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THETA AND ALPHA FREQUENCY MODULATION BY LEXICAL-SYNTACTIC INFORMATION DURING A LEXICAL DECISION TASK*

MODULAÇÃO DAS FREQUÊNCIAS TETA E ALFA POR INFORMAÇÃO LEXICO-SINTÁTICA EM UMA TAREFA DE DECISÃO LEXICAL

MODULACIÓN DE LAS FRECUENCIAS THETA Y ALFA POR INFORMACIÓN LÉXICO-SINTÁCTICA EN UNA TAREA DE DECISIÓN LÉXICA

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RESUMO: Estudamos incrementos (ERS) e diminuições (ERD) relacionadas a eventos da potência das bandas alfa e teta associadas a uma divergência léxico-sintática entre o *prime* e o alvo durante uma tarefa de decisão lexical. Os participantes viram 100 pares *prime*-alvo que compartilhavam toda a informação léxico-sintática (condição Igual) ou só diferiam no modo verbal (condição Diferente). O tempo de reação dos alvos na condição Igual diminuiu em relação à condição Diferente, mostrando a ativação do modo verbal durante a tarefa. Encontramos uma diminuição (ERS) significante da banda alfa, na condição Igual em relação à condição Diferente de 800 a 1.200 ms após a apresentação do alvo. Interpretamos este resultado como um indicador neurobiológico de efeito de repetição no nível léxico-sintático.

PALAVRAS-CHAVE: Decisão lexical; modo verbal; análise de Freqüência; dessincronização alfa.

RESUMEN: Estudiamos incrementos (ERS) y disminuciones (ERD) relacionadas con eventos en la potencia de las bandas alfa y theta asociadas con una divergencia a nivel léxico-sintáctico entre el prime y la meta durante una tarea de decisión léxica. Los participantes vieron 100 parejas prime-meta que compartían toda la información léxico-sintáctica (condición Igual) o diferían sólo en modo verbal (condición Diferente). Los tiempos de reacción a los objetivos disminuyeron en la condición Igual respecto a la Diferente, evidenciando activación del modo verbal durante la tarea. Se halló una disminución (ERS) significativa de la banda alfa en la condición Igual respecto a la Diferente de 800 a 1200 ms luego de la presentación del objetivo. Interpretamos este resultado como un indicador neurobiológico de un efecto de repetición a nivel léxico sintáctico.

PALABRAS CLAVE: Decisión léxica; modo verbal; análisis de frecuencia; desincronización alfa.

ABSTRACT: We studied theta and alpha event related increases (ERS) and decreases (ERD) in band power associated with a prime-target mismatch at the lexical-syntactic level during a lexical decision task. Participants saw 100 prime-target pairs that shared all lexical- syntactic information (Same condition) or differed only in verbal mode (Different condition). Reaction times decreased to targets of the Same compared to the Different group showing activation of verbal mode during the task. A significantly greater alpha ERD was obtained in the Same compared to the Different condition from 800 to 1200 ms after target presentation. We interpret this result as a neurobiological indicator of a repetition effect at the lexical-syntactic level.

KEYWORDS: Lexical decision task; verbal mode; time-frequency analysis; alpha desynchronization.

1 INTRODUCTION

Two important questions in models of word processing are i) what information is accessed during word recognition and, ii) which is the temporal dynamics of activation of this information. Concerning the first issue, the introduction of a prime before the target in lexical decision tasks has allowed analyzing what type of information is accessed during word recognition, because behavioural measures (e.g. reaction times) are influenced by the associations established between prime and target stimuli. Activation of information due to prime presentation influences reaction times over targets when both stimuli share at least part of the previously activated information. In this way semantic, orthographic and phonological effects have been

