Neurophysiol Clin 2002 ; 32 : 72-84

S098770530100291X/FLA
www.elsevier.fr/direct/nc-cn

ORIGINAL ARTICLE

Human brain potentials reveal similar processing of non-linguistic abstract structure and linguistic syntactic structure

Taïssia Lelekov-Boissard[1]*, Peter F. Dominey[2]

[1] *Laboratoire parole et langage, UMR 6057-CNRS, université de Provence, 29, av. Robert Schuman, 13621 Aix-en-Provence cedex 01, France ;* [2] *Institut des sciences cognitives, UMR 5015 CNRS-UCBL I, 67, boulevard Pinel, 69675 Bron Cedex, France*

(Received 12 December 2000; accepted 6 December 2001)

Summary – This research tested the hypothesis that shared or related neurophysiological processes are required for treating (a) non-linguistic abstract structure and (b) some aspects of linguistic syntactic structure. In language, one syntactic structure can be used to create an open class of sentences. We have previously proposed a relation between this generative aspect of syntactic structure and the abstract structure of non-linguistic sequences. For instance, the sequences 'ABCBAC' and 'DEFEDF' have different serial order or serial structure, but share the same abstract structure '123213'. Our recent studies of neuropsychology, simulation and ERPs argued that similar neurophysiological processes are involved in treating non-linguistic abstract structure and certain aspects of linguistic syntactic structure. The current research tests this hypothesis by examining the ERP profile evoked during the processing of non-linguistic sequences vs. sentences. Ten healthy subjects were trained to discriminate between syntactically correct and incorrect sequences and sentences presented visually on a video screen. During the subsequent ERP recording, subjects discriminated between correct and incorrect sequences and sentences presented visually on the screen. This discrimination task yielded, for anomalies in both the abstract and syntactic conditions, a late positivity around 550 ms with partially overlapping topography. These results support our hypothesis that shared or related neurophysiological processes are required for treating non-linguistic abstract structure and aspects of linguistic syntactic structure. However, they also suggest that the overlap between these two types of processing is not complete. © 2002 Éditions scientifiques et médicales Elsevier SAS

abstract structure / syntactic structure / P600 / sequence processing / syntactic comprehension

Résumé – Les Potentiels Évoqués révèlent des processus similaires dans le traitement de structures syntaxiques et de structures abstraites. Cette étude teste l'hypothèse que des processus neurophysiologiques partagés ou similaires sont requis pour le traitement d'une structure abstraite non-linguistique et pour certains aspects du traitement d'une structure syntaxique linguistique. Dans le langage, une même structure syntaxique peut être utilisée pour générer un ensemble de phrases. Nous avons proposé précédemment une relation entre cet aspect génératif de la structure syntaxique et la structure abstraite des séquences non-linguistiques. Par exemple, les séquences ABCBAC et DEFEDF ont une structure sérielle différente, mais partagent la même structure abstraite 123213. Nos études récentes de neuropsychologie, de simulation et de Potentiels Evoqués (PE) montrent que des processus neurophysiologiques

**Correspondence and reprints.*
E-mail address: taissia.lelekov@lpl.univ-aix.fr (T. Lelekov-Boissard).

similaires interviennent dans le traitement de la structure abstraite non-linguistique et dans le traitement d'une structure syntaxique linguistique. L'étude présentée teste cette hypothèse en examinant le profil des PE engendrés durant le traitement des séquences non-linguistiques vs. phrases. Dix sujets normaux ont été entraînés à discriminer des séquences et phrases correctes et incorrectes présentées visuellement sur un écran. Durant l'enregistrement qui suivait, les sujets étaient confrontés à des séquences et phrases correctes et incorrectes présentées visuellement sur un écran qu'ils devaient discriminer. Cette tâche de discrimination a engendré pour les anomalies dans les conditions abstraite et syntaxique une positivité tardive autour de 550 ms. Ce résultat soutient notre hypothèse de processus similaires; cependant la différence topographique des effets suggère que les deux types de processus ne sont pas strictement superposables.

structure abstraite / structure syntaxique / P600 / traitement de séquence / compréhension syntaxique

INTRODUCTION

What separates and links language to non-linguistic cognitive sequence processing

Our recent studies investigated the processing of non-linguistic sequences in order to determine whether the same processes that are involved in learning a single instance of a non-linguistic cognitive sequence are involved in the extraction and manipulation of generalized rules for generating new sequences. We introduce, for non-linguistic sequences, the notion of non-linguistic serial and abstract sequential structure as follows: in a series of items "the serial structure is the sequence of items itself (their serial order), while the non-linguistic abstract structure is formed by the logic that underlies the sequence" and permits the construction of other series of the same type. For instance, the sequences ABCBAC and DEFEDF have different serial order, but share the same non-linguistic abstract structure '123213'. This non-linguistic abstract structure can be used to generate an open set of new isomorphic sequences such as GHIHGI, JKLKJL etc. We have recently concluded, based on studies of simulation [4, 7], experimental psychology [7] and neuropsychology [5, 8] that the processing of non-linguistic serial and abstract sequential structure rely, at least in part, on dissociable neurophysiological processes.

