An event-related potentials study of face naming: Evidence of phonological retrieval deficit in the tip-of-the-tongue state

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Abstract

A famous-face naming task was used to establish the electrophysiological characterization of the states of tip-of-the-tongue (TOT), successful naming (K), and nonrecognition (DK). The differences in the direct event-related potentials (ERPs) and in the lateralized readiness potential (LRP) between those categories were studied.

The ERP correlates of recognition and access to semantic and lexical information were similar between K and TOT, but showed amplitude differences with respect to DK. A delayed onset of the response selection was obtained in TOT in comparison with K, suggesting an insufficient activation of phonological information from 360 ms onwards. The continuous search for the name and the conflict monitoring in TOT led to differences in ERP amplitudes between TOT and the other categories from 750 ms onwards as well as to a delayed onset of response preparation, indicating a continuous engagement of processing resources.

Descriptors: Cognition, Language/Speech, Learning/Memory, Normal volunteers, EEG/ERG

Face processing and naming is a socially relevant skill that human beings can perform with relatively little effort. However, the cognitive mechanisms underlying face processing are far from simple. The complexity of the process is reflected by the fact that the experimental evidence has led to several modifications of the first functional model of face recognition (Bruce & Young, 1986). A reformulation of that model, proposed by Valentine, Brennen, and Brédart (1996), integrated models of face recognition and naming with lexical access models (Burke, MacKay, Worthley, & Wade, 1991; Levelt, 1989) and suggested various levels of representation, some of which take place in series and others in parallel, from the moment a face is perceived to the final naming output. The two first levels of representation are the same as in the Bruce and Young model: the construction of a visual percept of the face (structural coding) and its comparison with the representations stored in face recognition units (FRUs). The next step is the access to person identity nodes (PINs), which function as token markers or prelexical nodes that identify individuals and that enable parallel access to identity-specific semantic information (traits, nationality, occupation, etc.) and names. The semantic system is divided into the general semantic system (access to names of descriptive properties) and identity-specific information. The access to the semantic lexicon (lemmas) is decomposed into two substores: common name lemmas, which are accessed via the general semantic system, and lemmas for proper names, accessed via PINs. The next step is the access to the phonological output lexicon or lexemes directly from the semantic lexicon¸ and, finally, the articulation of the name by means of muscle motor programs takes place. This model was supported by behavioral and psychophysiological results (see Galdo-Álvarez, Lindín, & Díaz, 2009b for a review).

The event-related potential (ERP) technique has been found to be a useful tool for assessing the validity of cognitive models of face processing. For example, the stages related to the recognition of a face (i.e., FRU activation) have been studied by comparing the ERPs associated with familiar and unfamiliar faces (Begleiter, Porjesz, & Wang, 1995; Bentin & Deouell, 2000; Eimer, 2000). However, as some of the stages take place in parallel (i.e., access to semantic and lexical information), researchers have made use of the ERP technique during several natural and experimental observable occurrences in order to isolate the different stages, for example, by analyzing the lateralized readiness potential (LRP) to study the temporal differences in the access to semantic and phonological information (Abdel-Rahman, Sommer, & Schweinberger, 2002; van Turennout, Hagoort, & Brown, 1997). Nevertheless, the dissociation between the access to semantic lexical (lemma) and phonological information (lexeme) has not been sufficiently studied. The tip-of-the-tongue (TOT) state would provide scientists with an opportunity to differentiate the lexical and the phonological access. TOT is a natural and universal phenomenon that involves a temporary failure to retrieve a word, even when it could be retrieved before, accompanied by the feeling of being on the verge of remembering (Brown & McNeill, 1966). In accordance with most of the behavioral data and cognitive models of lexical access, this phenomenon is characterized by successful semantic and lemma retrieval, but with incomplete phonological access (Bock & Levelt, 1994; Burke et al., 1991; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Gollan & Brown, 2006; Harley & Brown, 1998; Levelt, Roelofs, & Meyer, 1999). Although some criticism exists referring to the decomposition of the lexical access in the two steps adopted here, lemma selection and lexeme codification (Caramazza & Miozzo, 1997; Miozzo & Caramazza, 1997), the models that support this distinction have more acceptance, because they are capable of explaining most of the neuropsychological and TOT data.

From a psychophysiological perspective, Díaz, Lindín, Galdo-Álvarez, Facal, and Juncos-Rabadán (2007), and more recently Lindín and Díaz (2010), presented face-naming tasks to young participants while recording the electroencephalogram (EEG) activity to compare the ERP waveforms produced in a successful naming (KNOW–K–) category with those produced in a TOT category, whereas they only partially analyzed a third category (DON’T KNOW–DK–). The main objective in both studies was to characterize the ERP components associated with the different stages of face processing. In both studies, no differences were observed between K and TOT response categories in ERPs related to early domain-general visual processes (P100), structural coding (N170), or face recognition (P2 and N2). Nevertheless, smaller amplitude in TOT than in K category in the temporal interval was reported, corresponding to a P3 component (late P3), related to stimulus evaluation time and the completion of stimulus classification. The authors concluded that processing resources were divided in TOT between the stimulus classification (late P3 amplitude) and the continuous search for information in memory and, therefore, as a consequence of the deficit of activation in the lexical-phonological route. Additionally, in the study of Lindín and Díaz (2010), longer latencies for the early P3 and N450 components were found in TOT than in K category, indicating slower access to specific information about the person in the TOT category.

Although these previous studies shed light about the electrophysiological characterization of face processing and TOT phenomenon, several relevant aspects about the causes and consequences of the TOT state remained unanswered. Firstly, it is assumed that semantic and lemma retrieval is similar in TOT and successful naming

(Bock & Levelt, 1994; Burke et al., 1991; Dell et al., 1997; Gollan & Brown, 2006; Harley & Brown, 1998; Levelt et al., 1999). Consistently, Díaz et al. (2007) did not find differences between TOT and K in ERP components associated with these processing stages (P2, N2, and early P3). However, in order to establish clearly if TOT is not due to a transmission deficit in earlier stages of processing (recognition, semantic, and/or lemma access), 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 possible in previous studies because the DK category was poorly defined. Secondly, as mentioned above, both previous studies found larger amplitude in K than in TOT in late P3 component and, therefore, a consequence of the failure to access the name in that category. Lindín and Díaz (2010) also found latency differences between TOT and K in temporal intervals related to a slower access to specific information about the person in TOT, but neither of these studies has established clearly the temporal interval in which the genesis of TOT state occurs. Thirdly, previous neuroimaging (Kikyo, Ohki, & Sekihara, 2001; Maril, Wagner, & Schacter, 2001) and magnetoencephalographic (MEG) studies (Lindín, Díaz, Capilla, Ortiz, & Maestú, 2010) have consistently obtained greater activation of frontal cerebral regions in TOT than in successful naming, which has been attributed to the consequences of the TOT state: continuous search for information to retrieve the target name and conflict monitoring.