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detected (CARREIRAS et al., 2005; FERRAND; GRAINGER, 1994; PEREA; ROSA, 2002), showing that these types of information are retrieved during stimulus recognition. As for syntactic effects, experiments have shown that the presentation of a prime verb with a preponderant argument structure can bias participants' production preferences in a picture description task (MELINGER; DOBEL, 2005), thus showing that this type of verbal syntactic information is accessed during prime presentation. Nevertheless, the possible retrieval of other types of lexical-syntactic information and their temporal dynamics of activation have not been studied so far. Concerning the second point, EEG recordings have shown to be a valuable tool to study the fast dynamic changes that underlie cognitive processing, due to their high temporal resolution. During performance of language tasks several transient electrical components or event related potentials (ERPs) have been describe time-locked to stimulus onset. Results have shown that phonological processing during language comprehension is associated with ERP signals peaking around 200 ms post-stimulus onset (RODRÍGUEZ-FORNELLS et al., 2002), while semantic processing elicits signals with a peak latency of 350 to 450 ms post stimulus onset (KUTAS; FEDERMEIER, 2011 for a review). Syntactic incongruences within phrases typically elicit a positivity peaking approximately 600 ms after their appearance [GOUVEA et al., 2010 for a review]. Nevertheless, more recent findings show specific syntactic effects arising already within the first 200 ms post-stimulus onset (BARBER; CARREIRAS, 2005), thus raising the possibility of a parallel activation of the different types of information associated with words.

Furthermore, EEG recordings can be decomposed into oscillatory components, allowing to analyze the signal as a function of time and frequency. Event related increases (ERS) and decreases (ERD) in frequency band power are considered respectively, a measure of synchronization and desynchronization of neural firing over analyzed regions. This valuable information relates to the dynamics of the network involved during task execution. Human cortical oscillatory activity presents components from approximately 0.5 Hz to 100 Hz that are divided into specific frequency ranges, such as delta (0.5 to 3 Hz), theta (4 to 8 Hz), alpha (8 to 13 Hz), beta (13 to 30 Hz) and gamma (30 to 100 Hz). Theta and alpha frequencies have shown to be the most responsive during language and memory tasks. Changes in theta have been related to memory requirements while performing working memory tasks (RAGHAVACHARI et al., 2001) as well as during memory encoding (SEDERBERG et al., 2003). Additionally, increases in theta rhythms have also been found during verbal memory tasks (HWANG et al., 2005; JENSEN; TESCHE, 2002). Recent studies have analyzed theta activity in relation to linguistic processing demands (BASTIAANSEN et al., 2002; BASTIAANSEN et al., 2005) showing that this frequency component is modulated by syntactic violations within a phrasal context (BASTIAANSEN et al., 2002), as well as during lexical-semantic retrieval (BASTIAANSEN et al., 2005). Alpha band power changes have also been related to lexical-semantic activation and memory retrieval processes (KLIMESCH et al., 2005; KRAUSE, 2003), as well as syntactic processing of music (HERROJO et al., 2009). Thus, in the present work we aimed to: i) analyze whether a specific type of lexical-syntactic information (verbal mode) is activated during a word recognition task; and ii) study possible frequency band power changes associated with differences in lexical-syntactic information carried by prime and target verbs. In particular, based on previous findings within the language domain, we expected possible theta and/or alpha band power correlates of verbal mode information .

2 MATERIALS AND METHODS

2.1 Participants

26 healthy right-handed volunteers from undergraduate psychology courses (mean age 25.60±0.62 years), participated in this study. All participants were native speakers of Spanish, had normal or corrected to normal vision, and had no prior history of psychiatric or neurological disorders. Participants signed a written consent for their participation and the experiments were conducted in accordance with the Declaration of Helsinki.

2.2 Stimuli

100 relevant prime-target pairs and 100 prime-target fillers were employed. All prime and relevant target words were Spanish verbs in 3rd person, plural form, while 100 target non-words were fillers constructed resembling Spanish verbs conjugated in the same person, number and mode as target real verbs. 50 of the relevant prime-target pairs shared all lexical-syntactic information, including verbal mode (Same

condition), while the remaining 50 differed only in verbal mode between prime and target (Different condition). Prime and targets were matched in mean surface frequency of use and length (Table 1), and shared no semantic or formal relation. In order to ensure that the 100 experimental targets were preceded by both prime types, two versions of the experiment were constructed following a Latin Square Design. Both versions were matched for mean prime surface frequency and length.