Given this evidence for dissociable processes for serial and abstract structure, we recently predicted a corresponding difference in brain potentials evoked by the processing of these two types of sequential structure. We have recently realised an ERP study [17] in which we used coloured geometric figures organised in sequences as the stimuli. The subjects performed serial and abstract tasks. For both tasks, each sequence consisted of 6 sequentially presented figures. The serial task used a single six-element reference sequence (surface structure) for testing. Likewise, the abstract task used a single six-element reference non-linguistic abstract structure of the format: 1st figure– 2nd figure– 3rd figure– 4th figure – again 2nd figure – again 3rd figure (i.e. construction rule 1–**2–3**–4–**2–3**) for testing. Discrimination between well-formed vs. not well-formed sequences yielded a different profile of ERPs for the non-linguistic serial vs. abstract conditions, with non-linguistic abstract structure treatment evoking a late positivity around 500 ms, which was not seen in the serial structure processing, thus supporting our hypothesis of dissociable processes. A similar type of dissociation between syntactic vs. semantic processing in language has been extensively demonstrated in ERP studies [9, 24]. A number of studies indicate that the processing of semantic anomalies is associated with the N400 response, a negative going potential around 400 ms [15, 19, 23, 24]. In contrast, detection of syntactic anomalies has been associated with the P600, an enhanced centro-parietal positive going effect around 500–600 ms [9, 24] that can also spread to frontal regions [24]. Syntactic processing is also associated with the lateral anterior negativity (LAN) an early negative going wave around 400 ms predominantly over the left anterior cortex, though this appears to be a more selective response that does not occur for all syntactic processing [9, 14, 21, 24]. We previously observed that non-linguistic abstract structure is similar to linguistic syntactic structure in that both are based on generalized rules governing the specification of sequential form, rather than content [4, 6]. Our ERP study [17] demonstrates that non-linguistic abstract structure treatment evokes a late positivity around 500 ms, similar to that seen in linguistic syntactic structure processing, thus supporting the idea of similar processes involved in treatment of these two structures.

This proposed similarity between processes for linguistic syntactic and non-linguistic abstract structure processing would predict that patients with syntactic processing impairments, including agrammatic aphasic subjects and schizophrenic subjects should be similarly impaired in both types of processing. In order to test this hypothesis we compared performance for processing linguistic syntactic and non-linguistic abstract structure in a group of agrammatic aphasic subjects [6, 16] and in a group of schizophrenic subjects [18]. First, we tested the ability of agrammatic aphasic subjects and of schizophrenic subjects to learn and process the non-linguistic abstract structure of letter sequences. Subjects were required to learn the target complex non-linguistic non-canonical abstract structure (i.e. 1–2–3–2–1–3) by studying a set of 6 isomorphic sequences derived from this abstract structure and then to classify 20 new letter strings by indicating whether or not they corresponded to the learned target non-linguistic abstract structure. This same procedure was also employed with a canonical (i.e. 1–2–3–1–2–3) non-linguistic abstract structure. Performance in this task was compared to syntactic comprehension as evaluated by the nine-sentence type "who did what to whom" task developed by Caplan et al. [1]. We found a significant correlation between the processing of abstract structure of non-linguistic sequences and linguistic syntactic structure of sentences. More precisely, the observation that performance on complex (non-canonical) non-linguistic abstract structure predicts performance on complex (non-canonical) order of thematic roles in syntactic comprehension suggests indeed the possibility of a common underlying impairment in transformation processing that is required in both tasks (*figure 1*).