To date, no electrophysiological correlates of a continued search in memory stores have been found later than the stimulus-classification stage (i.e., late P3). In these latter intervals, Díaz et al. (2007) observed a late negative wave (LNW), with apparently larger amplitude in DK and K than in TOT, which was attributed to the greater amount of processing resources released after the closure of the stimulus epoch in the DK and K categories. However, as the authors indicated, this difference might have been modulated by the cerebral activity associated with verbal-related potentials, due to the participants having to perform two motor responses sequentially, with no delay between them; that is, they had to press a button and then say the name of the person or a specific phrase. This hypothesis was tested and later demonstrated by Buján, Lindín, and Díaz (2009), by evaluation of motor-related cortical potentials (MRCPs) in a subsample of the participants in the study of Díaz et al. (2007). In fact, this is consistent with the smaller amplitude of the LNW found by Lindín and Díaz (2010), using a similar task but with a 2-s delay between both motor responses, although the results of the latter study were inconclusive.

Therefore, and in order to advance in the electrophysiological characterization of the TOT phenomenon in particular, and of the face processing and naming in general, in the present study a modified face-naming task was presented to young participants (see Procedure). The main objectives of the present study in order to investigate the main causes and consequences of the TOT state, therefore, were:

- to determine whether the access to semantic and lexical information is similar between the TOT state and successful naming (K category) or whether the access to this kind of information in TOT state is affected. To this aim, the amplitude of ERP components previously related with the access to this kind of information (E-P3 and N400) were compared between both categories and a category in which no recognition of the face or no access to person-specific information takes place (DK category).

- 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), and to establish the temporal interval of TOT genesis, by means of s-LRP analysis in both response categories. The onset latency of the stimulus-locked LRP (s-LRP) has been used as an index for the timing of response choice (Kolev, Falkenstein, & Yordanova, 2006; Praamstra, Plat, Meyer, & Horstink, 1999), and in previous studies it has been used as an indirect measure of the access to phonological information (Abdel-Rahman et al., 2002; van Turennout et al., 1997).
- to obtain the electrophysiological correlates of the TOT consequences (i.e., continuous search for information and conflict monitoring once the TOT state is established). To this aim, a delay between the two motor responses to avoid the electrophysiological activity related to the verbal response was included in order to compare the latter temporal intervals of direct waveforms between the categories. In addition, the latency onset of the response-locked LRP (r-LRP), which has been used as an index of the motor processing (Van der Lubbe & Verleger, 2002), was compared between the categories, which might clarify how the consequences of the TOT state could affect the initiation of the motor processes.

Method

Participants

Nineteen participants (5 men, 14 women) between the ages of 18 and 27 years (mean: 20.9, *SD*: 3.03), took part voluntarily in the study. All participants were healthy, with normal or corrected-to-normal vision acuity, with no history of neurological or psychiatric disorders, and were not taking any medication during the 4 weeks prior to the study. Seventeen of the participants were right-handed, one was left-handed, and one was ambidextrous, as assessed by the Edinburgh inventory (Oldfield, 1971). The study received prior approval by the local ethical review board. All participants gave their informed consent prior to their inclusion in the study, and did not report fatigue due to insufficient sleep. None of the participants were familiar with the protocols used in the study.

Procedure

The participants remained seated in a comfortable chair in an electrically isolated laboratory with attenuated light and sound, and were instructed not to move during recording.

Stimuli were photographs of the faces of famous people. The images were obtained from various sources (i.e., analyzed databases from the media or Internet or analyzed images from magazines). The photographs were all software edited for homogeneity of background and with respect to color, contrast, and average luminance. All images were in color, and showed a frontal view of the face, with clear representation of all major features, against a neutral background. Negative facial expressions were avoided, and images with neutral or mildly positive expressions were generally used.

Each participant was shown 300 photographs, each for 1,000 ms (instead of the 314 ms used in the previous studies to prevent overlapping of cognitive ERP components and possible exogenous potentials related to photograph offset), at a distance of 1 m, with a subtended visual angle of 6.01° × 7.73° of arc, on a 19″ flat screen monitor with a vertical refresh rate of 120 Hz. The photographs were presented in 4 blocks of 75, with an interblock interval of 90 s in order to limit the effects of fatigue.

During presentation of the stimuli, participants maintained a steady position by looking at a cross that appeared in the center of the screen during intervals without a photo. In response to each photograph (see Figure 1), the participants were required to press, as rapidly as possible, one of two keys on a response device, with a different hand, depending on whether they knew or did not know the name of the person. They had to press the blue key with one hand if they were sure that they knew the person's name and the red key with the other hand if they were sure that they did not know the name.

The manual responses were counterbalanced within the task; that is, in the two first blocks the participants had to press the blue key with one hand and the red key with the other hand, and in the next two blocks they had to respond in the opposite way. The manual responses were also counterbalanced between participants. Immediately before each of these two parts of the task, a practice block of 10 photographs (different from the 300 used in the study) was presented to ensure that the participants had correctly understood the procedure.

One second after pressing the key, three questions marks appeared on the screen, and at that moment the participants were required to produce a verbal response. If the participants knew the name of the person, they had two options: (1) to say aloud the name of the famous person (K response category); 1 s after this response the next photograph in the series appeared, or (2) to say aloud, "I can't retrieve it" if they were sure they knew the name and felt that they were on the verge of producing it, but could not remember it at that moment (TOT response category). After a TOT response, two questions appeared on the screen to check whether this was an authentic TOT state; the participants were asked the profession of the person and, after they answered, they were shown a list of three names, including the correct name, a semantic prime, and a fictitious name. After the participant answered, the next photo appeared. Only trials in which the answers given to both questions were correct were considered as authentic (positive) TOTs.

If the participants had pressed the key indicating they did not know the name, they had to say aloud, “I don’t know it” when the three questions marks were shown on the screen. The question, “Do you recognize the person?” was then presented. Regarding the answer to this question, the DK responses were divided into two subcategories: (1) DK without semantic information: the participants answered “NO” (they did not recognize the person) and the next photo appeared; and (2) DK with semantic information: if the participants answered “YES” (they recognized the person), a question about the person’s profession appeared on the screen and, after the participant answered, the next photo was presented. Only correct answers to this question were considered as DK with semantic information.

