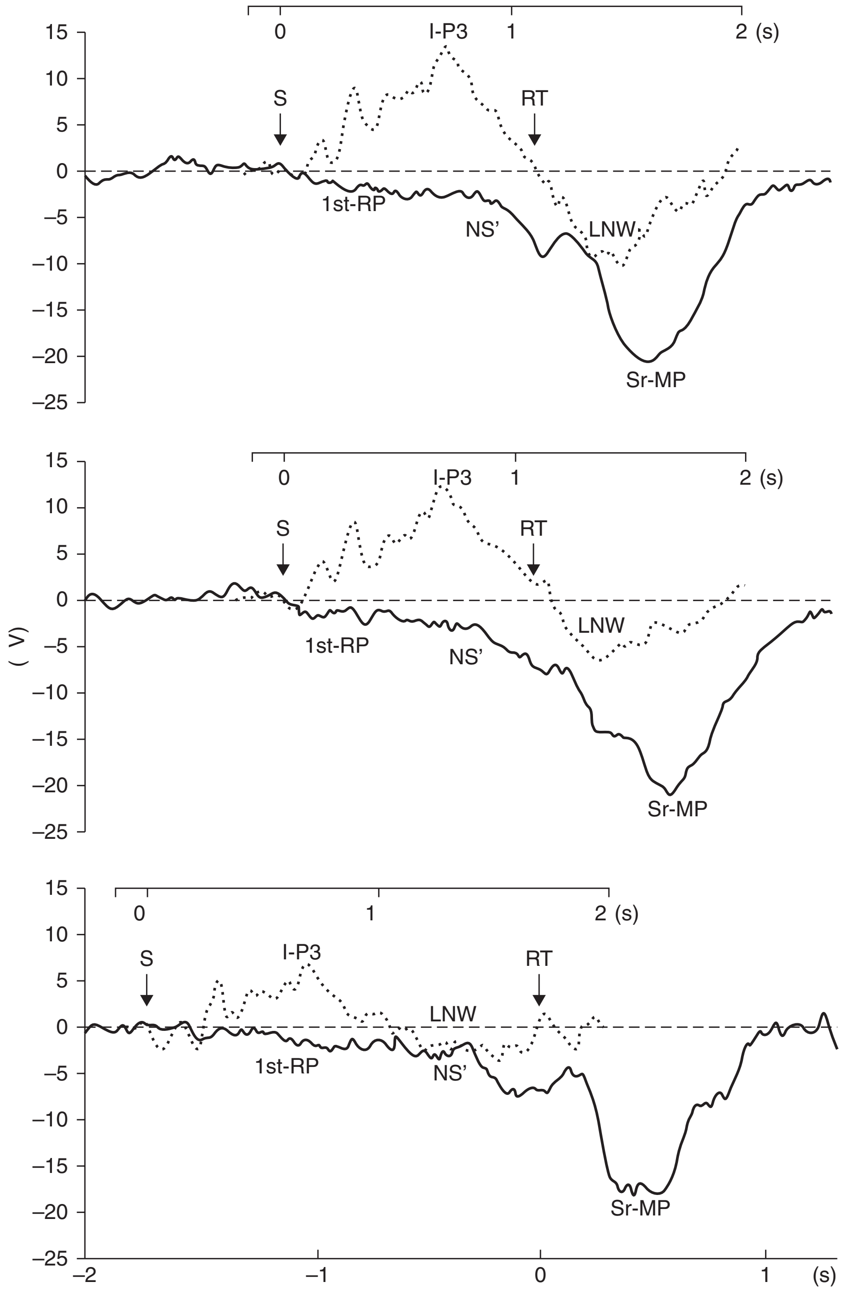


FIGURE 10.6. Mixed plots of the grand-averaged ERP waveforms obtained by stimulus-onset average in Pz electrode site (dotted line) and by response-onset average in Cz electrode site (solid line) for the DK (top), K (middle) and TOT (bottom) response categories (S: stimulus presentation; RT: reaction time; l-P3: late-P3; NS': negative slope; LNW: late negative wave; Sr-MP: speech-related motor potential). (From Buján et al., 2009).

possible in the previous studies because the DK category was poorly defined (as it did not allow differentiation of whether the participant recognized the character of the picture whose name he/she did not know). Second, none of these studies had definitively established the temporal interval in which the genesis of TOT state occurs.