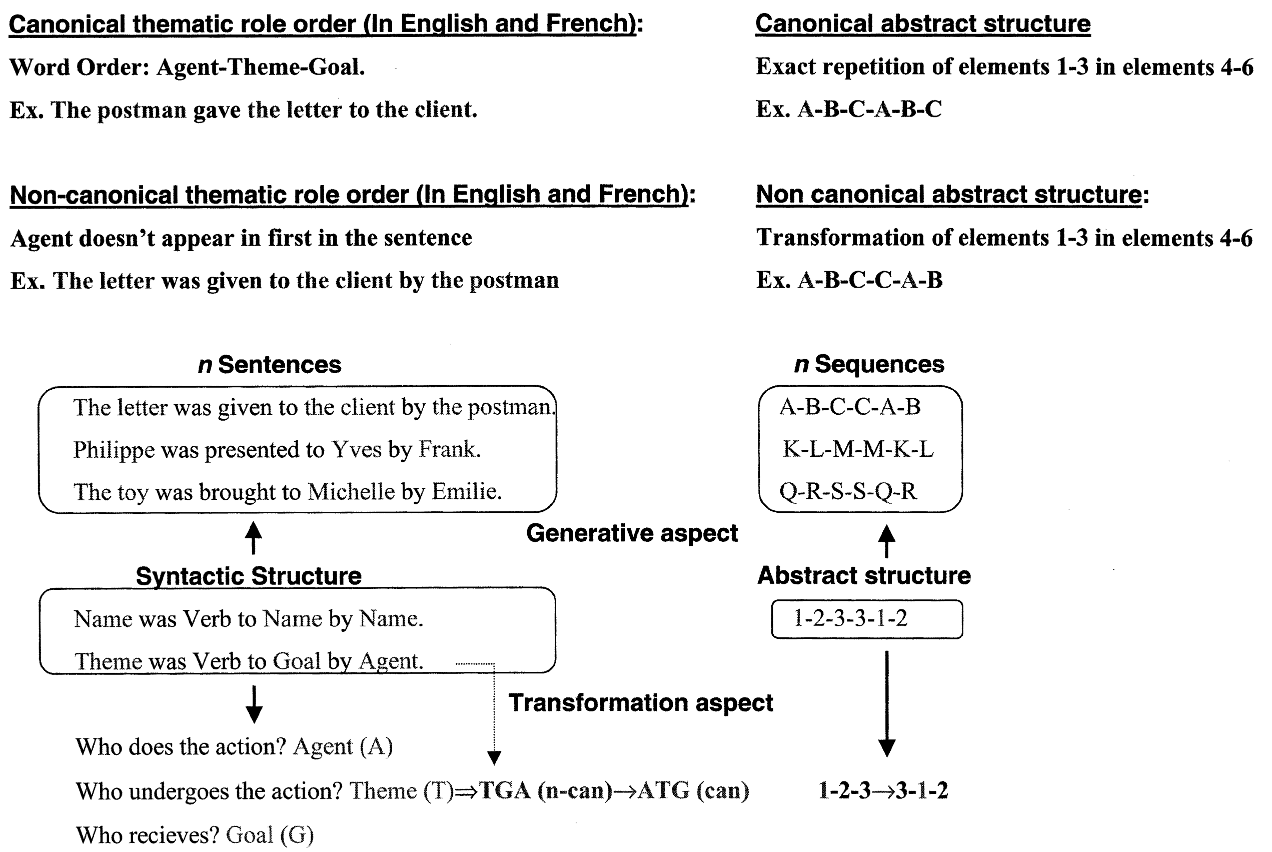

Figure 1. Syntactic and abstract structures. In the case of non-canonical syntactic structure (SS) and non-canonical abstract structure (AS), each of these structure, is characterized by generative and transformation aspects. The generative aspect permits the generation of several sentences and sequences all constructed based on the same model. The transformation aspect permits the reorganisation of the initial order of the sentence and the first triplet of the sequence. In this sense, abstract structure is similar to syntactic structure.

Therefore, we consider the following hypothesis: similar neurophysiological processes are required for treating non-canonical non-linguistic abstract structure and non-canonical linguistic syntactic structure. Given this hypothesis concerning non-linguistic abstract structure and linguistic syntactic structure processing, we predict that processing of these two structures would be accompanied by a late positivity (of the 'P600' type). To test this prediction we recorded ERPs while subjects performed the non-linguistic abstract structure discrimination task and a linguistic syntactic structure discrimination task.

MATERIALS AND METHODS

Participants

Ten young adults (6 men and 4 women, mean age = 26,3 ± 4,8), free of neurological impairment participated in our experiment. They were all native speakers of French. All subjects were advised of the details of the procedure and gave their informed consent to participate. All were right handed. Subjects were seated 80 cm in front of a 19" colour video monitor to observe the presentation of sequences of letters or of sentences.

Materials

A set of 10 trials of each type (sentences in French and sequences) was constructed for the training period.

A set of 100 sentences in French (50 syntactically correct, 50 syntactically incorrect) and set of 100 sequences (50 correct, 50 incorrect) were constructed for the subsequent ERP recording.

For both the non-linguistic abstract structure discrimination task and the linguistic syntactic structure discrimination tasks, each sequence and sentence was composed of 8 elements. Elements were presented for 200 ms with a stimulus onset asynchrony of 800 ms. The whole of 200 trials presented during the subsequent ERP recording was distributed in four conditions (see *table I*). For abstract structure discrimination task, on a half of the trials (both for training and recording), the sequence was rendered unacceptable by changing the 6th element. For syntactic structure discrimination task, on a half of the trials (both for training and recording), the sentence was rendered unacceptable by exchanging the 6th and 7th element.

Procedure

The experiment was composed of two periods: a training period and the subsequent ERP recording.

Before the training period the subjects learned the correct and incorrect non-linguistic abstract and linguistic syntactic structures (see *table II*). During learning of non-linguistic abstract structure subjects studied a list of 4 letter-sequences of each type (correct e.g. A–***B***–C–***B***-–C–***B***–C–D, B–***L***–A–***L***–A–***L***–A–F, incorrect e.g. A–***B***-–C–***B***–C–***D***–C–D, B–***L***–A–***L***–A–***F***–A–F) generated

Table I. The four conditions of experiment. For abstract structure (AS) discrimination task, the sequence was rendered unacceptable by changing the 6th element. For syntactic structure (SS) discrimination task the sentence was rendered unacceptable by exchanging the 6th and 7th element. C = condition; N = noun; V = verb

	Element 1	**E2**	*E3*	**E4**	*E5*	**E6***	*E7*	*E8*
C1: Correct sequence (Acceptable)	A	***B***	C	***B***	C	***B***	C	D
AS = 1–**2**–3–**2**–3–**2***–3–8								
C2: Incorrect sequence (Unacceptable)	A	***B***	C	***B***	C	***D***	C	D
AS = 1–**2**–3–**2**–3–**8***–3–8								
C3: Correct sentence (Acceptable)								
SS (French) = N a été V à **N*** par N.	Philippe	a	été	présenté	à	**Yves**	par	Frank.
SS (English) = N was V to **N*** by N.	Philippe		was	presented	to	**Yves**	by	Frank.
C4: Incorrect sentence (Unacceptable)								
SS (French) = N a été V à **par*** N N	Philippe	a	été	présenté	à	**par**	Yves	Frank.
SS (English) = N was V to **by*** N N	Philippe		was	presented	to	**by**	Yves	Frank.

Table II. Correct and incorrect abstract and syntactic structures. Examples of isomorphic sequences (same AS) and isomorphic sentences (same SS). abstract structure (AS), syntactic structure (SS).

Correct abstract structure: 1–**2**–3–**2**–3–**2**–3–8	
Examples of isomorphic sequences with correct abstract structure:	
A–***B***–C–***B***–C–***B***–C–D	
B–***L***–A–***L***–A–***L***–A–G	
Incorrect abstract structure: 1–2–3–2–3–8–3–8	
Examples of isomorphic sequences with incorrect abstract structure:	
A–***B***–C–***B***–C–***D***–C–D	
B–***L***–A–***L***–A–***F***–A–F	
Correct syntactic structure:	
SS (French) = N a été V à **N*** par N.	SS (English) = N was V to **N*** by N.
Examples of correct isomorphic sequences:	
Philippe a été présenté à **Yves** par Frank.	Philippe was presented to **Yves** by Frank.
Yves a été conduit à **Michelle** par Emilie.	Yves was led to **Michelle** by Emilie.
Incorrect syntactic structure:	
SS (French) = N a été V à **par*** N N	SS (English) = N was V to **by*** N N.
Examples of incorrect isomorphic sequences:	
Philippe a été présenté à **par** Yves Frank.	Philippe was presented to **by Yves** Frank.
Yves a été conduit à **par** Michelle Emilie.	Yves was led to **by Michelle** Emilie.