Electroencephalographic (EEG) Monitoring

The EEG activity was recorded with 49 active electrodes inserted in a cap (see Figure 2), in accordance with the International 10-10 System, with a nose reference and frontopolar ground. The signal was passed through a 0.01–100 Hz analog band-pass filter, and the sampling rate was 500 Hz. Simultaneous with EEG recordings, ocular movements (EOG) were recorded with two electrodes located supra and infraorbitally to the right eye (VEOG) and another two located at the lateral canthi of each eye (HEOG). All impedances were maintained below 10 kΩ. After signal storage, the signal was passed through a 0.1–20 Hz (12 dB/octave slope) digital band-pass filter, and ocular artifacts were corrected by use of the Independent Component Analysis (ICA) algorithm (Makeig, Jung, Bell, Ghahremani, & Sejnowski, 1997); the EEG was then segmented in epochs of 2,200 ms associated with presentation of the stimulus (200 ms prestimulus baseline). Each epoch was classified a posteriori as K, TOT, DK without semantic information, or DK with semantic information, depending on the participant's response. Epochs were then corrected to the mean voltage of the 200 ms prestimulus recording period (baseline). Finally, epochs with signals exceeding ± 150 μV were automatically rejected, and all remaining epochs were individually inspected to identify those still showing artifacts; the epochs with artifacts were also excluded from subsequent averaging. For each response category, at least 25 artifact-free epochs were averaged. As the number of participants presenting a minimum of 25 epochs for the DK with semantic information category was not sufficient, only the analyses for the other three categories were carried out.

Data Analysis

The percentage of manual responses and the mean reaction times between the onset of the stimulus and pressing the key (considering only reaction times above and below 3 standard deviations from the mean of all the trials) in the three response categories (K, TOT, and DK without semantic information) were analyzed.

For ERP recordings, three averaged ERP waveforms were obtained for each participant (one for each response category: K, TOT, and DK without semantic information), for both LRP and direct ERPs.

Five components were identified in direct ERP waveforms for the three response categories: P1, N170, P2, early P3, and N450. In addition, the late P3 component was observed in K and TOT. The latency and the amplitude of P1 and N170 components were measured at the maximum peak relative to the baseline: P1 in the interval between 80–170 ms at O1, Oz, O2, P9, and P10; N170 in the interval between 150–200 ms at P9, P10, PO7, and PO8.

The mean amplitudes over four time intervals corresponding with the rest of the identified ERP components were analyzed: 200–300 ms (P2), 300–400 ms (early P3), 400–550 ms (N450), and 550–750 ms (late P3). In addition, the mean amplitudes over five latter time intervals were analyzed: 750–1,000 ms, 1,000–1,350 ms, 1,350–1,550 ms, 1,550–1,750 ms, and 1,750–2,000 ms. The mean amplitudes were measured at midline electrodes (Fz, Cz, Pz, and Oz) and in eight lateral regions of interest (ROIs) (see Figure 2): left frontal (LF: AF3, AF7, F3, F5, F7), right frontal (RF: AF4, AF8, F4, F6, F8), left central (LC: FC3, C3, C5, CP3), right central (RC: FC2, C4, C6, CP4), left temporal (LT: FT7, FT9, T7, TP7, TP9), right temporal (RT: FT8, FT10, T8, TP8, TP10), left parietal-occipital (LPO: P3, P7, P9, PO7), and right parietal-occipital (RPO: P4, P8, P10, PO8).

The s-LRP and the r-LRP were calculated by the averaging method (Coles, 1989; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988). The onset of the LRP in each category was measured using the segmented regression (SR) method developed by Schwarzenau, Falkenstein, Hoormann, and Hohnsbein (1998). To obtain a measure of the resources allocated in the preparation and execution of the response, the mean amplitude in an interval around the maximum peak was measured (600 to 800 ms for s-LRP, and -200 to 0 ms for r-LRP). Comparisons were made between pairs of categories (K and TOT; K and DK; TOT and DK) because for each category the number of participants included in the analyses was different, as not all of the 19 participants produced a sufficient number of epochs in all categories to enable calculation of the LRPs.

Statistical Analyses

Repeated measures analysis of variance (ANOVA) with one within-subjects factor (Response Category, with three levels: K, TOT, and DK) was used to compare the percentage of responses and RTs in the three response categories.

To investigate the factors affecting the peak amplitude and latency of P1 and N170 components, repeated measures ANOVAs were performed, with two within-subjects factors, Response Category (with three levels: K, TOT, and DK) and Electrode Position (with five levels for P1: Oz, O1, O2, P9, and P10; with four levels for N170: P9, P10, PO7, PO8).

To compare the mean amplitudes in the time intervals in the three response categories and at the different regions, two types of repeated measures ANOVAs were performed: (1) with two within-subjects factors, Response Category (with three levels: K, TOT, and DK) and Midline (with four levels: Fz, Cz, Pz, and Oz); and (2) with three within-subjects factors, Response Category (with three levels: K, TOT, and DK), ROI (with four levels: frontal, central, temporal, and parietal-occipital) and Hemisphere (with two levels: right and left). The Greenhouse-Geisser correction was applied to degrees of freedom in all cases in which the condition of sphericity was not met. When the ANOVAs revealed significant effects due to the factors and their interactions, posterior comparisons of the mean values were carried out by paired multiple comparisons (adjusted to Bonferroni correction).

The onset latencies and mean amplitudes of s-LRP and r-LRP were compared between pairs of categories (K and TOT; K and DK; TOT and DK), by use of *t* tests for paired samples.

Differences in results were considered significant at $p < .05$.

Results

Performance

The mean percentage of responses was 36% for the K category, 19% for the TOT category, and 37% for the DK category without semantic information (Figure 3). The remaining 8% corresponded to the DK category with semantic information. The repeated measures ANOVA (Response Category) showed a significant effect for the percentage of responses, $F(2,36) = 6.12$; $\varepsilon = .58$; $p < .05$, as the percentage of K and DK responses was significantly higher than the percentage of TOT responses. The repeated measures ANOVA (Response Category) for the reaction times also revealed significant differences between the response categories, $F(2,36) = 14.81$; $p < .001$, as the reaction time was significantly longer for TOT (1,231 ms) and DK (1,111 ms) responses than for K (986 ms) responses (Figure 3).

Event-Related Potentials (ERPs)

Direct event-related potentials. The grand-averaged ERP waveforms for each response category (K, TOT, and DK) are shown in Figure 4. The *F* values in repeated measures ANOVAs (Response Category × Midline and Response Category × ROI × Hemisphere) for mean amplitudes over the intervals evaluated are shown in Table 1.