Therefore, and to advance in the electrophysiological characterization of the TOT phenomenon in particular, and of the face processing and naming in general, Buján and colleagues (2012) conducted a new study with a modified face-naming task (Figure 10.7). As in Lindín and Díaz (2010), the task included a delay between the two motor responses (manual and verbal) to avoid the influence of the electrophysiological activity related to the verbal response in order to compare the latter temporal intervals of direct waveforms between the categories.

With the new task design, we tried to determine whether previous ERP studies may have masked differences between the KNOW and TOT conditions, which both may include successful access to semantic and lexical information. To test this hypothesis, the participants had to press a button with one hand if they knew the name of the famous person and press another button with the other hand if they did not know the name, but halfway through the task, in a second block of stimuli, the participants were instructed to change their hands to respond to each condition (knowledge vs. ignorance of the name). This change was necessary to isolate an ERP component named the *lateralized readiness potential* (LRP, a motor component associated to the selection of the response), which informs of the time required to access the necessary information to respond.[2] Specifically, researchers have used the onset latency of the stimulus-locked LRP (s-LRP) as an index of the timing of response selection (Kolev, Falkenstein, & Yordanova, 2006; Praamstra, Plat, Meyer, & Horstink, 1999), and in previous studies researchers have used it as an indirect measure of the access to phonological information required to select a response (Abdel-Rahman, Sommer, & Schweinberger, 2002; Van Turennout, Hagoort, & Brown, 1997). Thus, the s-LRP could represent an appropriate index to measure when the availability of phonological information differed between the successful naming and the TOT state. In addition, in the case of both the DK and the TOT state, several control questions were presented to ensure that TOTs were positive (that is, that participants' missing target was the correct one), and to confirm that in the DK the participant had no knowledge of the person seen in the photo. Finally, the onset latency of the response-locked LRP (r-LRP), which researchers have used as an index of the motor processing (Van der Lubbe & Verleger, 2002), was compared between the response