from the correct and incorrect non-linguistic abstract structure (correct non-linguistic abstract structure; 1–**2**–3–**2**–3–**2**–3–8, incorrect non-linguistic abstract structure; 1–**2**–3–**2**–3–**8**–3–8). Subjects were instructed to study the list in order to decide how complete the sequence P–U–X–? –? –? –? –H. After this part, subjects demonstrated their understanding of non-linguistic abstract structure by completing the above sequence (P–U–X–U–X–U–X–H). During learning of linguistic syntactic structure subjects studied 4 examples of sentences of each type (correct, incorrect, e.g. (see *table II*)).

During the training period just prior to the recording, subjects classified the set of 10 trials of each type (sentences in French, and sequences) by answering at the question "Acceptable or Unacceptable?" displayed on the screen at the end of each sentence or sequence, thus demonstrating the learning of correct non-linguistic abstract and linguistic syntactic structures. The subject responded by making the corresponding touch (correct touch, incorrect touch) of the response pad. The trials had a random distribution.

The subsequent ERP recording then took place. Each subject was recorded during 4 permutated sessions of approximately 10 min each, with a break between sessions. Two sessions tested the ability to categorize sequences as acceptable or unacceptable with respect to learned non-linguistic abstract structure (non-linguistic abstract structure task), and two sessions tested the ability to categorize sentences based on learned linguistic syntactic structure (linguistic syntactic structure task). The 4 sessions were administered in a sentences–sequences–sequences–sentences permutation. For each session, trials had a random distribution. After each trial, the question "Acceptable or Unacceptable?" was displayed on screen and the subject was required to answer as described above.

ERP recording

Brain activity was recorded with 65 electrodes (64 Channel Geodesic Sensor Net) attached to the scalp and referenced to the vertex [28]. The EOG was monitored by two frontal (supraorbital) and infraorbital (below eyes) electrodes *(figure 2)*.

Electrode/skin impedance's were kept below 50 KΩ. Responses were amplified with high input impedance amplifiers (200 MΩ, bandpass filter 0.1–200 Hz) and digitized at 500 Hz by an Electrical Geodesics recording system. The recorded EEG signal was automatically edited for exclusion of trials containing eye and motion artefacts. We rejected trials with voltages exceeding ±100 μV, transients exceeding ±50 μV or EOG activity exceeding ±70 μV. The remaining trials were averaged in synchrony with stimulus onset, low-pass filtered (0–40 Hz), referenced to the recomputed average reference and corrected for baseline over a 100-ms window prior to stimulus onset and grand-

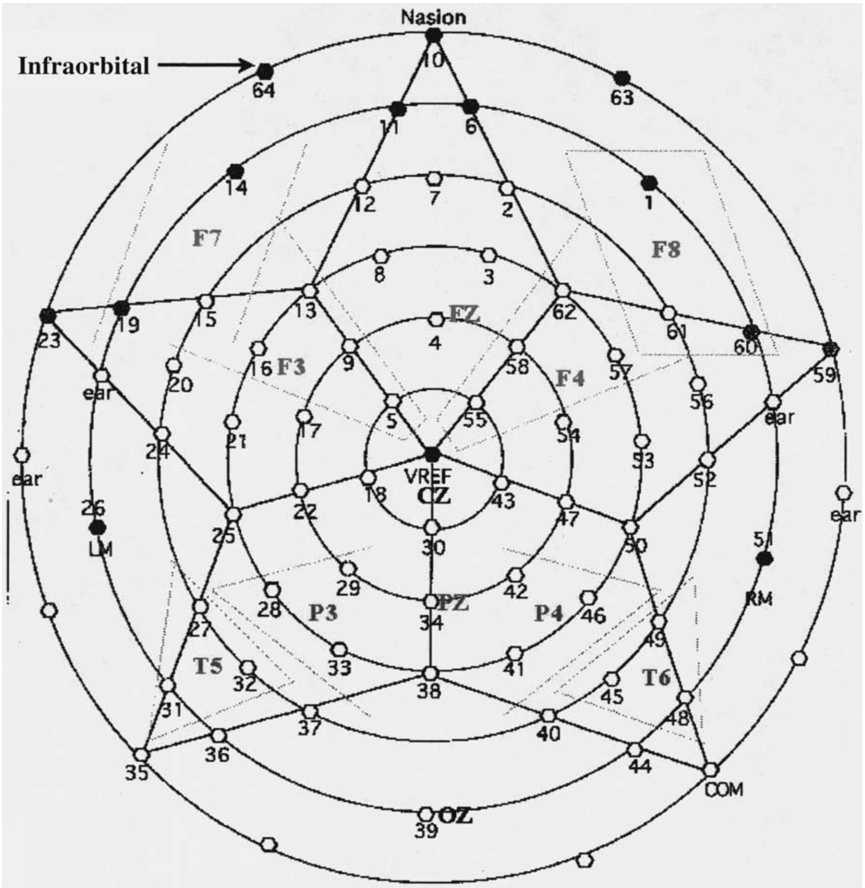

Figure 2. Locations of 64 electrodes on the head (the 64 Channel Geodesic Sensor Net Map). Front is on the top, and subject's left is on the left. Areas named F7, F3, F4, F8; P3, P4, T5 and T6 bring together the groups of frontal, parietal and temporal electrodes. These electrodes are named in terms of the International 10–20 System. Electrodes n° 4, 34, 39 and VREF are named in terms of the International 10–20 System. LM-left mastoid, RM-right mastoid, VREF-vertex.

averaged across subjects [29]. Topographical maps of the scalp distribution of ERP signals were obtained with Electrical Geodesics system.