As indicated in the introduction, the main objective of the study was to investigate the causes and consequences of TOT state by means of comparing the TOT responses with successful naming and DK categories, so only the comparisons concerning the Response Category factor or its interactions were considered further. The comparisons for the Midline, ROI, and Hemisphere factors and their interactions are shown in Table 1.

As was the case in our previous studies (Díaz et al., 2007; Lindín & Díaz, 2010), there were no significant main effects of or interactions with Response Category in the P100 and N170 latency windows.

In the 200–300 ms interval, in which the P2 component was observed, the ANOVA for midline revealed a significant effect of the Response Category factor, as the mean amplitude was more positive in the K than in the DK response category. The ANOVA for ROIs showed the same effect, but the significance was marginal.

For the 300–400 ms interval, corresponding with early P3 component, analysis of both midline and ROIs revealed a significant effect of Response Category factor, as the mean amplitude was significantly more positive in K and TOT than in DK. In addition, in the ANOVA for ROIs the Response Category × ROI × Hemisphere interaction was also significant, as the mean amplitude was more positive in K and TOT categories than in the DK category at frontal ROI in both hemispheres and at the central region in the right hemisphere. Also, the mean amplitude was more positive in K than in DK at central ROI in the left hemisphere and at temporal and parieto-occipital ROIs in both hemispheres.

In the temporal interval in which N450 component was observed, 400–550 ms, both ANOVAs revealed a significant effect of Response Category, as the mean amplitude was more negative in the DK response category than in K and TOT.

Both ANOVAs revealed a significant effect of the Response Category factor for the 550–750 ms interval, corresponding with the late P3 component latency window. The positivity was significantly larger in K than in DK. The ANOVA for midline electrodes also showed marginally larger amplitude in TOT than in DK.

Both ANOVAs revealed a significant effect of Response Category factor in the 750–1,000 ms interval, with more positive mean amplitude in K than in DK. In the ANOVA for midline, the amplitude was significantly larger in K than in TOT as well. The ANOVA for ROIs also revealed a significant effect for the interaction between

Response Category and Hemisphere factors, but which only affected the ERP topography in each category.

The ANOVAs revealed larger positivity in K than in TOT both for midline and for ROIs analyses in the 1,000–1,350 ms interval. In the analysis for ROIs, the interaction between Response Category × Hemisphere was also significant, but the effect was due to differences in the topography of each category.

Between the 1,350–1,550 ms interval and the final interval (1,750–2,000 ms), both ANOVAs showed a significant effect of Response Category factor, with more positive amplitude in K and DK than in TOT. The ANOVA for ROIs revealed a significant effect of Response Category × Hemisphere interaction, but the effect was again due to differences in the topography of each category.

In the final interval, 1,750–2,000 ms, the Response Category × ROI × Hemisphere interaction was significant, as the mean amplitude was more positive in K and DK than in TOT at frontal and central regions in both hemispheres. At the temporal region in the left hemisphere, there were differences between K and TOT, and in the same region in the right hemisphere the amplitude was significantly more positive in K and DK than in TOT. In the parietal-occipital region in the left hemisphere, the mean amplitude was more positive in DK than in TOT, and in the right hemisphere the amplitude was more positive in K and DK than in TOT.

Lateralized readiness potential (LRP). The grand-averaged s-LRP and r-LRP waveforms for each response category (K, TOT, and DK) are shown in Figure 5.
The *t* values for s-LRP and r-LRP onset latencies and for mean amplitudes over the intervals evaluated are given in Table 2.

For s-LRP onset latencies, the *t* tests revealed significant differences between K (362 ms, *SD*: 113 ms) and DK (480 ms, *SD*: 149 ms), and between K (363 ms, *SD*: 105

ms) and TOT (460 ms, *SD*: 113 ms). There were no differences between the TOT and DK categories. The mean amplitude of s-LRP in the 600–800 ms interval was significantly larger in K (-.65 μV, *SD*: 1.09 μV) than in TOT (-.07 μV, *SD*: 1.35 μV) and no differences were observed in the other comparisons.

For r-LRP onset latencies, the *t* test revealed a marginally significant difference between TOT and DK, as the onset was earlier in DK (-415 ms, *SD*: 190 ms) than in TOT (-293 ms, *SD*: 73 ms). There were no differences with regard to the mean amplitudes.

Discussion

In the present study, three main aims were proposed: (1) to determine whether the access to semantic and lexical information is similar between the TOT state and successful naming (K category) or whether the access to this kind of information in TOT state is affected; (2) to establish the temporal interval of TOT genesis; and (3) to obtain the electrophysiological correlates of the TOT consequences (i.e., continuous search for information and conflict monitoring once the TOT state is established).

The comparison of the visual percept with the representation of faces stored in FRUs has been associated with ERP modulations in the 200–300 ms interval (Bindemann, Burton, Leuthold, & Schweinberger, 2008; Herzmann, Schweinberger, Sommer, & Jentzsch, 2004; Herzmann & Sommer, 2007; Milivojevic, Clapp, Johnson, & Corballis, 2003; Pfütze, Sommer, & Schweinberger, 2002; Schweinberger, Pickering, Jentzsch, Burton, & Kaufmann, 2002). In the present study, P2 component was observed at parietal-occipital positions in this time interval. The mean amplitude in the interval was similar between K and TOT categories, consistent with data of previous studies (Díaz et al., 2007; Lindín & Díaz, 2010). Nevertheless, the mean amplitude was significantly larger in K than in DK. Milivojevic et al. (2003) showed that P250 is related to configural recognition, as it had greater amplitude for normal than for distorted (thatcherized) faces. Therefore, the smaller positive amplitude in DK than in K may indicate the lack of configural recognition in DK, probably reflecting the lower activation of the face representations or the lack of matches with a particular FRU.

The empirical data showed that parallel access to person-specific information stores takes place between 300 and 600 ms (Abdel-Rahman et al., 2002; Díaz et al. 2007; Huddy, Schweinberger, Jentzsch, & Burton, 2003). In the present study, two components were found in this interval: early P3 and N450. The mean amplitude in the interval corresponding to early P3 component (300–400 ms) was larger in K and TOT than in DK, reflecting positive activation of PINs and access to semantic and lexical-phonological information in K and TOT, but a lack of activation of this information in DK. These data support the interpretation of Díaz et al. (2007) regarding the functional significance of early P3 component.

Following early P3, a negative wave with a mean latency of about 450 ms and maximum amplitude at frontal-central positions was found. Although the N450 component was not analyzed in the study of Díaz et al. (2007), a similar component was found in studies of face recognition, and it was identified as the N400 analog elicited by faces (Bentin & Deouell, 2000; Eimer, 2000; Galdo-Álvarez, Lindin, & Diaz, 2009a; Lindín & Díaz, 2010; Olivares, Iglesias, & Rodríguez-Holguín, 2003). Modulations in the N400-analog interval in face recognition and identification tasks have been interpreted as indexes of the activation of knowledge about a person.