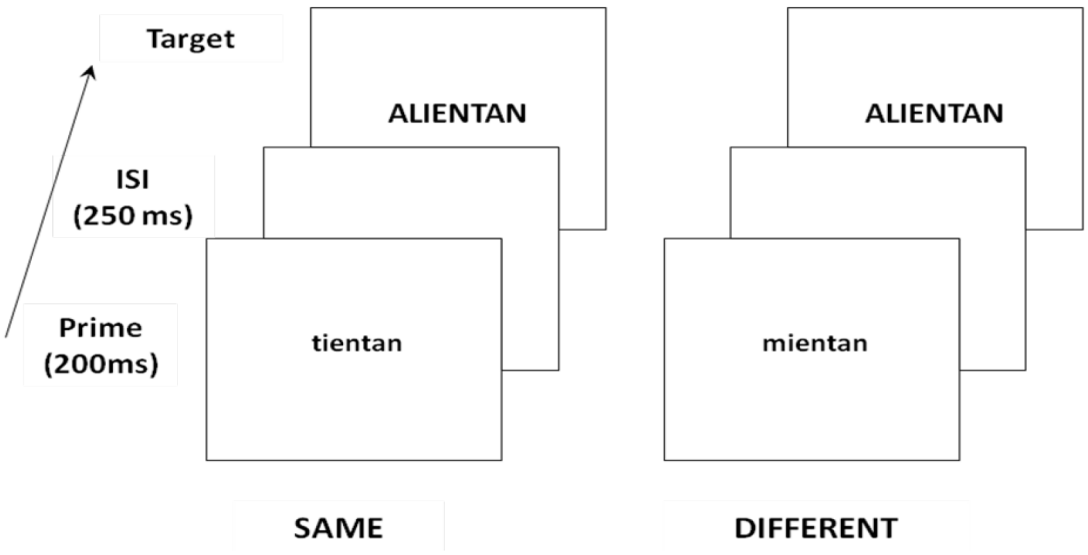
Table 1 - Mean surface frequency and length of all employed stimuli (standard error in parentheses). P levels correspond to the Repeated measures Anova (within-subject factor: Experimental Condition)

	Stimulus type			
	Prime-Same	Prime-Different	Target	p-level[a]
Surface frequency	2.89±0.37	2.37±0.44	3.89±0.49	0.35
Length	6.96±0.12	7.07±0.11	7.17±0.12	0.29

2.3 Procedure

Participants were seated in front of a 14 inch PC screen with their right and left index fingers in contact with two different keys of a standard computer keyboard. They were instructed to keep their eyes on the center of the screen throughout the experiment and move as little as possible. Each trial consisted of a 3000 ms resting period followed by prime presentation (200 ms); inter-stimulus interval (250 ms) and target presentation (until response, Fig. 1). In every trial participants decided as quickly and accurately as possible whether the target was a real word or not by pressing the key assigned to each case. No feedback was provided after each response.

Figure 1 - Experimental procedure for the same and different conditions



2.4 EEG recordings and time-frequency analysis

EEG recordings were gathered during the task from 19 cap-mounted tin electrodes (international 10/20 system, biauricular reference, Electro-Cap International Inc.). Recordings were synchronized with the beginning of each trial. An AC computerized amplifier system (Akonic model Bio-PC) was employed with a

bandwidth of 0.5 to 30 Hz (6 dB/octave). Recordings were sampled and digitized at 256 Hz. Electrode impedances were kept under 10 kΩ.

After the recording, trials were separated from -200 ms to 2300 ms since onset of prime presentation. Independent Components Analysis [27] implemented in EEGLAB software [10] was used to identify eye movement and blink artifacts, and were then removed. Trials that showed other type of artifacts or corresponded to omitted or error responses were eliminated (less than 10% of total trials). Recordings corresponding to two subjects were eliminated from further analysis due to excessive movement artifacts.

ERS and ERD were calculated with EEGLAB software. Morlet (gaussian-tapered) wavelets were implemented, with 0.5 cycles at lowest frequency to 8.18182 at highest, increasing by a factor of 0.1 cycles per frequency. 100 log-spaced frequencies from 1.1 Hz to 20.0 Hz were estimated for spectral amplitude, generating 200 time points from 52.7 to 2244.1 ms since the presentation of the prime. Synchronization/desynchronization values were expressed as the deviation in dB, i.e. $10*\log_{10}(\mu V^2)$, relative to the 200 ms pre-stimulus interval power.