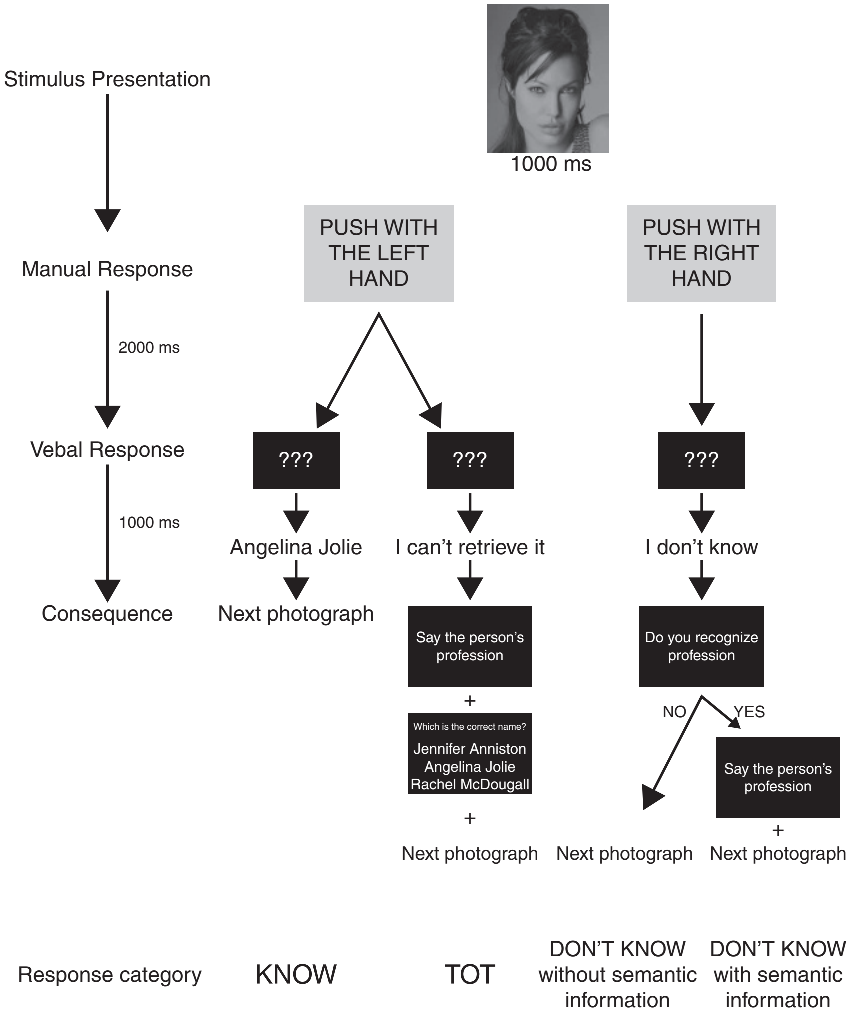


FIGURE 10.7. Face-naming task utilized in Buján and colleagues' (2012) study. The main differences regarding the previous tasks consisted of the improved characterization of the TOT and DK response categories, the time interval between the manual and the verbal responses and between the verbal response and the consequence, as well as a longer stimulus presentation time.

categories, which might clarify how the consequences of the TOT could affect the initiation of the motor processes.

The aims of Buján and colleagues' (2012) study were: 1) to investigate the main causes and consequences of TOTs, 2) to determine whether the access to semantic and lexical information is similar between the TOT state and successful naming, 3) to determine the moment at which the selection of the response takes place in successful naming (and therefore the access to enough information to emit a response), 4) to establish the temporal interval of TOT genesis by means of the stimulus locked lateralized readiness potential (s-LRP) analysis in both response categories (TOT and successful naming), and 5) to obtain the electrophysiological correlates of the TOT consequences (i.e., continuous search for information and conflict monitoring once the TOT is established).

The results again confirmed the similarities between successful naming (K) and TOTs, as they did not show differences in the ERP components related to the processing of faces (P1, N170, P2) and the access to specific information of the person (early P3, N450), although there were differences between both K and TOT and the DK category. However, as reflected by the s-LRP onset, the response was selected around 300 ms in the K category, whereas in the TOT category a delay occurred in the selection of the response (Figure 10.8). This data would indicate that around 300 ms enough information to carry out a successful naming was only retrieved in the K category, supporting the hypothesis of early hypoactivation in TOT for explaining the genesis of the TOT.

In addition, at later stages of processing (from 750 ms onward), researchers observed a smaller amplitude in the TOT category than in the K and DK categories, which they attributed to the devotion of many resources in later stages of processing in the TOT state to conflict management and a continued search of the name in memory. This metacognitive control of the attempt of name retrieval during the TOT state was supported by findings from behavioral studies that related TOTs to retrieval time in recall (Schwartz, 2001) and to the ways people attempt retrieval (Schwartz, 2002), and by findings from fMRI studies (Maril et al., 2001, 2005).

How? An Approximation to the Temporal-Spatial Information: The Sequence of Brain Activation in Successful Naming and TOTs

Lindín, Díaz, Capilla, Ortiz, and Maestú (2010) recorded, simultaneously with brain electrical activity (see Lindín & Díaz, 2010), the magnetoencephalography activity (using the MEG technique) to examine name retrieval and TOTs (see Figure 10.4). Because MEG presents a higher spatial resolution than EEG, the goal was to identify the network of brain areas that respond differently during successful naming (K response category) and failed naming of known faces (TOT response category), in order to delimit the brain regions associated with and the timing of the TOT.

