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The role of the P300 component in a translation-recognition task

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This study focuses in language processing and memory representation in a sample of bilingual subjects using a translate-recognition task. The revised model of Kroll and Stewart (1994) and Chapman's model (1981) about the relationships of the component P300 and short term memory were used as theoretical framework. Results seems to show significant effects of word frequency and kind of task on reaction times and P300 amplitude as well as some interaction effects with subject's linguistic dominance. The main conclusions are that the results of Spanish dominant subjects seem to fit with the asymmetry proposed by Kroll & Stewart model. Moreover ERP data seems to show the relevance of the P300-P600 complex during the stimulus identification process in the short-term memory. From this viewpoint both components maybe viewed as measures of the stimulus relevance and the concordance between the stimulus and its representation at the short-term memory.

El papel del componente P300 en tareas de reconocimiento de traducción. La presente investigación se centra en el procesamiento del lenguaje en bilingues y su representación en la memoria en una tarea de reconocimiento de traducciones, basándose en el modelo jerárquico revisado de Kroll y Stewart (1994) y el modelo de Chapman et al. (1981) sobre las relaciones del componente P300 y la memoria a corto plazo. Los resultados parecen mostrar efectos significativos del tipo de respuesta y de la frecuencia de las palabras y diversos efectos de interacción con la dominancia lingüística de los sujetos. Las principales conclusiones apuntan hacia el hecho de que los sujetos con dominancia castellana parecen ajustarse a la asimetría propuesta por el modelo jerárquico mientras que los de dominancia catalana no lo hacen. Por otra parte los datos obtenidos mediante potenciales evocados muestran la importancia del complejo P300-P600 en la identificación de estímulos en la memoria a corto plazo. Desde esta perspectiva ambos componentes pueden ser indicadores de la relevancia del estímulo para la tarea y del grado de concordancia entre el estímulo y la representación almacenada en la memoria.

Previous research into bilingual memory focuses on the controversy between one integrated language-independent memory system, versus two memory systems with shared or separated subsystems accessible through language-dependent processes (Kolers, 1963, 1966; Glanzer & Duarte, 1971; Kolers & González, 1980; Paivio, Clark & Lambert, 1988). Current models such as the revised hierarchical model or the distributed model (Potter, So, Eckardt & Feldman, 1984; De Groot, 1992a, 1992b, 1993; Kroll & Sholl, 1992; Kroll, 1993; Kroll & Stewart, 1994), generate clear predictions, specify lexical and conceptual representations and attempt to reconcile both perspectives.

Some authors (Durgunoglu & Roediger, 1987; Heredia & McLaughlin, 1992) have argued that the hypotheses that favors one or two memory systems depend mainly upon the processing demands in recall and recognition tasks respectively. For example, in recall tasks, that are sensitive to conceptual and semantic processes, the results obtained support the hypothesis of one memory system (Kolers & González, 1980; Durgunoglu & Roediger, 1987).

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On the other hand, in tasks that are sensitive to perceptual processes such as recognition tasks, the results obtained show the specific characteristics of each language, supporting the two memory systems hypothesis (Kirsner, Brown, Abrol, Chadha & Sharma, 1980; Kirsner, Smith, Lockhart, King & Jain, 1984; Sharma, 1984). The most obvious conclusion is that in the study of bilingual memory, task requirements must be considered as a very important factor (de Groot & Comijs, 1995).

There are two main hypothesis which explain the connections between the distinct components of the system and the meaning and/or formal representations of these units. The Word Association Hypothesis assumes the existence of direct lexical connections between the lexical entries of the first language or mother tongue (L1) and their equivalent lexical entries in the second language (L2). Likewise, there are no connections between the representations of the L2 lexicon and the shared and language-independent conceptual system (Kirsner et al., 1984; Kroll & Curley, 1988). In contrast, the Concept Mediation Hypothesis (Potter, 1979; Potter, So, von Eckhart & Feldman, 1984; Kroll & Curley, 1988) assumes the latter connection but not the former, which means that both lexicons are connected by a common conceptual representation, although there are not direct connections between the two lexicons.

Derived from the two previous hypotheses, a third Mixed Hypothesis accepts both types of connections between the lexico-semantic representations (de Groot, 1992a; de Groot & Nas, 1991). The proposal of Chen and colleagues (Chen, 1990; Chen & Ho, 1986; Chen & Leung, 1989) is along these lines and involves an interdependence between the structure of the lexicon and the level of proficiency in the second language. They suggested that bilinguals use lexical associations when they begin to learn a second language, but these associations are gradually replaced by concept mediation links as their proficiency in the second language increases. This structure will change as the bilinguals become more skillful in their new language.

Within this framework, the more important models proposed are the Distributed Model and the Revised Hierarchical Model. The Distributed Model proposes that the individual units (forms, meanings) and their memory representations do not correspond one-to-one, but one unit may correspond to several others (Taylor & Taylor, 1990; de Groot, 1992b, 1993). Thus, both the forms and the meanings may be represented and/or distributed in more than one memory node. This distribution of the conceptual representations in the bilingual memory is due to the fact that different meanings of a word in L1 and their corresponding translations in L2 do not completely overlap nor is shared by all their equivalents in L2 (de Groot & Hoecks, 1995; de Groot & Comijs, 1995).