Data Analysis

Analyses were performed on the scalp electrode voltages elicited by the four conditions in a time window: 300–800 ms from the onset of the critical 6th element. We chose three regions for analysis; frontal, left and right; each consisting of 12 electrodes (see *figure 4B*). These data were analysed in 4-way ANOVA on task (sequences, sentences), condition (correct, incorrect), region (frontal, left, right) and electrodes (n = 12). The dependent variable was the voltage in μV for responses to four conditions (unacceptable sequences, acceptable sequences, unacceptable sentences, acceptable sentences). The voltages for responses to these four conditions were calculated for each subject as the average of the 50 trials for given condition, electrode and temporal period.

RESULTS

The subjects were well trained to discriminate sequences based on the correct and incorrect non-linguistic abstract and linguistic syntactic structures, with performance above 90% correct in all cases. *Figure 3* illustrates the surface maps of electrical activity differences in μV, between responses to unacceptable sequences and those for acceptable sequences and between responses to unacceptable sentences and those

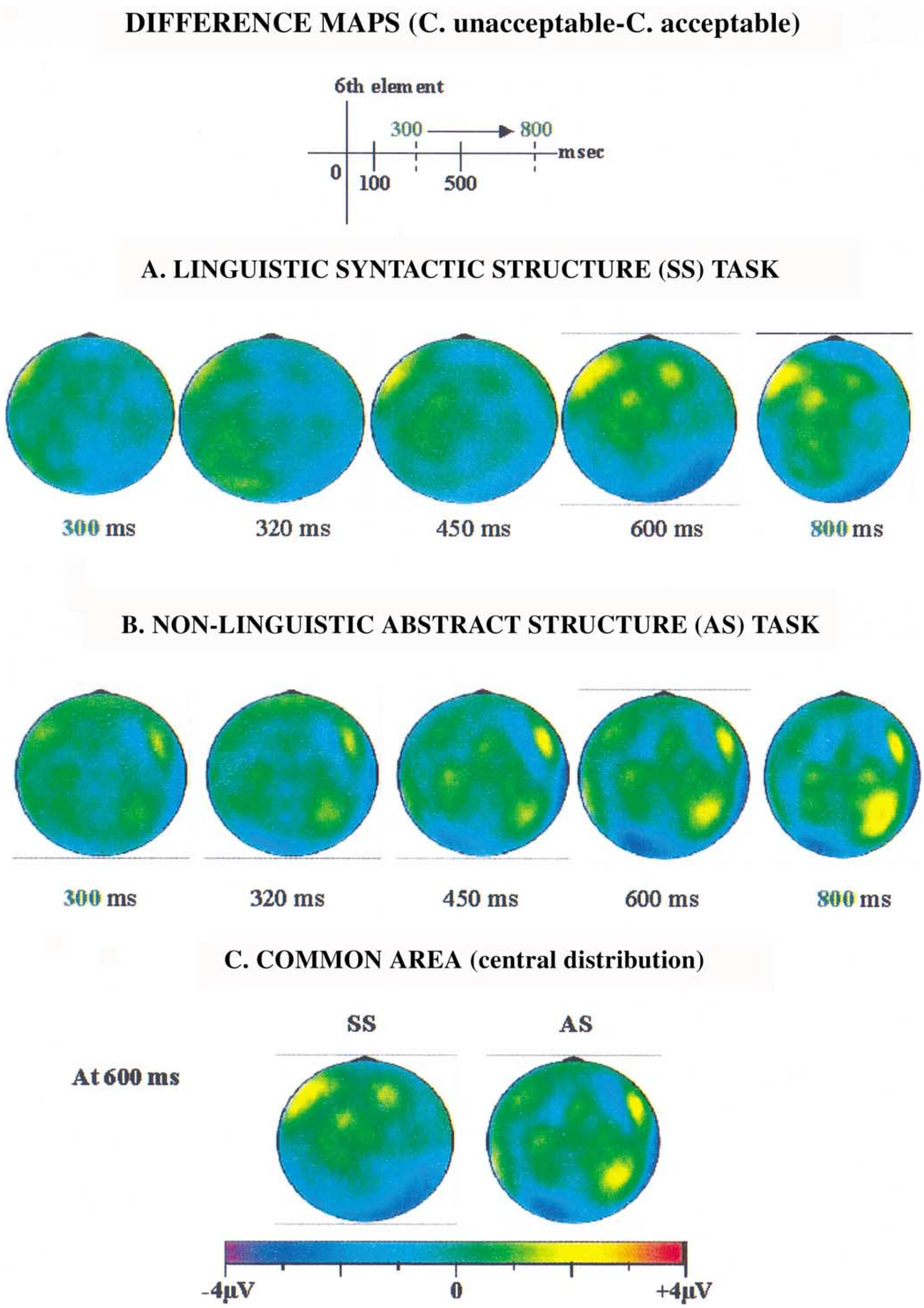

Figure 3. Comparison of abstract vs. Syntactic processing conditions for the critical 6th stimulus. The surface maps of the difference in μV, between potentials to unacceptable sentences and those for acceptable sentences (A) and between responses to unacceptable sequences and those for acceptable sequences (B) during the late positivity (LP) period (300–800 ms). At around 600 ms appears a late positivity for two conditions. The common area for two tasks (C) of positive difference is situated in central areas in which are brought together frontal, parietal and central electrodes. SS-syntactic structure, AS-abstract structure.