2.5 Statistical Analysis

2.5.1 Behavioural data

Reaction times from error responses and extreme values (> 2300 ms) were excluded from the analysis. This accounted for 8.20% of all responses. Reaction times were log transformed in order to carry out further statistical analysis. The percentage of correct responses and reaction times were averaged by subject and condition and a repeated measures ANOVA with condition (Same vs. Different) was performed.

2.5.2 Time-frequency data

Frequency and time limits for statistical analysis of the theta and alpha bands were defined based on visual inspection of the time-frequency plots. Two time windows relative to the onset of prime presentation were considered: i) 50-250 ms (Early window); and ii) 800-1200 ms (Late window). In the Early window power values were averaged by subject and condition across trials and collapsed across the 4.1 to 8.0 (theta) and 8.1 to 12.0 Hz (alpha) frequencies. In the Late window power values were averaged by subject and condition across trials and collapsed across the 8.5 to 13.0 Hz (alpha) frequency range. The obtained values for each time and frequency range were compared against the values obtained in that same frequency range during the 200 ms prior to prime presentation (Baseline). A three-way repeated measures ANOVA with factors Electrode (Fp1 to Pz), Experimental Condition (Same, Different) and Time (Baseline *vs.* Early or Late window) was performed for each analyzed frequency band. Greenhouse-Geisser corrections were applied when necessary, and Bonferroni adjustments were used for pairwise comparisons.

3 Results

3.1 Behavioural analysis

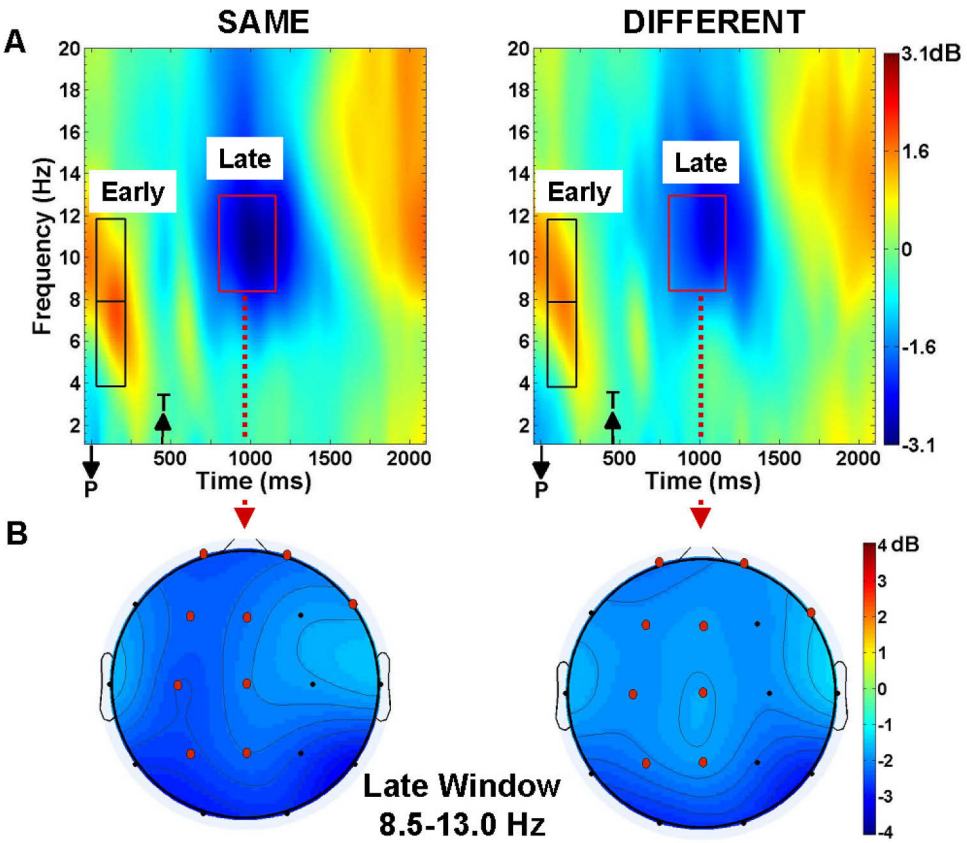
No differences between conditions were found in the total number of responses or the accuracy rates, although participants recognized target verbs approximately 25 ms faster when preceded by a prime in the Same condition compared to targets preceded by a prime in the Different condition (Table 2). The repeated measures ANOVA showed a significant effect of Condition on reaction time ($F(1,25) = 5.56$, $p=0.026$). Thus, the coincidence of verbal mode between prime and target stimuli facilitated the recognition of the target verb.