Furthermore, a distributed lexical representation is also proposed because the form of many words of L1 partially or totally agree with their corresponding translations in L2. Words with a similar form (cognates) may share a set of representational elements on a lexical level, while words without this similarity of form (non-cognates) do not share it; the size of the set of shared representational elements depends upon the similarity of form.

In contrast, the Revised Hierarchical Model, proposes a directional asymmetry in the strength of the connections between the different types of memory units. In this model the bilingual memory is represented in two separated but interconnected lexicons (Kroll & Sholl, 1992; Kroll & Stewart, 1990, 1994), corresponding to the first language or mother tongue and to the second language. It is also hypothesized that the L1 lexicon is greater then the L2 under the assumption that bilinguals always know more words in their L1 than in their L2.

The lexicon of L2 has stronger lexical connections to the lexicon of L1 (automatic or associative links), while the lexicon of L1 has weak lexical connections to the L2 lexicon, sensitive to semantic processing (knowledge based links). On the other hand, the conceptual connections from the L1 lexicon to the L2 lexicon were stronger than the weaker conceptual connections from L2 to L1 lexicon.

These differences between the strength of the lexical and conceptual connections presumably reflect the manner in which the second language was learned. That is, when people begin to learn a second language they usually associate the new word to a word in their L1, making a direct and strong association to the meaning of the word in L1. From this assumption we could think that the meaning of the word in L2 is subordinated to the meaning of the word in L1. In spite of this, there is no reason to develop direct connections between the lexicon of the L1 and the lexicon of the L2 in subjects who learn their L2, because development of the lexicon of their L2 does not have the information about the concepts or meanings of the new language. Thus, subjects who learn a second language are forced to provide some meaning for the word that they are learning by associating it to the information they already have (Ervin & Osgood, 1954). As a result, the development of lexical connections from L1 to L2 is worse than the development of lexical and active connections from L2 to L1.

In addition to the existing connections between both lexicons, bilingual memory is like a conceptual store which contains abstract representations about the world (Potter et al., 1984). This conceptual store is connected with both lexicons, but while connections between the conceptual store and the lexicon of L1 are direct and strong, the connections with the lexicon of L2 are weak. This leads to an easier and more direct access to the conceptual store from subject's L1, conceptually mediated, than from subject's L2.

The logical prediction derived from this model in a translation task is that bilinguals would translate faster from their L2 to their L1 than from their L1 to their L2, due to the existence of a direct connection from the lexicon of L2 and the lexicon of L1 (Kroll & Steward, 1994; Dufour & Kroll, 1995). It seems that translations from L2 to L1 are sensitive to lexical processes (for example, factors that have a direct effect only on lexical access), while translations from L1 to L2 are sensitive to conceptual/semantic processes and involve a greater effort.

A recent revision of this model (Heredia, 1995) suggests that the two lexicons proposed by the hierarchical model are not clear, and that the bilingual structural organization is not simply a structure without changes. It is suggested that the structure changes as a function of «language dominance» and the first lexicon could turn into the subordinate and not remain as the forerunner all the time.

ERPS, recognition and memory matching.

Research carried out using ERPs have found that late positive components may be sensitive in tasks that require the memory matching of several successive stimuli. These components may be related to the requirements in the short-term memory and to target recognition.

In a classical oddball paradigm, for instance, the elicitation of a P300 is contingent on the recognition of the target. In this task, subjects are instructed to pay attention to the low probability stimulus and, then, to judge the degree of match between the stimulus that they hear and the representation of this stimulus in the short-term memory. Subjects have to discriminate an infrequent stimuli from a series of similar stimuli, and the appearance of this component reflects the perceptual and memory processes underlying stimulus recognition and categorization. That is to say, P300 is not an indicator of memory processes by itself, but it indexes the end product of the memory scan processes such as the stimulus relevance (Donchin, 1981; Donchin & Coles, 1988; Johnson, 1986; Ritter & Ruchkin, 1992; Polich & Kok, 1995) .

This type of late positive component is also elicited in some tasks where the test stimulus must be compared in the short-term memory with a preceding stimulus and, in general, subjects are asked to take a binary decision on the relationship between the two stimuli (Rockstroh, Elbert, Birbaumer & Lutzenberger, 1982; Donchin & Coles, 1988).

The first stimulus of the pair elicits a positive component with a post-stimulus maximum around 250 msec, labeled the Storage Component, and it is viewed as a sign of the storage of stimulus information in the short-term memory. More specifically, this component reflects the process of reading information out from the sensory registers into short-term memory. The second member of each pair which has to be compared with the first elicits a large P300 component depending on its relevance for the task.

Although ERP components exclusively related to memory scanning during retrieval have not been found, the proposal of Chapman, McCrary and Chapman (1978; 1981) is trying to integrate some aspects of ERP research that may be related with memory processes, clarifies the relationship between some components and the underlying memory processes, and makes some interesting suggestions about its possible consequences.

Chapman and colleagues suggests that the P200 component may be related to the very short-term memory sensory register. Several studies have shown that this component may be altered by the physical characteristics of the stimuli. Subsequent storage in the short-term memory has been associated with a positive component -the Storage Component- with a maximum at around 250 msec. However, the end of the scanning period in the short-term memory appears to be indicated by the peak latency of the P300 and by the amplitude which indicates the relevance of the stimulus for the current task. Between the P300 and the behavioral response there is another period the duration of which depends basically on the memory set size, and on the processing load imposed by the following reanalysis processes required for the task demands (Chapman et al., 1978; 1981; Vigil, Ferrando & Andrés, 1993).