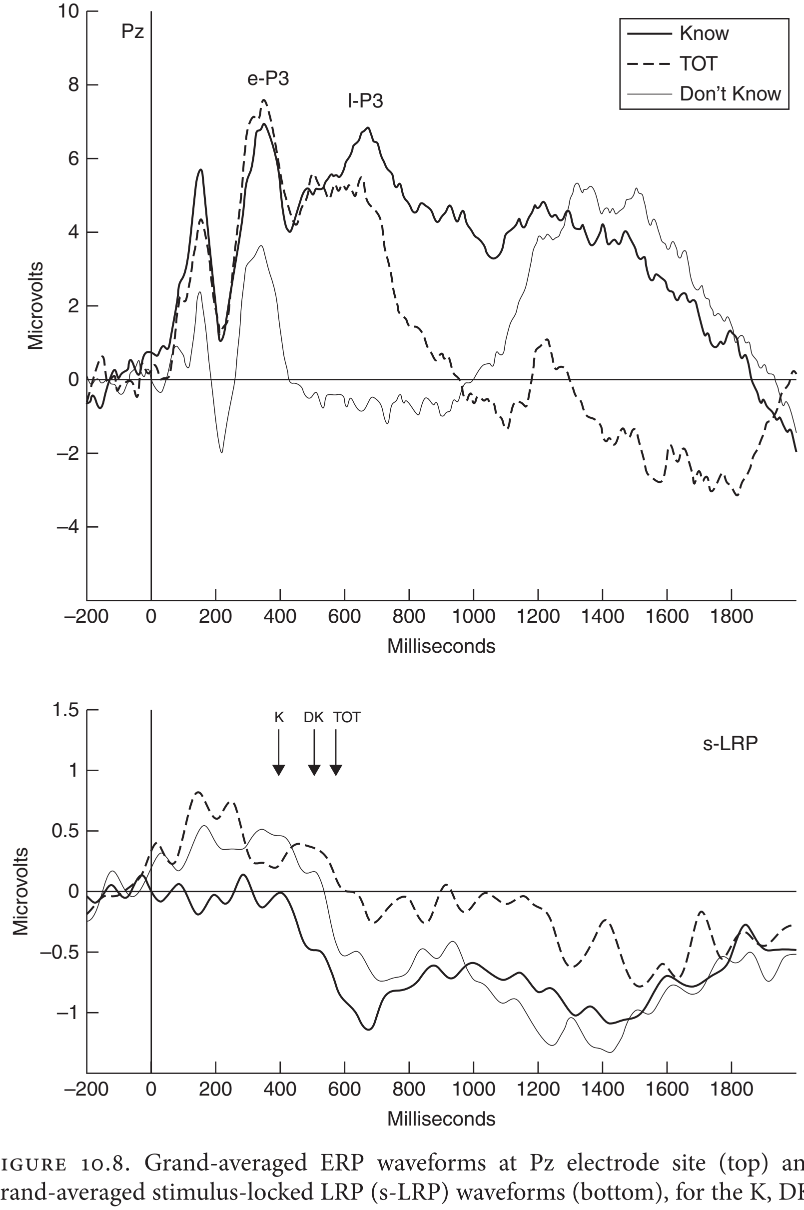


FIGURE 10.8. Grand-averaged ERP waveforms at Pz electrode site (top) and grand-averaged stimulus-locked LRP (s-LRP) waveforms (bottom), for the K, DK, and TOT response categories. The onset of the s-LRP in each category is indicated by arrows. (Modified from Buján et al., 2012).

Consistent with the results of ERP studies, in the first 210 ms in face processing, no differences appeared between both states, consistent with models of face processing and naming (e.g., Bruce & Young, 1986; Valentine, Brennen, & Brédart, 1996). Significantly greater activation in K than in TOT was observed in the 210–310 ms interval in the left anterior medial prefrontal cortex, the left orbitofrontal gyrus, the left superior temporal pole, and the left inferior and anterior middle temporal gyri, a network that could contribute to successful naming. In addition, in the 310–520 ms interval, Lindín and colleagues (2010) identified a smaller activation in TOT than in K in left frontal and temporal areas, bilateral parahippocampal gyrus and right fusiform gyrus, which was associated with the failure to retrieve the complete phonology of the name, that is, the genesis of the TOT state. In a later interval (between 740–820 ms), they observed greater activation in TOT than in K in bilateral occipital, left temporal and right frontal and parietal regions, what they interpreted as reflecting the active but fruitless search of the name in the TOT condition (Figure 10.9; see also Figure 10.1).

Galdo-Álvarez, Lindín, and Díaz (2011) compared, by means of the LORETA program, the temporal sequences of activation of ERP neural sources for the K and TOT conditions using Díaz and colleagues' (2007) face-naming task. The authors found significant differences in activation between the two conditions during the interval 538–698 ms (Figure 10.10), with greater activation for the K than for the TOT condition, in the anterior cingulate cortex and supplementary motor area (SMA), which was interpreted as a reflection of the preparation of the motor response and the successful retrieval of semantic and phonological information in the K condition. However, in late intervals (1000–1500 ms), they only observed activation in the anterior cingulate in the TOT condition, a result they attributed to the TOT experience once it has been established, as the cognitive control to search for the name in this category.

CLOSING THE CIRCLE: INTEGRATION OF NEUROCOGNITIVE DATA WITH CURRENT MODELS OF TOT PHENOMENON

From 2001 to the present, 14 papers have been published about brain functional correlates of TOTs. Each study, given the type of technique used by the experimental design, has provided various clues to understanding the TOT phenomenon. A comprehensive understanding of how the TOT state occurs and how it progresses requires exploring the spatiotemporal sequence of activation of neural networks involved in accessing information in memory and naming.