Table 2- Mean percentages of responses, accuracy and reaction time according to experimental condition (standard error in parentheses)

	Experimental Condition		
	Prime-Same	Prime-Different	p-level[a]
% responses	99.8±0.15	99.6±0.16	0.33
Accuracy	92.5±1.02	91.2±1.24	0.18
Reaction time	840.14±13.89	865.16±16.62	0.02

Note: Repeated measures Anova (within-subject factor: Experimental Condition).

Figura 2



Note: A) Grand average time-frequency plots at one representative electrode site (P3) for the Same and Different conditions. Rectangles show the selected time and frequency limits considered for statistical analysis. P: onset prime presentation. T: onset target presentation. B) Topographic map of the desynchronization values averaged over the Late window interval in the alpha range. Electrodes in red showed statistical differences between conditions.

3.2 Time-frequency analysis

3.2.1 Early window

The three-way repeated measures ANOVA yielded a main effect of Time for both the theta ($F_{1,23}=34.61$; $p<0.0001$) and alpha ($F_{1,23}=33.50$; $p<0.0001$) frequencies. This result shows that compared to baseline,

both analyzed frequency bands displayed comparable power increases (i.e. synchronization levels). No other statistical main effects or interactions were obtained. Therefore, the increase in power was not influenced by task condition (Figure 2A, Early window).

3.2.2 Late window

A significant main effect of Time was found for the analyzed alpha frequency range ($F_{1, 23}=116.58$; $p<0.0001$). In this case, frequency power values were significantly lower (desynchronization) compared to baseline values. In addition, a significant Electrode x Condition x Time interaction was obtained ($F_{18, 414}=2.33$; $p= 0.032$). Post-hoc comparisons showed greater desynchronization values in the Same compared to the Different condition mainly on frontal to parietal electrodes of the left and central lines ($p<0.02$, Figure 2B).

4 Discussion

4.1 Behavioral results

A significant decrease in reaction time to targets of the Same compared to the Different condition was found. Given that both prime conditions were matched for surface frequency and length, and shared all syntactic information other than verbal mode, results seem to indicate that verbal mode information was indeed activated by the presentation of prime and target verbs, exerting a significant priming effect at the behavioral level, i.e. facilitating the recognition of the target verb when it agreed with the prime's verbal mode.

4.2 Time-frequency analysis

4.2.1 Early Window

Analysis of theta and alpha frequencies showed a power increase (ERS) of both bands within an early time window after prime presentation. This result agrees with previous works involving online sentence processing [3] and lexical decision tasks [5]. During word by word presentation of sentences, Bastiaansen et al. (2002) found that frequencies from 4 to 6 Hz increased their power approximately from 100 to 300 ms after word onset, while the 6-8 Hz band showed power increases somewhat earlier, approximately from 0 to 250 ms following word onset. Similarly, time-frequency analysis of a lexical decision task showed significant theta and alpha ERS approximately 100-400 ms (theta) and 50-150 ms (alpha) after word onset (BASTIAANSEN et al., 2008). As regards the possible functional meaning of these power increases, previous works have found that theta activity is related to successful memory encoding and retrieval processes (KLIMESCH et al., 2007; KLIMESCH et al., 2001], as well as working memory operations (KLIMESCH et al., 2005; JENSEN et al., 2002). More specifically, theta synchronization has been related to lexical–semantic retrieval from long-term memory (BASTIAANSEN et al., 2008; BASTIAANSEN et al., 2005). Thus, the early increase of theta power in the present experiment could have been a consequence of lexical retrieval processes elicited by the presentation of the prime. In addition, alpha power increases have been found to reflect attentional processes and active maintenance of working memory (JENSEN et al., 2002; PESONEN et al. 2006). Several works have found that alpha ERS is elicited in situations where subjects withhold the execution of a response (KLIMESCH et al. for a review]. The inhibition of a previously acquired motor sequence generates a significant ERS in the upper alpha band (HUMMEL et al., 2002). Similarly, during retention of encoded information in a memory scanning task, a strong alpha ERS is obtained (SAUSENG et al., 2005). In this period, subjects refrain from responding until the appearance of the probe. In the present work, after the appearance of the prime participants refrained from responding until presentation of the target. Thus, we interpret the early ERS in the alpha band as a neurobiological marker of an active inhibition of the response that is sustained while participants await the appearance of the target. It is worth noting that alpha ERS preceded the appearance of the prime (Fig. 2A). A prestimulus alpha increase was also found by Ellfolk et al. (ELLFOLK et al., 2006) in a verbal working memory task in normal subjects. The authors interpreted this result in terms of attentional direction and/or memory retention processes since the subjects were expecting the appearance of the stimuli.