Other studies related to the P300 component have shown that it has a greater amplitude in words that are best recalled or recognized and also depends on the subject's degree of confidence in their responses. In this sense, words which are best remembered or recognized in a word list task have larger P300 amplitudes (Rugg 1995). The P300 amplitude increases as a function of the degree of subject confidence when a subject makes a choice between two possible responses (Paller, Kutas & Mayes, 1985; Paller, McCarthy & Wood, 1987). Furthermore P300 amplitude has been associated to the task difficulty and the quantity of information of the stimuli, lower amplitudes has been associated to greater difficulty and increased stimuli information and vice-versa (Kramer, Schneider, Fisk & Donchin, 1986; Andrés, Vigil & Codorniu, 1999). In this sense, Palmer, Nasman & Wilson (1994) have found that in a same/different letter classification task the P3 amplitude was inversely related to the task decision difficulty, founding relatively larger P3 associated with matched letter pairs.

Paller and cols. (1987a, 1987b, 1988, 1990) have reported a series of studies on ERPs and memory. ERPs were obtained during several «same/different» tasks which varied the level of processing. Some of the tasks required matching on semantic attributes and others did not. They found a more positive ongoing waveform for remembered than for forgotten items, in all tasks used, although this effect was larger for those tasks that required semantic processing. They also observed that this effect was more prominent for words of high frequency than for words of low frequency of occurrence. The main conclusions of the studies of Paller and associates (1987a) are that the effects might reflect the degree of associative processing undergone by words once their meanings have been derived. On the other hand, they suggest (Paller et al., 1987b) that memory effects on ERPs index some general level of activation of a word's memory representation, rather than the encoding operations important for the formation of episodic memories. In a similar sense, Smith, Stapleton & Halgren (1986) proposed that the repetition of an item within the same context triggers the retrieval of the episodic trace of its first presentation, forestalling the generation of the N400 and leading to an enhanced late positive component.

More recent research, specially in the field of syntactic processing, has centered its attention on another component, the P600. This component has been interpreted as a marker of syntactic anomaly. Several authors have suggested that P600 could be a member of the P300 family, since it shares many of the characteristics that have been attributed to the P300, and its elicitation is conditioned by the same factors that lead to the elicitation of the P300 (Osterhout & Holcomb, 1993; 1995). It could be thought that P600 is a certain type of delayed P300 and it is elicited in situations -in word pair paradigms- in which the target word is not the expected target, and a reanalysis process is invoked in order to make a behavioral response. This reanalysis process may be indexed by the P600.

Finally, few studies have analysed the effects of bilingualism on the N400 component, and the data available have been obtained in expectancy violation paradigms. Those studies have found that the N400 amplitude is smaller in the L2 -less fluent language- of the subjects (Ardal, Donald, Meuter, Muldrew & Luce, 1990) . Furthermore, the timing of the N400 effect is also affected in bilinguals, peaking later and lasting longer in the L2 of a bilingual than in the L1 -the more fluent language- (Kutas & Kluender, 1993).

Regarding the experiment presented here, using a translation-recognition task, we could hypothesize that the most significant component that we would find in the ERP register may be a P300, reflecting the translation match. If this is the case, its amplitude would be modulated by the type of response (greater for translations and absent for non translations) and by word frequency (greater for high frequency words than for low frequency words) but not by the direction of the translation due to the fact that our sample is made up of relatively well balanced and proficient bilinguals. Moreover, for non translations, the subjects in this kind of task could be expected to internally propose a candidate for the target, and the mismatch between the word expected and the target presented could elicit a N400 and then, a P600. On the other hand, the difference in bilingual fluency between bilinguals of different language dominance could be reflected in a greater amplitude of the P300 component for the more-fluent group. If we compare the two sub-samples of our experiment (Catalan dominants on the one hand and Spanish dominants on the other), we could think that the amplitude of P300 would be greater for Catalan dominants than for Spanish dominants because Catalan dominants are more-fluent bilinguals than Spanish dominants.

It is important to point out that although the P300 is not a component clearly related to language processing, we expect it can show some sensitivity to linguistic manipulations and variables such as word frequency or linguistic dominance. If this is the case, ERP research in psycholinguistics can use a new tool of study and would not be restricted only to the N400 and P600 components.

Method

Subjects

Twenty four university students (17 women and 7 men with a mean age of 21:3, all of them right-handed) participated as volunteers in this study. All the subjects were bilinguals Catalan-Spanish (with a high proficiency level both in Catalan and Spanish) 12 of them had Catalan as their mother tongue and the remaining 12 subjects had Spanish. They had normal or corrected-to-normal vision. The bilingual status of the subjects in our sample is worthy of special mention. People living in Catalonia have the benefit of special bilingual status. Both languages are official and very often children do not learn one language before the other. For the last 20 years both Catalan and Spanish have been obligatory in primary and secondary school and when they finished secondary school all the subjects had a high level of proficiency in Spanish and Catalan. Between them there is only one difference: the everyday frequency of usage of each language. In Catalonia about 90% are bilingual and the remaining 10% are Spanish monolinguals, there are no Catalan monolinguals. It is difficult to find this situation in another country in the world (Hoffman, 1991).