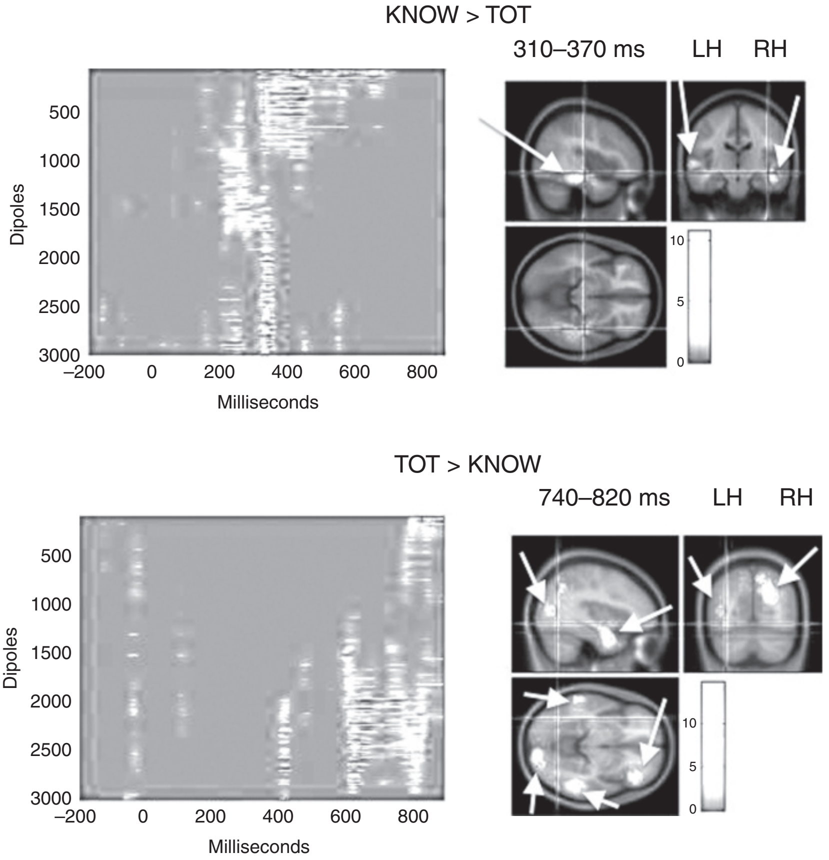
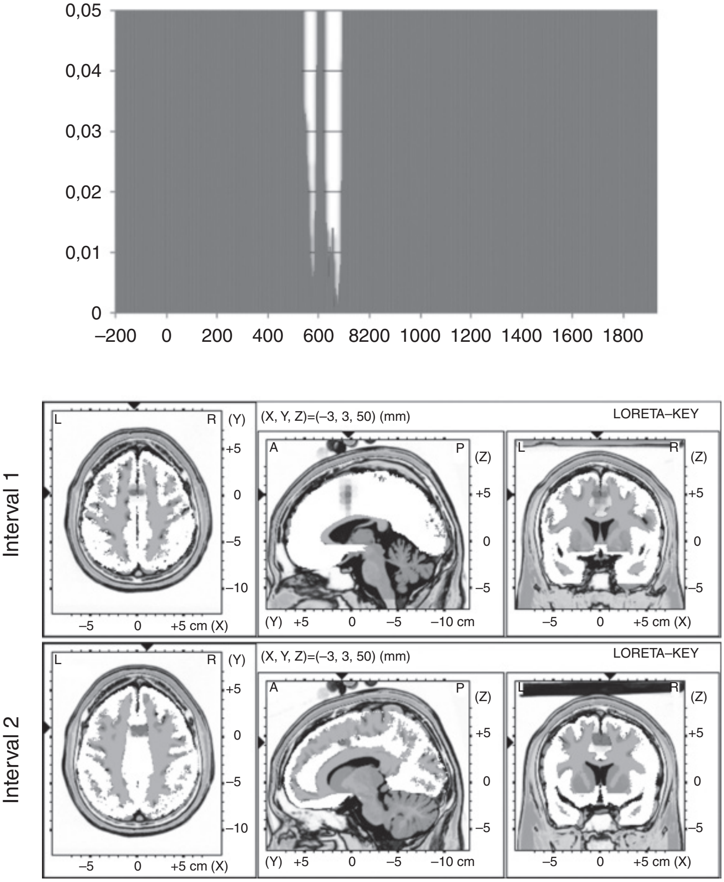


FIGURE 10.9. Temporal windows that showed a higher MEG dipolar activity (left), and some brain areas that showed significantly greater activation (right), in KNOW than in TOT response category (top), and in TOT than in KNOW response category (bottom). The color scale indicates the T values obtained in the t-tests. (Modified from Lindín et al., 2010).