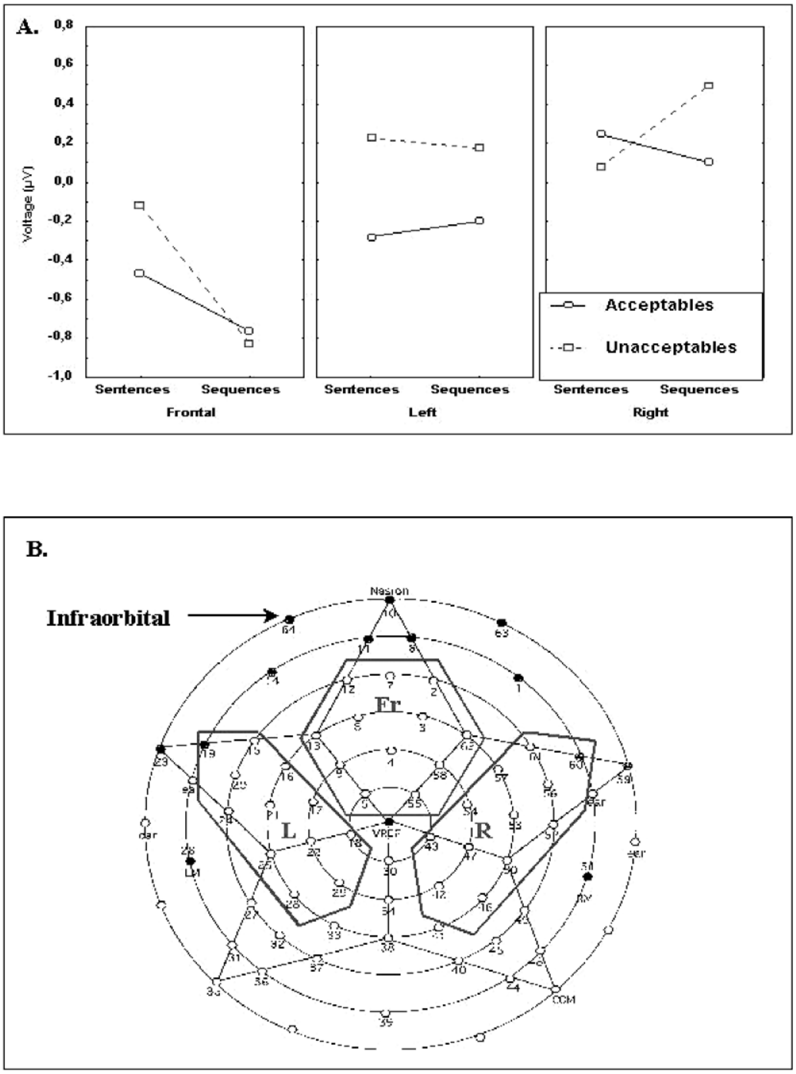

Figure 4. (A) Comparison of voltage values (μV) for responses to unacceptable sentences minus those for acceptable sentences and for responses to unacceptable sequences minus those for acceptable sequences. This voltage differences for responses to unacceptable vs. acceptable sentences appeared more pronounced in the left region. Voltage differences for responses to unacceptable vs. acceptable abstract sequences appeared equal for left and right regions or slightly more pronounced for right region. (B) The three regions (Fr-frontal, L-left, R-right) chosen for statistical analyse. Front is on the top, and subject's left is on the left.

for acceptable sentences during the late positivity (LP) period *(figure 3)*.

These difference maps indicate a positivity at 600 ms that appears for both tasks (linguistic syntactic structure task, non-linguistic abstract structure task). This positivity is located in frontal and central areas of left hemisphere in sentence condition. In the abstract sequence condition, this positivity appears lateralized to the right hemisphere and appears more posterior for frontal area and more symmetric for central area than in the linguistic condition.

Voltage differences during the 300–800 ms interval for responses to unacceptable vs. acceptable sentences are more pronounced for left region *(figure 4A)*. Voltage differences for responses to unacceptable vs. acceptable abstract sequences during this temporal interval are equal for left and right regions or slightly more pronounced for right region.

Figures 5 and *6* display responses at the 6th element for acceptable and unacceptable syntactic structure *(figure 5)* and abstract structure *(figure 6)* at frontal, parietal and the midline electrodes.

For both tasks in the time epoch 0–200 ms we observe the standard N1–P2 complex in response to physical stimulation. For both tasks in the time epoch 300–800 ms, for frontal electrodes there is a biphasic