Stimuli and task

We selected 200 pairs of words in which one word of each pair was a Spanish word and the other one was the corresponding translation in Catalan. All word-pair translations had a high cloze probability (more than 92%). For Spanish words we controlled the frequency (Alameda & Cuetos, 1995): half of them were high frequency words (more than 80 occurrences per half million, mean = 291.91) and the other half were low frequency words (less than 30 occurrences per half million, mean=26.27). We could not do the same in Catalan because there was no dictionary of frequencies available. We did care to exclude from all word-pairs all the words that had some orthographic and/or phonologic similarity (cognates), so all word-pairs used were non-cognate words. Word length ranged from 4 to 8 letters. We used a translate-recognition task where the subjects were asked to judge whether the second word of each pair was a translation of the first word or not.

Procedure

Words were presented in white capital letters (2 x 1 cm) on a blue background for 500 ms. each one on a computer screen located 50 cm from the subjects. Stimuli were presented in pairs, one word at a time. ISI between prime and target was randomly set between 1000-2000 ms and the interval between two pairs of words was fixed at 2 seconds. Prior to each pair a fixation point was shown in the middle of the screen.

Each subject was tested in an acoustically shielded room with low-normal illumination, seated in a comfortable reclining chair with a neck support. After 24 practice trials the recording session began, lasting about 25 minutes. The subjects were asked to press the «Yes» button when they found that the second word of the pair was a translation of the first word of the pair and the «No» button when they did not. They were asked to respond as fast as possible, while trying to make as few errors as possible. Subjects were asked after the task in order to know if they have found any unknown word. None of them found any unknown word.

A mixed factorial repeated measures design was carried out with the following within-subjects factors: Agreement (translation vs. non translation), Direction of the translation (from Spanish to Catalan vs. from Catalan to Spanish), and Frequency (high frequency vs. low frequency). Seven dependent variables were used: the reaction times and the mean voltage at six time windows at each electrode site. The time windows used were: 100 to 200 msec, 200 to 300 msec, 300 to 400 msec, 400 to 500 msec, 500 to 600 msec and 600 to 700 msec. Due to the high number of comparisons, a previous multivariate analysis of variance was carried out, using the mean amplitudes at each electrode sites as dependent variables. After this analysis, univariate analysis of variance were carried out only for the effects that in the multivariate analysis reached signification at an alpha level of $p<0.05$. This strategy protects the univariate analysis against the increment of experimentalwise error rate (Hummel & Sligo, 1971). Because of the high number of comparisons, the level of significance for the univariate analysis was stated as 1% in order to avoid a high experimentalwise error rate. For the same reason the effects that were significant in only one electrode site are not commented. The size of each significant effect was computed. The Linguistic Dominance of the subjects was introduced into the design as a between-subjects factor. Subjects were defined as Spanish dominants if they usually spoke Spanish at home, with their friends, etc., and preferred to speak in Spanish if possible. Catalan dominants were defined in the same way. The main reason for introducing this factor was the possibility that some effects of the within-subjects factor «direction of the translation» were increased or attenuated across the subjects as a function of the frequency of usage in everyday life for each language.

EEG recording

The electroencephalogram (EEG) was recorded monopolarly with Ag/AgCl electrodes from FP1, FP2, F7, F8, F3, F4, Fz, Cz, C3, C4, Pz, P3, P4, O1, O2, T3, T4, T5 and T6 of the 10-20 International Location System, using an elastic cap (Electro Cap International). The electrooculogram (EOG) was recorded bipolarly from electrodes placed above the right eye and at the outer canthus

Table I
Descriptive statistics for reaction times (CD: Catalan Dominant; SD: Spanish Dominant; TS: Total Sample; D: Dominance)

RESPONSE FREQUENCY DIRECTION	D	Translations HF Mean	SD	D	Translations LF Mean	SD	D	Non-Translation- HF Mean	SD	D	Non-Translation LF Mean	SD
CATALAN-SPANISH	(CD)	436.7	78.9	(CD)	494.2	85.1	(CD)	550.0	76.8	(CD)	554.2	83.2
	(SD)	436.1	75.2	(SD)	536.4	62.4	(SD)	571.7	48.3	(SD)	577.5	46.9
	(TS)	436.4	75.4	(TS)	515.3	76.1	(TS)	560.8	63.7	(TS)	565.9	67.1
SPANISH-CATALAN	(CD)	420.1	55.8	(CD)	452.2	61.1	(CD)	532.8	73.6	(CD)	563.4	76.8
	(SD)	469.2	87.7	(SD)	564.5	82.3	(SD)	572.9	70.6	(SD)	613.3	81.1
	(TS)	444.7	76.2	(TS)	508.3	91.2	(TS)	552.8	73.4	(TS)	588.3	81.3

of the left eye. Epochs were accepted only if the activity in the ocular artifact channel between 0-700 msec was in the interval -40 mV to 40 mV (approximately 10 % of the trials were lost for this reason). All sites were referred to earlobes, using an external ground electrode. All EEG and EOG channels were amplified with a bandwidth of 0.03-30 Hz and digitized with 2 msec resolution. Electrode impedance was always less than 5 kOhm. The epoch began 100 msec before stimulus onset and ended 1000 ms after (using the 100 ms pre-stimulus as baseline).