In the present study, the mean amplitude in the interval of N450 component was smaller for K and TOT categories than for DK. This result differs from findings of previous studies, in which the opposite pattern was found (Bentin & Deouell, 2000; Eimer, 2000; Jemel, Schuller, & Goffaux, 2010). However, the tasks used in previous studies (i.e., familiarity judgments or semantic classification) were rather different than the task used here; in the present design, the main objective of participants was to access the person's name, and therefore it was necessary to access the lexical representation of the name. Moreover, Kutas and Federmeier (2000) and Lau, Almeida, Hines, and Poeppel (2009) pointed out that reductions in the N400 amplitude may reflect ease of lexical access resulting from priming or preactivation. The reduced amplitude in K and TOT may reflect facilitated access of stored lexical information due to preactivation of the corresponding lexical entries in those categories. In accordance with the model of Valentine et al. (1996), such preactivation would be caused by top-down influences, given the parallel access to semantic and lexical stores and the bilateral excitatory connections among them, once the PINs have been activated.

Therefore, the results obtained for P2, early P3, and N450 components showed the existence of clear amplitude differences between K-TOT and DK, indicating a similar processing between K and TOT at these stages, in accordance with behavioral data and cognitive models of face recognition and naming. Consequently, in accordance with the transmission deficit hypothesis of Burke et al. (1991), the main cause of the TOT state is probably the insufficient phonological access due to weaker connections between the lexical and phonological nodes.

Consistently, an earlier onset of the s-LRP was obtained in K than in TOT, implying a slowing down in the response selection in TOT. These data suggest that the recovery of enough phonological information about the name in order to select the manual response was faster in K than in TOT, specifically 100 ms faster. The s-LRP onset in K category was around 360 ms, coinciding with early P3 component of the direct waveform, which supports parallel access to semantic and lexical-phonological information once the PINs have been activated. The successful spread of activation across lexical and phonological nodes in K led to an earlier response selection, whereas the lower activation of those nodes or the weaker connections between lexical and phonological stores in TOT delayed the response selection. In addition, the amplitude of s-LRP was greater in K than in TOT, probably reflecting more confidence in the response selected in K, or that more processing resources were allocated to the motor process in this category (Carrillo-de-la-Peña, Galdo-Álvarez, & Lastra-Barreira, 2008; Carrillo-de-la-Peña, Lastra-Barreira, & Galdo-Álvarez, 2006), which would be consistent with a division of resources between the response selection and the continued phonological search in memory stores during a TOT state (Maril, Simons, Weaver, & Schacter, 2005).

It seems paradoxical that no differences were found between K and TOT in direct ERP components around the intervals in which the s-LRP showed differences between K and TOT. However, these results agree with previous behavioral data that showed an effective access to semantic and lexical information in TOT, just as in successful naming, but only a partial access to phonological information (Bock & Levelt, 1994; Burke et al., 1991; Dell et al., 1997; Gollan & Brown, 2006; Harley & Brown, 1998; Levelt et al., 1999), which may result in a delay in the selection of the response in TOT but a similar direct ERP waveform with respect to K.

The onset of the s-LRP was also earlier in K than in DK. The selection of the response just after the N450 ms in DK, around 480 ms, appears to support a strategy based on taking a decision on the basis of an attempt to identify all the faces completely, independently of whether the face is recognized or not. In accordance with Debruille, Pineda, and Renault (1996), top-down mechanisms may favor activation of representations of stimuli that are congruent with the context, and representations of famous people, even if inaccurate, receive an additional amount of activation in contexts wherein known faces are expected.

Once the TOT state has been established, subsequent processing is characterized by a continuous search of information and conflict monitoring, as was established in neuroimaging (Kikyo et al., 2001; Maril et al., 2001) and MEG studies (Lindín et al., 2010). In the previous studies of Díaz et al. (2007) and Lindín and Díaz (2010), a positive component, named late P3, was observed in the 550–750 ms interval, and had larger amplitude in K than in TOT, which was interpreted as a consequence of the established TOT state due to differences between the response categories in the effective processing resources dedicated to stimulus evaluation and classification, based on the lexical-phonological information retrieved.

Unlike previous studies, in the present one there were no significant differences in mean amplitude between the K and TOT categories in the interval corresponding with late P3 component. Nevertheless, the mean amplitude was significantly larger in K than in DK, but only marginally larger in TOT than in DK. This appears to indicate a ranking in the late P3 amplitudes in the different categories, with the largest in K, followed by TOT, and finally DK. The reduced amplitude in this interval in DK suggests that the categorization was not made on the basis of the lexical-phonological information (as no information was retrieved), but was probably made on familiarity and on the lack of semantic and lexical information. In accordance with data obtained for the s-LRP, the largest amplitude observed in K suggests complete activation of the lexical-phonological route, and therefore the allocation of processing resources to the stimulus categorization. The intermediate position of the TOT amplitude may be due to the division of resources between the stimulus categorization and the continued search for information, due to the retrieval of partial phonological information about the name.

This pattern was established in subsequent intervals, between 750 ms and 1,350 ms, in which significant larger positive amplitudes were observed in K than in TOT, probably reflecting insufficient activation of the lexical-phonological route in TOT and the continued search for the name, in accordance with the predictions from the models of Valentine et al. (1996) and Burke et al. (1991). Although such modulations of ERP amplitudes are consistent with the findings of previous studies (Díaz et al., 2007; Lindín & Díaz, 2010), the time interval in which they took place was different (550–750 ms in the previous studies compared with 750–1,350 in the present study), which may be related to the different duration of the presentation of the face stimuli (1,000 ms compared with 314 ms in previous studies), although further investigation is needed in order to confirm this.

In the previous study of Díaz et al. (2007), amplitude differences were observed between the categories in a LNW identified in latter intervals. But, those differences were modulated by the motor activity related to the verbal response (Buján et al., 2009; Lindín & Díaz, 2010). In the present study, the task design included a delay between the responses, which enabled us to study the latter intervals avoiding the influence of verbal motor activity, and no LNW was identified. From 1,350 ms onwards, the mean amplitude was more negative in TOT than in K and in DK, indicating that in TOT the processing resources may still be involved in the search for lexical-phonological information about the person, reflecting a continued but unsuccessful effort in this category in order to resolve the conflict, whereas in K and in DK the processing resources may be completely released.