4.2.2 Late Window

The results obtained in the late window showed a pronounced ERD in the alpha band. Alpha ERD has been associated with the onset of retrieval processes in cognitive and motor memory tasks (NEUPER et al., 1999; KLIMESCH et al., 2007; KRAUSE, 2003). Sauseng et al. [34] found that upper alpha ERD was obtained when visual information was retrieved from long term memory. Similarly, the presentation of a probe item signaling the retrieval phase of a verbal working memory task, elicited a pronounced ERD (ELLFOLK et al., 2006; PESONEN et al., 2006). A strong alpha ERD was also obtained after presentation of the probe in a visual n-back task (PESONEN et al., 2007). Thus, it is likely that in the present work the pronounced alpha ERD found in the late window was related to memory retrieval and lexical-semantic activation processes (KLIMESCH et al., 2005; KRAUSE, 2003) that were initiated after presentation of the target.

The most interesting result was that the late alpha desynchronization was significantly more pronounced in the Same compared to the Different condition. During the recognition stage of a visual n-back task, Pesonen et al. (2007) found stronger alpha ERD after presentation of probes that had appeared previously compared to those that were new. In a similar way, results obtained during the recognition stage of a Sternberg auditory memory search task showed that words that had been previously included in the memory set elicited stronger alpha ERD compared to words that had not been included (PESONEN et al., 2006). Furthermore, during a word and face recognition memory task, Burgess and Gruzelier (2000) found a lateralized repetition effect for words in the upper alpha range, such that compared to newly presented words, old words elicited greater desynchronization levels in left temporo-parietal sites. In the present work differences in alpha ERD between experimental conditions were lateralized in a similar way: desynchronization levels after target presentation were more pronounced in left- and mid-line electrodes when the target shared verbal mode with the prime. The results described in the above mentioned works show that repetition of a lexical item increases alpha ERD levels. In the present work although prime and target stimuli were different words, repetition of modal verb information also elicited increased alpha ERD. Thus, we interpret this result as a neurobiological indicator of a repetition effect at the lexical-syntactic level. This effect was obtained mainly in frontal to parietal electrodes of the left- and mid-line regions. Alpha ERD during retrieval has been seen to be consistently pronounced over parietal areas. This is thought to reflect activation of areas involved in the storage of episodic and semantic memory traces (KLIMESCH et al., 2006). Thus, in the present case it is likely that alpha ERD over parietal electrodes was a consequence of the activation of lexical-semantic information after presentation of the target word. It is possible that the differences of desynchronization levels obtained in frontal to parietal sites might have been related to the activation of lexical-syntactic information. Biran and Friedmann (2012) explored the relation between syntactic and lexical semantic impairments in aphasic patients and retrieval of lexical-syntactic information. They found that patients with impaired lexical syntactic knowledge showed intact lexical-semantic knowledge, thus concluding that lexical-syntactic information is represented separately from the semantic lexicon in a specific syntactic lexicon.

In closing, present results show a modulation of alpha ERD as a consequence of a repetition effect at the lexical-syntactic level. The topography of the obtained differences might be related to the activation of cortical sites relevant for lexical-syntactic information retrieval. Further studies should help deepen our understanding of the neurobiological bases of stored lexical-semantic and syntactic information.

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