ERP waveforms were averaged separately for each cell in the design. Each average was made up, on average, 22 trials (range, 19 - 25). Only correct answers were averaged.

Results

RT Data

Descriptive statistics for reaction times are shown in Table I, both for Catalan and Spanish dominants and for the total sample.

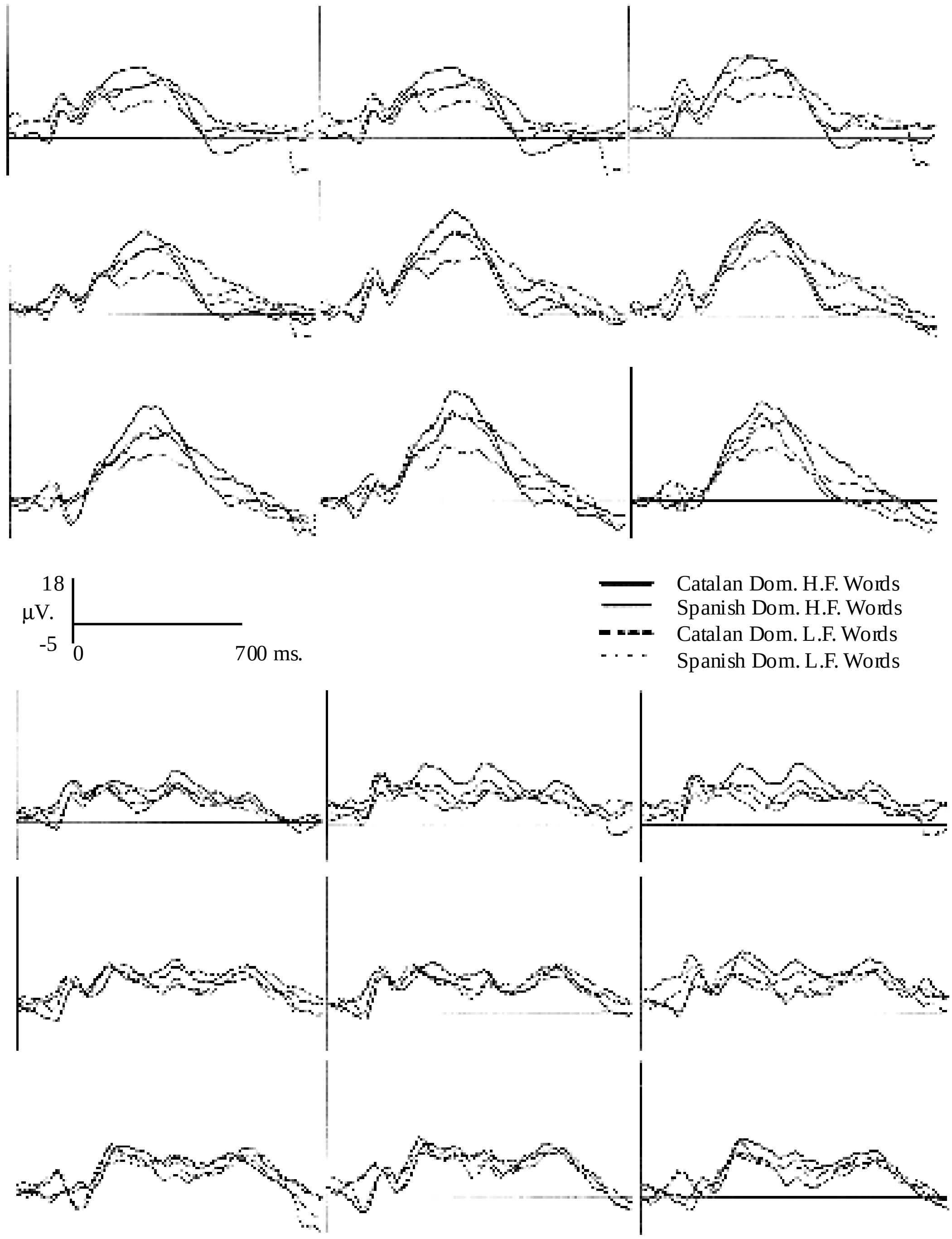

Figure 1. *Grand average for translations from Catalan to Spanish. Electrode sites: From left to right and from up to down: F3, Fz, F4, C3, Cz, C4, P3, Pz and P4 (UP: Translations; Down: Non-Translations)*

The error rates, including omissions were similar for all the experimental levels (range 2-8 % with less than 0,5% of omissions) and there were no significant differences between them.

Univariate analysis

The main effect of the Response factor was significant [F=195.21; p<.01] reflecting the faster RTs for translations as compared to non-translations; the main effect of the Frequency factor was significant too [F=44.43; p<.01], showing faster responses for high frequency words. The interaction effect between these two factors was significant too [F=14.96; p<.01] due to the fact that the subjects were considerably faster in correctly translating high frequency words and, as usual, the frequency effect is mainly produced in translations.