The consequences of the TOT state can be also seen in the analysis of the r-LRP. The onset latency of the r-LRP in TOT was around 280 ms, the latest of the three categories. Although no significant differences were observed between K and TOT, marginally significant differences were obtained between TOT and DK, whereas K was in intermediate position, indicating a delay in the effective motor preparation in TOT, probably due to the continued search for information in memory stores and the attempt to resolve the cognitive conflict.

Finally, taken together the results obtained for both s-LRP and r-LRP allow us to explain the behavioral data obtained in the present study in relation to the data obtained in previous ones. The results found by Buján et al. (2009) showed that a lengthening in motor processes would cause the slower RTs in TOT than in K. The LRP results from the present study support this hypothesis. The differences in RT between K and TOT strongly corresponded to the sum of the differences in both s-LRP and r-LRP onset latencies, thus the differences can be attributed to a delay in the TOT category, in both the response selection (due to the retrieval of incomplete phonological information) and in the effective motor preparation (probably due to the continued search for information in memory stores). In addition, the differences in RT between K and DK corresponded to the slowing observed in the s-LRP onset latency in DK with respect to K and therefore may be related to a delay in the response selection in the DK condition.

The current study shed light on the temporal dynamics of the brain electrical activity during the face-naming and TOT state; nevertheless, in future studies the analysis of neural sources of this activity might be addressed, taking into account recent findings with magnetic resonance imaging (MRI) (Shafto, Burke, Stamatakis, Tam, & Tyler, 2007) and MEG (Lindín et al., 2010).

In summary, the present study showed that the recognition and access to semantic and lexical information is similar between the successful naming and the TOT state, as differences were found in P2, early P3, and N450 between K-TOT and DK, but not between K and TOT. The selection of the response (s-LRP) in K took place around 360 ms; however, the insufficient phonological access in TOT might delay the response selection, as s-LRP onset took place 100 ms later. Finally, the consequences of TOT (continuous search for the name and conflict monitoring) were reflected in differences in amplitude between TOT and the other categories from 750 ms onwards as well as in a delayed onset of response preparation (r-LRP).

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Figure captions

Figure 1. General trial procedure. After pressing the corresponding blue or red button, the participants had to say aloud (a) the correct name (K category), after which the next photo appeared; (b) "I can't retrieve it," after which a series of questions appeared (correct answers: TOT category); or (c) "I don't know it," after which a series of questions appeared (person unknown: DK without semantic information; person known and correct profession: DK with semantic information). Note: Stimulus size is not to scale.

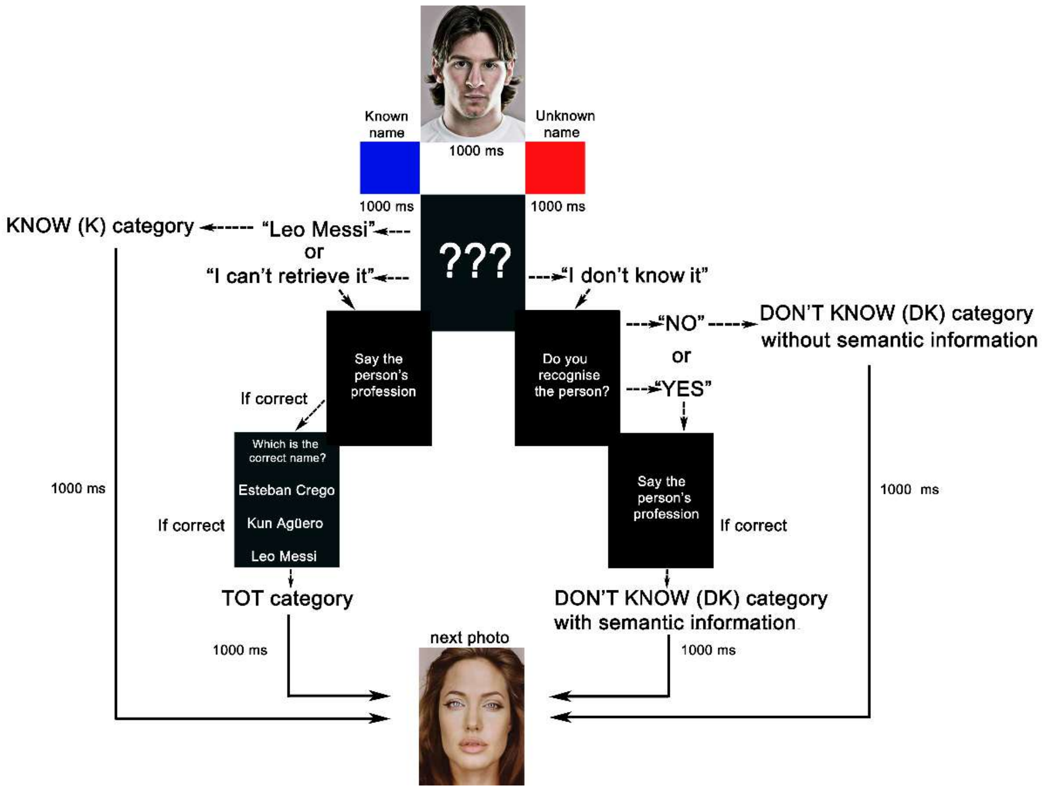

Figure 2. Electrode montage used for recordings and scalp regions of interest grouped for statistical analyses (LF = left frontal region; RF = right frontal region; LC = left central region; RC = right central region; LT = left temporal region; RT = right temporal region; LPO = left parietal-occipital region; RPO = right parietal-occipital region).

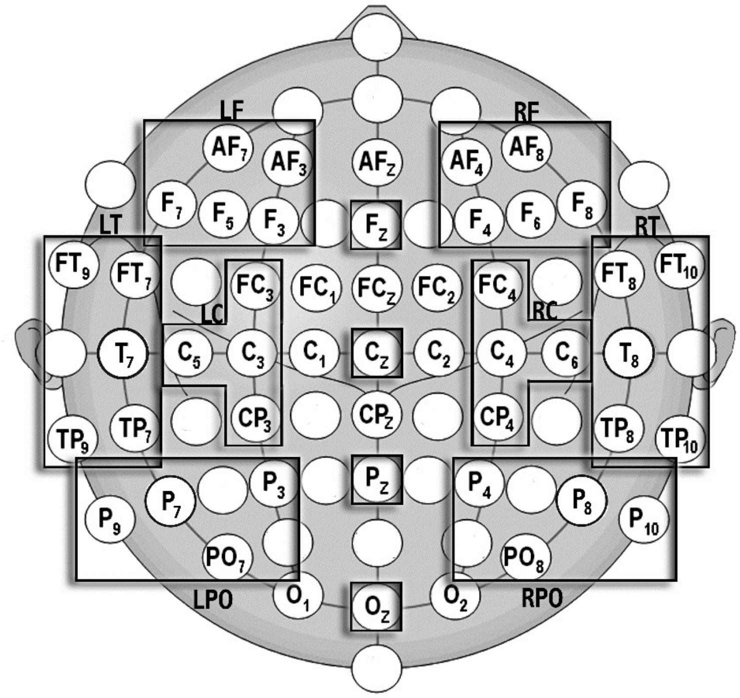

Figure 3 Means and standard deviations for the percentage of responses (A), and means and standard deviations for the reaction times (B) in each response category