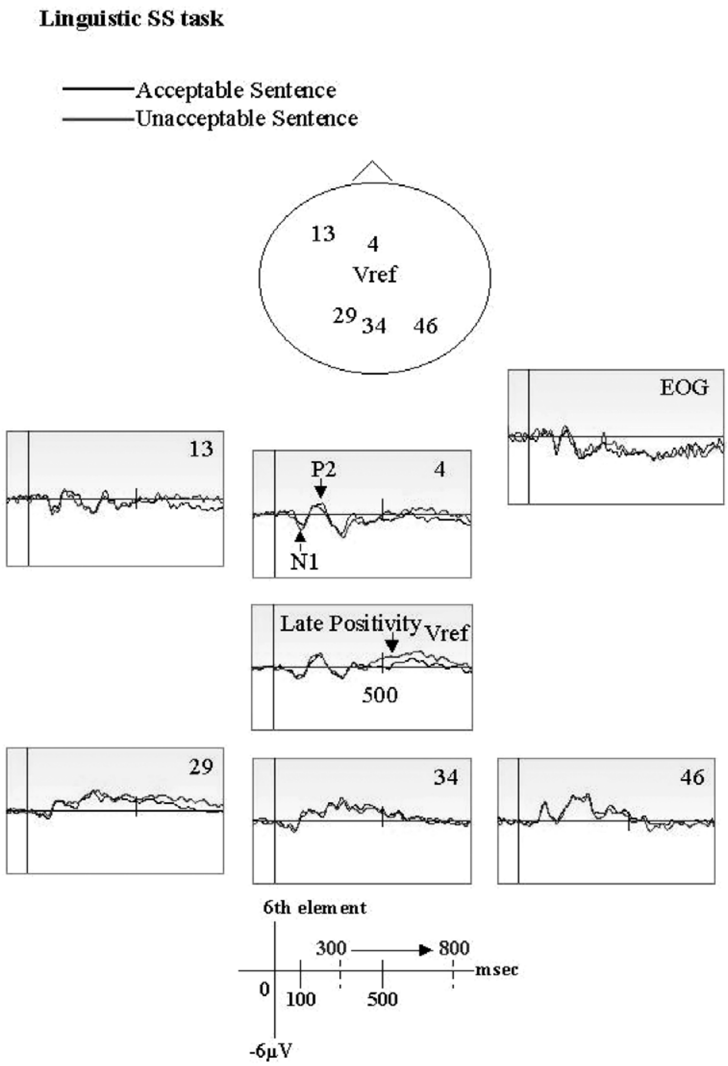

Figure 5. Linguistic syntactic structure (SS) processing for the critical 6th stimulus. Grand-average traces for the unacceptable and acceptable sentences for the frontal (n° 13), parietal (n° 29, 46) and the midline electrodes (n° 4, 34, VREF). The total segment is 1000 ms long, starting 100 ms before a 6th element was presented. Element was presented for 200 ms. The late positivity appears around 600 ms.

response with an early negativity, followed by a late positivity. In both tasks for parietal electrodes there is a late positivity (see *figures 5* and *6*).

These observed similarities between the ERP profiles for non-linguistic abstract and linguistic syntactic structure processing were confirmed in the task × condition × region × electrode ANOVA. There was no significant effect for task: $F(1.9) = 0.79$; $P = 0.3981$. The condition effect was significant: $F(1.9) = 12.98$; $P = 0.0057^*$). Most important, the condition effect is not different between the two tasks: task × condition effect: $F(1.9) = 0.00$; $P = 0.9857$. Likewise, the nature of the task doesn't induce the processing difference between acceptable and unacceptable structures for electrodes of the area of positive activity difference (the task × condition × region × electrode effect: $F(22.198) = 1.21$; $P = 0.2407$; the task × condition × electrode effect: $F(11.99) = 0.51$; $P = 0.8898$. Planned comparisons revealed that the condition effect has a topographical distribution that is significant for the left region for responses to unacceptable vs. acceptable sentences: $P = 0.0139^*$ (0.44 µV), but not for the frontal region: $P = 0.3935$ (0.14 µV); nor the right region: $P = 0.4978$ (0.11 µV)).

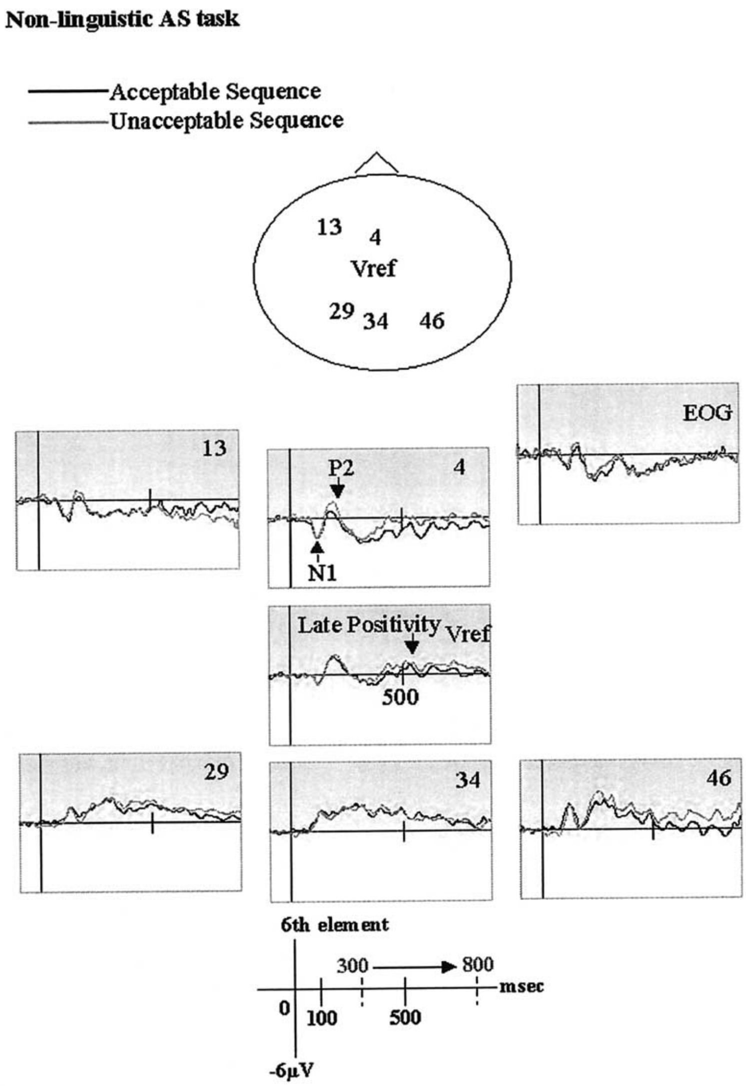

Figure 6. Non-linguistic abstract structure (AS) processing for the critical 6th stimulus. Grand-average traces for the unacceptable and acceptable sequences for the frontal (n° 13), parietal (n° 29, 46) and the midline electrodes (n° 4, 34, VREF). The total segment is 1000 ms long, starting 100 ms before a 6th element was presented. Element was presented for 200 ms. The late positivity appears around 600 ms.