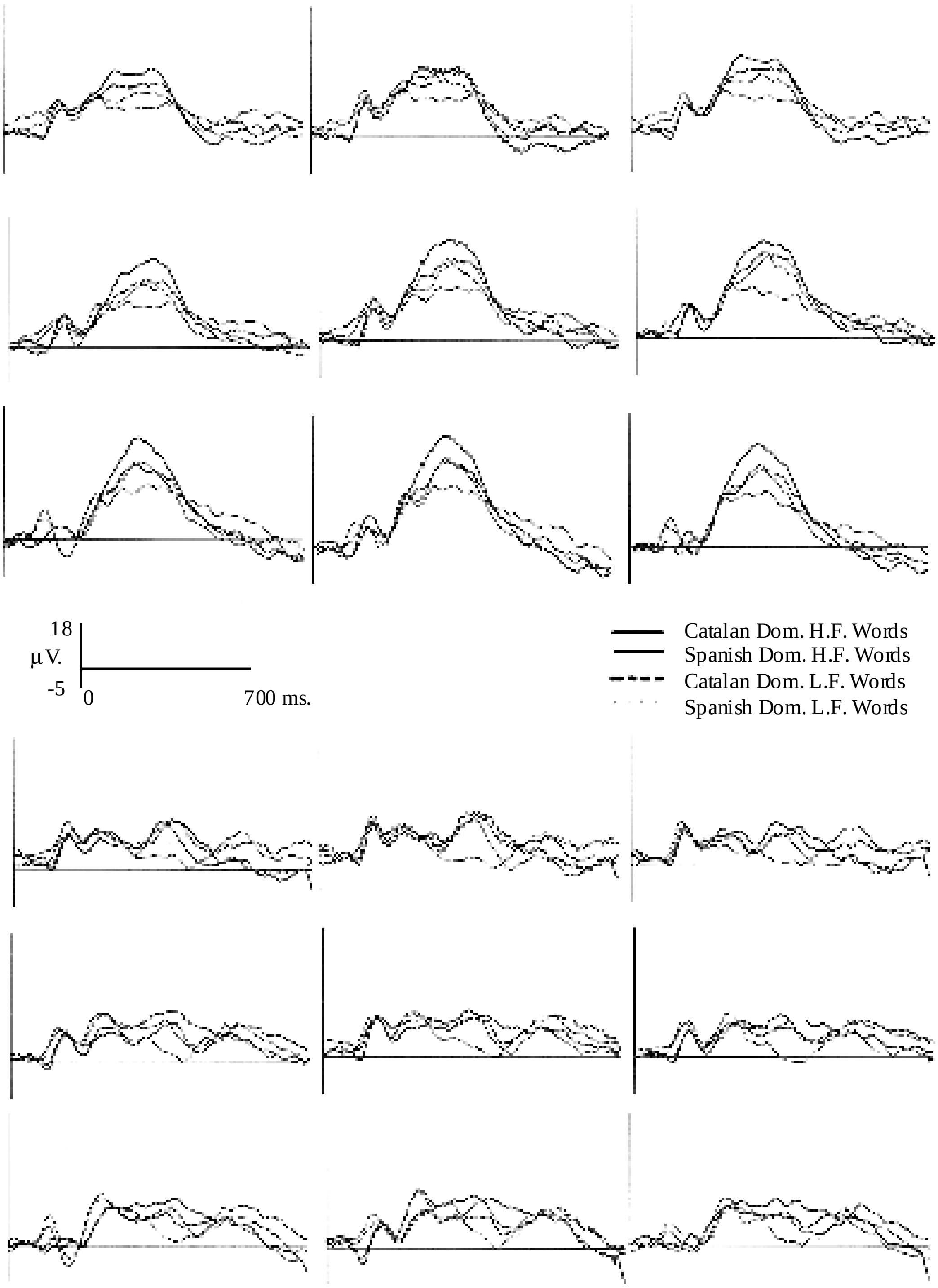

Figure 2. *Grand average for translations from Spanish to Catalan. Electrode sites: From left to right and from up to down: F3, Fz, F4, C3, Cz, C4, P3, Pz and P4 (UP: Translations; Down: Non-Translations)*

The between-subjects Linguistic Dominance factor was non-significant but had a three-way interaction with Response and Direction [F=5.1; p<.05]. Post hoc analysis shown that at p<0.05 level, the translations from L2 to L1 were faster except for catalan dominants and high frequency words.

ERP Data

ERP Morphology: The grand average ERPs (N= 24) to the second words of each word pair comparing the high and low frequency words are shown in Figures 1 for the Catalan to Spanish direction, and in Figure 2 for the Spanish to Catalan direction. For the first 200 msec the ERP waveform is quite similar for all conditions. Approximately 250 msec after the stimulus onset an ongoing positive peak begins with centro-parietal maximum amplitude around 300 msec. For the non translation condition there is a late positive component with maximum amplitude around 600 msec.

Multivariate analysis

Results for the 1st time window: No effects were found in this time window.

Results for the 2nd time window: The main effect of the Response factor was significant (F=5.64; p<.01) showing that the mean amplitude for translations was greater than for non correct translations. The main effect of the Frequency factor was significant too (F=3.17; p<.05) with higher mean amplitudes for high frequency words. There was an interaction between Dominance and Response (F=3.85; p<.05), showing higher amplitudes for Catalan dominants in translations.