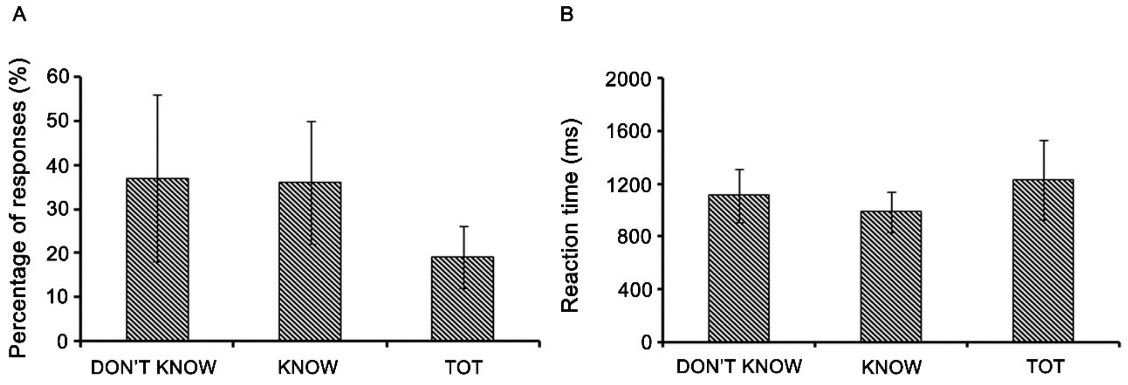

Figure 4 Grand-averaged ERP waveforms for the K (thick line), TOT (dashed line) and DK (thin line) response categories at midline electrodes and at eight regions of interest (LF: left frontal region; RF: right frontal region; LC: left central region; RC: right central region; LT: left temporal region; RT: right temporal region; LPO: left parietal-occipital region; RPO: right parietal-occipital region).

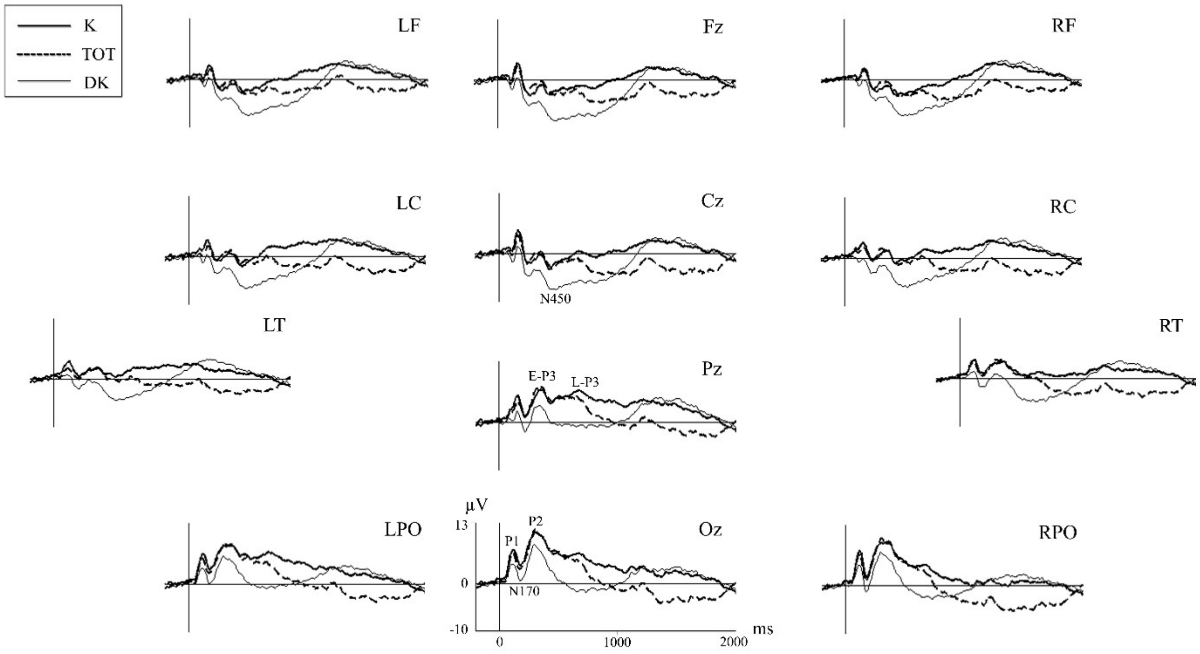

Figure 5 Grand-averaged stimulus-locked LRP (s-LRP–upper row–) and response-locked LRP (r-LRP–lower row–) waveforms for the K (thick line), TOT (dashed line) and DK (thin line) response categories. The onset of the s-LRP and r-LRP in each category, measured using the segmented regression method, is indicated by arrows (1: K category; 2: TOT category; 3: DK category).