The data obtained up to now with ERP and MEG to face-naming tasks suggest that the origin of the TOT could be due to an early hypoactivation (from approximately 300 ms) of brain regions involved in access to lexical and phonological information in memory, including insula and the left frontal and temporal lobes, along with the bilateral activation of the parahippocampal and fusiform gyri. In addition, greater activation for K than for the TOT condition in the interval between 538–698 ms, in the anterior cingulate cortex and the supplementary motor area, could reflect the actual preparation of the motor response in the successful naming condition (K)



Interval 1: (X= –3, Y=3, Z=50) BA 24/32/6: Left ACC and SMA

Interval 2: (X= 11, Y=10, Z=43; X=–3, Y=10, Z=43) BA 32: Bilateral ACC

FIGURE 10.10. TANOVA results with the LORETA software: Top Panel: p values of the comparison throughout the entire ERP waveforms between the K and the TOT conditions; the graphical representation shows two time intervals presenting significant differences ($p<.05$). Bottom 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). (From Galdo-Álvarez et al., 2011).

once successful information retrieval about the person, including the name, has taken place.

The neurocognitive data seems, therefore, to rule out that the TOT may be due to activation of intrusive words, which would result in a similar or higher brain activation in the TOT than in the K condition in the early stages of the processing, in line with behavioral results (see Brown, 2012). The transmission deficit hypothesis (Burke et al., 1991) seems, therefore, a more appropriate explanatory hypothesis to understand how TOTs arise. Successful access to the name allows one to prepare the response faster than when in a TOT, which explains the shorter reaction times commonly found in successful naming when comparing this condition with the TOT state (Buján et al., 2012; Díaz et al., 2007; Galdo-Álvarez et al., 2009a).

The transmission deficit hypothesis (Burke et al., 1991) explains how the TOT state originates, but does not explain the features, the consequences, and the processes that occur once a TOT has been initiated. In this concern, the neurocognitive data indicate greater activation in the TOT state than in the successful naming condition, from approximately 750 ms onward, of the bilateral occipital, left temporal, right frontal, and parietal areas, and the anterior cingulate cortex (see Kikyo et al., 2001; Lindín et al., 2010; Maril et al., 2001, 2005), which could be associated with conflict management and with the unfruitful search in the memory for the name corresponding to the face once the TOT state was established, in line with the inferential theories of TOT.

In summary, neuroimaging techniques are useful tools to delve into explanatory mechanisms and characteristics of the TOT phenomenon. Neuroimaging is also critical in understanding the mechanisms of access to semantic, lexical, and phonological information in memory and naming. We examined, using ERP and MEG, the origin and consequences of TOT. Confirming the data obtained through behavioral studies, we have found similarities between the successful naming and the TOT state, while finding only subtle differences in brain activation (hypoactivation of areas involved in the retrieval of lexical-phonological information) in early processing stages. We assert that this hypoactivation serves as the genesis of the TOT. Moreover, a complete characterization of the TOT phenomenon requires attention to metacognitive conflict management once this has occurred, including the continued search for information that has not been retrieved, and that is reflected in activation of specific brain regions, including the ACC, in late processing stages.

NOTES

1. The MEG records magnetic fields only from cortical, not subcortical neurons, and the magnetic field should be perpendicular to the sensors for being recorded. Given that the brain cortex is folded forming ridges (named gyri) and furrows (named sulci), the activity this technique measures corresponds to

populations of pyramidal neurons in cortical sulci disposed parallel to the scalp, being a technique relatively blind to neuronal activity in the cortical gyri.

2. The LRP is the result of isolating the larger activity of the motor cortex contralateral to the hand that executed the movement. Thus, a larger negativity is observed at contralateral than at ipsilateral central electrodes when the participant is performing a response with a hand. The hand selection is associated with the access to the required information in tasks in which the response depends on the retrieval of specific information.

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