Results for the 3rd time window: The effects of the Response (F=11.8; p<.01) and Frequency (F=3.44; p<.05) factors and the interaction between Dominance and Response (F=3.77; p<.05) were the same. The higher effect sizes suggest that in this time window the P300 component reaches its maximum amplitude.

Results for the 4th time window: The same significant effect of the Response (F=4.3; p<.05) factor obtained in the previous time windows was found here. An interaction between Response and Frequency (F=3.71; p<.05) was found. This effect may reflect the greater amplitude of the low frequency words in translations in this time window. That is, the process indexed by P300 shows a greater amplitude for high frequency words, but this process ends earlier than for low frequency words, as we can see in the results obtained in the previous time window. This result seems to be compatible with the faster RTs obtained for high frequency words.

Results for the 5th time window: We again found the same main effect of Response (F=4.63; p<.05) that were found in the previous time windows, but these effects show an inverse pattern,

Table II
Univariate analysis: Significative effects (p<=.01) and effect size

Legend:
S: Response (Correct translate vs. Incorrect translate).
F: Frequency (High vs. Low).

Time Window Electrode	**1 100 - 200 msec**	**2 200 - 300 msec**	**3 300 - 400 msec**	**4 400 - 500 msec**	**5 500 - 600 msec**	**6 600 - 700 msec**
F3		S .425 F .332	S .362 F .424	S x F .349	S .260	S .273
F4		S .676 F .556	S .547 F .558			
C3		S .461 F .303	S .604 F .517	S x F .462	S .438	S .429
C4		S .610 F .363	S .745 F .482	S x F .303	S .395	S .404
P3		S .462 F .359	S .727 F .560	S x F .365	S .701	S .704
P4		S .524 F .450	S .720 F .360	S x F .510	S .723	S .729
F7			F .336	S .380		
F8		S .638	S .635 F .279	S x F .250	S .440	S .450
T3			S .492 F .540		S .537	S .535
T4		S .317	S .441		S .443	S .445
T5			S .600 F .500	S x F .284	S .651	S .644
T6		S .419	S .629		S .522	S .515
Fz		S .637 F .350	S .588 F .354	S x F .591		S .250
Cz		S .554	S .688 F .345	S x F .303	S .417	S .406
Pz		S .506 F .357	S .740 F .570	S x F .651	S .674	S .676

that is, greater amplitudes were found for non translations. An interaction between Dominance and Response and Frequency (F=3.57; p<.05) was found too, with the amplitude being greater in Spanish dominants for non-translations of high frequency words.

Results for the 6th time window: The overall effect of Response (F=4.5; p<.05) factor was found again. In addition, the same interaction observed in the previous time window between Dominance and Response and Frequency (F=3.79; p<.05) was also found. These results reflect the same differences shown in the 5th time window.

Interhemispheric comparisons: a second multivariate analysis was carried out introducing a new factor (laterality) that depends upon the right or left hemisphere localization of the electrodes. Midline electrodes were removed of this analysis thus they could generate artifactual interactions due to their orientation in respect to generator sources, as a consequence a separate analysis for lateral electrodes is preferred (Garnsey, 1993). The effects found for this analysis were similar to the ones exposed above but no laterality effect was found. This fact could be reflected in the univariate effects shown in table II were we can see that most of the significant effects are found in both hemispheres.

Univariate analysis

Significant effects and effect size for the ERPs for all electrode sites and time windows are presented in Table II (level of significance stated at 1%). This analysis allow us a first approach to the distribution across the scalp of the effects described in the multivariate analysis. As we can see the response and frequency effects related to P300 and P600 components have an overall distribution across the scalp with higher amplitudes at central and parietal sites. This is the typical distribution of these components. Although in figures 1 and 2 we can see that Catalan dominants show greater P300 amplitudes than Spanish dominants at almost all sites for the translation condition, none of the between- subjects comparisons reached significance. This fact could be due to the lower sensitivity of between-subjects factors, and it is possible that with a greater sample size the effect of linguistic dominance can show the same overall distribution.

Discussion

The effects observed in this experiment show a complex data pattern. Nevertheless, there are some interesting issues that may help to clarify certain aspects concerning representations in bilingual memory, and the role of the P300 in memory processes.

RT data of Spanish dominants seem to adapt better to the Revised Hierarchical Model than those for Catalan dominants. As we can see, the language asymmetry proposed which expected L2 to L1 translations to be faster than L1 to L2 translations is significant for Spanish dominants and only for low frequency words for Catalan dominants. Moreover, this effect is greater but not significant, for high frequency words rather than low frequency words. These results suggest that both conditions -L1 to L2 and L2 to L1- seems to be more sensitive to conceptual or semantic factors than to lexical factors for Catalan dominants, while L2 to L1 is more sensitive to lexical processes for Spanish dominants. As in the case of Heredia (1995), our subjects were classified as highly proficient and fully fluent in both their languages, Spanish and Catalan. Moreover, taking into account the fact that our subjects received their formal education in their two languages, as far as written words are concerned Catalan becomes the subordinate language, because about 90% of printed words are in Spanish. In this respect Catalan dominants make a supplementary effort to even up their knowledge of the languages and make their two languages equally active. This effort is neither needed nor made by Spanish dominants for whom Catalan is clearly the subordinate language. Perhaps the revised hierarchical model only explains bilingual memory for unbalanced bilinguals like our Spanish dominants but not for balanced bilinguals like our Catalan dominants.