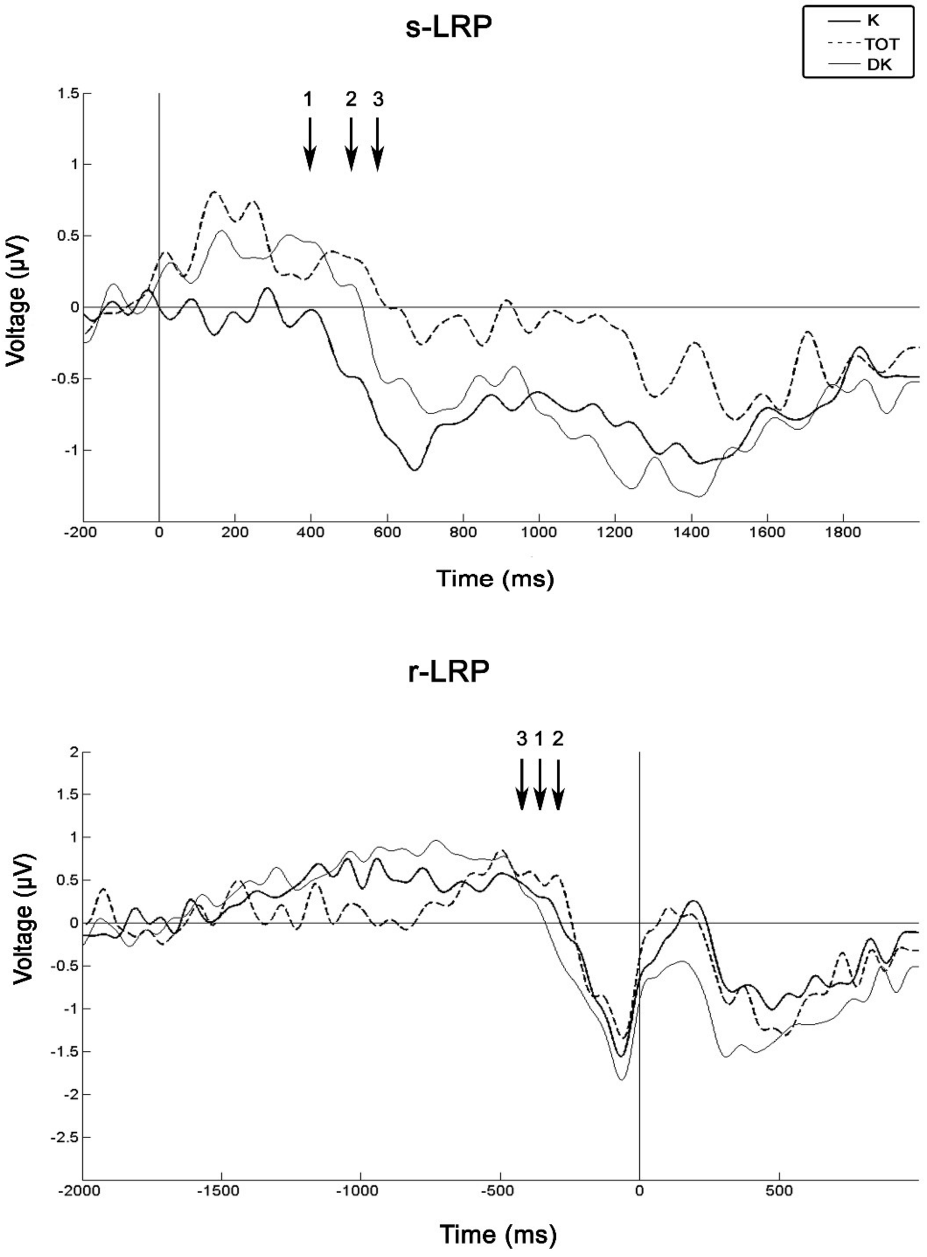

Table 1. F values from repeated-measures ANOVA (Response Category × Midline) and repeated-measures ANOVA (Response Category × Region × Hemisphere) for mean amplitudes over the nine time intervals analysed.

	Interval 200-300 ms	**Interval 300-400 ms**	**Interval 400-550 ms**	**Interval 550-750 ms**	**Interval 750-1000 ms**	**Interval 1000-1350 ms**	**Interval 1350-1550 ms**	**Interval 1550-1750 ms**	**Interval 1750-2000 ms**
ANOVA (RC × ML)									
RC	**3.54***	**4.92****	**7.79****	**8.16*****	**4.54***	**3.74***	**8.72**** (ε: .66)	**8.31****	**6.59****
ML	**54.10***** (ε: .51)	**101.33***** (ε: .57)	**68.99***** (ε: .66)	**49.19***** (ε: .64)	**33.03***** (ε: .59)	**7.09**** (ε: .55)	**3.80*** (ε: .60)	2.92 (ε: .58)	2.85 (ε: .60)
RC × ML	1.42	.88 (ε: .49)	.68 (ε: .45)	.79 (ε: .42)	.65 (ε: .37)	.79 (ε: .35)	1.80 (ε: .36)	1.34 (ε: .47)	.81 (ε: .48)
ANOVA (RC × R × H)									
RC	**3.12**^{m}	**4.74***	**7.31****	**7.60****	**3.97***	**3.45***	**7.77**** (ε: .68)	**8.07****	**5.89****
R	**78.07***** (ε: .54)	**103.69***** (ε: .64)	**56.96***** (ε: .62)	**25.16***** (ε: .61)	**8.46**** (ε: .62)	.64 (ε: .69)	**4.03*** (ε: .63)	2.81 (ε: .57)	**7.33**** (ε: .62)
H	1.33	2.00	.17	**4.28**^{m}	**12.68****	**11.05****	1.58	.02	.68
RC × R	2.03 (ε: .40)	1.49 (ε: .48)	1.00 (ε: .45)	2.13 (ε: .45)	2.26 (ε: .47)	2.58 (ε: .45)	2.68 (ε: .42)	2.00 (ε: .44)	1.15 (ε: .51)
RC × H	.83	.29	2.26	1.98	**6.80****	**4.31***	**4.60***	**5.31***	**3.75***
R × H	**3.42***	**3.78*** (ε: .69)	2.61	**4.07*** (ε: .73)	**7.75**** (ε: .68)	**12.93***** (ε: .57)	**12.33***** (ε: .63)	**8.40*****	**10.69*****
RC × R × H	1.68 (ε: .56)	**2.47***	1.46	1.78 (ε: .48)	1.42 (ε: .40)	1.18 (ε: .49)	2.14 (ε: .64)	1.83 (ε: .57)	**2.89***

RC = Response Category factor, ML = Midline factor, R = Region factor, H = Hemisphere factor, ε = epsilon value.

Degrees of freedom in ANOVA (Response Category × Midline): RC = 2, 36; ML = 3, 54; RC × ML = 6, 108
Degrees of freedom in ANOVA (Response Category × Region × Hemisphere): RC = 2, 34; R = 3, 51; H = 1, 17; RC × R = 6, 102; RC × H = 2, 34; R × H = 3, 51; RC × R × H = 6, 102

* p < .05
** p < .01
*** p < .001
^{m} marginally significant differences (between .051 and .060)

Table 2. t values for s-LRP and r-LRP onset latencies and mean amplitudes for each pair of comparisons.

	s-LRP		**r-LRP**	
	Onset latency	***Mean amplitude (600-800 ms)***	***Onset latency***	***Mean amplitude (-200-0 ms)***
K compared with DK	**-2.34*** (df: 11)	-.31 (df: 14)	.84 (df: 13)	.87 (df: 14)
K compared with TOT	**-2.35*** (df: 11)	**-2.10*** (df: 14)	-.75 (df: 9)	1.17 (df: 12)
TOT compared with DK	.8 (df: 12)	1.04 (df: 12)	**2.12^{m}** (df: 9)	-.10 (df: 10)

* $p < .05$

^{m} marginally significant differences (between .051 and .06)