In this respect the proposal and the modifications made by Heredia (1995) may be very useful for clarifying our results. His model does not deal with the order in which the languages were learned, but with which language is most used (the most dominant language) and which is the least used (least dominant language). On the other hand, his proposal avoids the problem of having one memory structure for non-fluent or unbalanced bilinguals and another memory structure for more fluent or balanced bilinguals, as occurs with other proposals. What he suggests, which may explain our results, is that the information, independently of the lexicon in which is stored, may not be readily accessible or as easy to access due to a low frequency of usage. This point directly concerns our results and confirms our belief that the frequency of usage of Catalan in our Spanish dominants is the cause of language asymmetry in the direction of translations; but this fact is not produced in our Catalan dominants because of the effort they make to compensate for the inferiority of the Catalan language compared with Spanish in the case of printed materials.

ERP data seems to be in accordance with the model proposed by Chapman, McCrary and Chapman (1981), about the relationship between memory processes and the P300 component. We observed that the first word of each pair elicited a positive component with a peak latency at about 250 ms. This component is called «the storage component» by Chapman and colleagues, and it has been associated with the storage of the stimulus in the short-term memory. As far as the target or second word of each pair is concerned, we found that the P300 component was greater for high frequency words and translations than for low frequency words and non-translations. Furthermore, the P300 component for low frequency words lasts longer. This is compatible with the idea that the amplitude of P300 is related to the relevance of the stimulus for the task and to the degree of match between the stimulus and the representation stored in the memory (Johnson, 1986). If the P300 is triggered, as it seems, by target identification and matching of information against stimulus categories in memory, it also seems plausible that the first candidates activated when subjects see the first word of each pair are their corresponding translation. On the other hand, we all know that lexical access processes are faster for high frequency words rather than low frequency words.

Furthermore, for non-translations we found a P300 component of very low amplitude followed by a later positive peak around 600 ms. The time difference between P300 and P600 peak latencies depends basically on the memory set size and the load of processing imposed by the reanalysis processes required for the task. Recent research in the field of syntactic processing has focused on the P600 (Hagoort et al., 1993; Osterhout & Holcomb, 1993). This component has been interpreted as a marker of syntactic anomaly. Several authors have suggested that P600 could be a member of the P300 family, for it shares many of the characteristics that have been attributed to P300, and they are elicited by the same factors that elicit the P300. P600 could be regarded as a certain type of delayed P300 which is elicited in situations -in word pairs paradigms- in which the target word is not the expected target, and a reanalysis process is invoked in order to make a behavioral response. The P600 component we found, which appears after the behavioral response, could be an index of the end of these processes. For this component we observed the same frequency effect that we found for the P300 component but with an inverse pattern, that is, greater amplitudes for low frequency words than for high frequency words.

This data pattern may reveal the role of the P300 component. In this task, when the subjects see the first word of a given pair, a set of possible candidates are activated, basically as a function of their meaning. It is possible that one of these candidates has a higher level of activation (as in our case, in which all the translations have a cloze probability greater than 92%) and blacks out the activation of the remaining candidates, leading the subject to give an answer with a subjective higher degree of confidence when the second word of the pair appears. The P300 component may also be affected by this high degree of confidence in the answer and the high degree of activation of the candidate. In contrast, when the target word is not an activated candidate (as in the non-equivalent translations), the task is more difficult, so increasing the processing resources for the subjects, who need an additional reanalysis process before giving an answer. The P600 component may be what marks the end of the reanalysis process.

The hypotheses used to explain the data discussed above are based on the kind of manipulations that affect the amplitudes of P300 and P600 in language processing. First, P300 amplitude seems to be increased by words which are best recognized or recalled in a memory test after any task, and it also increases as a function of the degree of subject confidence when they make a choice between two possible responses (Paller, Kutas & Mayes, 1985; Paller, McCarthy & Wood, 1988). Second, P600 has been viewed at the sentence level as an indicator of syntactic closure after a reanalysis process (Picton & Stuss, 1984). It is also affected by the amount of work required by the task because of the processing demands and the complexity of the mental processes involved (Rugg, 1990; Rösler & Heil, 1991). Finally its latency is delayed as a function of the difficulty of discriminating the target stimulus (Osterhout & Holcomb, 1993; Hagoort, Brown & Groothusen 1993).

These characteristics of the two components suggest that when there is a match between the two words of a pair, the increase in the amplitude of the P300 component may reflect the degree of activation of the second word in the short-term memory and the confidence of the subjects in their choice. Finally, factors like cloze probability and frequency of usage may help to increase the level of activation of some activated candidates.

Finally, for non-translations an N400 component was found. This component was more prominent for low frequency words than for high frequency words. Apparently L1-L2 translations could be related to a high amplitude N400 component for Spanish dominants, this result could give us evidence favoring the hierarchical model but this effect didn't reach statistical significance. Further research must increase the sample size in order to reach the necessary power to verify the significance of these between-subjects effect.

In order to clarify the differences between Catalan and Spanish dominants it would be interesting to use a third language -for example English- as a probe, to compare the performance across languages of Catalan and Spanish dominants with regard to an authentic subordinate language like English.

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