DISCUSSION

In our experiment we observed a positive difference between responses to unacceptable linguistic sentences minus those for acceptable linguistic sentences and likewise between responses to unacceptable non-linguistic sequences minus those for acceptable non-linguistic sequences. From this observation we first address the question whether this positivity has characteristics which permit us to consider it as a P600 in both the linguistic and non-linguistic conditions.

The P600 is a positive wave, which appears around 500–600 ms with centro-parietal distribution associated with the processing of syntactic anomalies [9, 11, 12, 21, 22, 24]. In our experiment, violation of linguistic syntactic structure and violation of non-linguistic abstract structure both evoke a positivity around 600 ms. But, the topography of this positivity did not match the classic centro-parietal distribution. In our linguistic syntactic structure task the observed positivity has central and unusual left frontal distribution with regard to distribution of P600, though such frontal distributions have been seen [24]. In our non-linguistic abstract structure task the observed positivity has central and unusual right frontal distribution with regard to distribution of P600. Consequently, the processing of linguistic syntactic structure and the processing of non-linguistic abstract structure both evoked a late positivity around 600 ms, but this latter had a partially dissimilar topography in both tasks; left frontal in case of linguistic syntactic structure task and right frontal for non-linguistic abstract structure task. On the other hand this late positivity shared a similar distribution in central areas in both tasks. Therefore, the observed late positivity in our experiment shares the temporal characteristic of the P600, as well as a partial spatial overlap with the 'classical' P600. The amplitude of the late positivity in this study is smaller with regard to classical amplitude of P600 (~ 5 µV). In this regard, it is important to note that the critical stimuli (word, letter) in our experiment was in a sentence-embedded position. Osterhout [24] observed that "ERPs to sentence-final words were reliably more positive-going than those to sentence-embedded words." (page 502). The amplitude of our positivity thus might have been larger if syntactic violations had occurred in sentence final position.

Regarding the dissimilar topography in the linguistic syntactic structure task and in the non-linguistic abstract structure task, we may propose the following explanation. A common generator involved in detecting and signalling of the violation of structures (linguistic syntactic structure, non-linguistic abstract structure) would be responsible for the similar central distribution observed in both tasks. Then dissociated generators would reflect the retreating of the incorrect linguistic phrase structure of the sentence and of the incorrect non-linguistic abstract structure of the sequence. In case of linguistic syntactic structure task these possible generators – dorsolateral left frontal sources – would be reflected in the left frontal distribution. This unusual frontal distribution of the observed positivity may be related to the fact that our language violations were phrase structure violations which lead to unrecoverable analysis. In case of the non-linguistic abstract structure task the possible generator, the prefrontal cortex, would be reflected by right hemisphere distribution. Involvement of prefrontal cortex may also reflect an increased working memory load in the non-linguistic abstract structure task. We may suppose that dorsolateral left frontal sources may be more implicated in language than in detection of sequence non-linguistic abstract structure abnormalities. In support of our suggestion of a common distributed neural network treating shared aspects of the linguistic syntactic structure and of the non-linguistic abstract structure, a number of previous studies [2, 3, 10, 20, 27, 30] consider that syntactic processing involves an extensive neural network, whose most important region is left perisylvian cortex.

While our ERP analysis demonstrates a significant positivity (significant effect for condition (correct vs. incorrect)) associated with the treatment of both syntactic and abstract incongruities, we should also consider several methodological issues of potential concern. In our ERP analysis the existence of a similar late positivity 'in both tasks (linguistic and non-linguistic)' was confirmed by the non-significant effect for task × condition interaction. The lack of task × condition interaction could result from small statistical power associated with $n = 10$ subjects. However, we note that the condition effect was highly significant, while the task effect was small, and particularly the task × condition effect was near zero ($F\,(1.9) = 0.00034$; $p = 0.9857$). These statistical results permit us to suppose that interaction is really not significant.

With respect to the temporal window used for analysis (300–800 ms) such a large time window could eventually weaken statistical effects that might be more temporally focused. In our experiment the linguistic syntactic structure and non-linguistic abstract structure processing both evoke a positivity around 600 ms. Previous work [9, 14, 21, 24] observed a positivity termed P600 during the treatment of syntactic category violations. In our experiment unacceptable sentences had as syntactic anomaly the incorrect order of words in the phrase. Several studies found a positive wave elicited by this violation [12, 22, 25].

In our linguistic syntactic structure task, the critical word is a noun (an open class word) in the grammatical sentences, whereas in the ungrammatical sentences the critical word is a preposition (a closed class word). Therefore, there is a risk to confound the effects of grammaticality with the effects of lexical factors. Data from Osterhout [24] however confirms that the P600 in previous experiments is elicited as a function of anomaly type rather than lexical category. Thus, we may consider that also in our experiment the late positivity was anomaly-related, and not lexical-related.

Recently Patel et al. (1998) demonstrated a P600-like response to incongruities in the syntactic phrase structure of music in musically educated subjects [26]. These authors used as stimulus the sounds of different tones which have been organised in a musical suite. The linguistic and musical structural incongruities elicited positivities that were statistically indistinguishable in a specified latency range. In our precedent ERP study [17] we observed that non-linguistic abstract structure treatment evoked a late positivity around 500 ms. These facts provide further arguments that abstract structural organization for both linguistic and non-linguistic sequences may rely on partially overlapping neurophysiological processes.

CONCLUSION

Are similar neurophysiological processes required for treating the non-canonical non-linguistic abstract structure and the non-canonical linguistic syntactic structure? Our objective here was to test this hypothesis. A common late positivity observed during processing of non-linguistic abstract structure vs. linguistic syntactic structure was revealed by the significant effect for condition (correct vs. incorrect) in both tasks and the non-significant task × condition interaction. These results suggest the possibility of a common 'partially' overlapping neurophysiological basis for the transformation processing involved in treating non-linguistic abstract structure and linguistic syntactic structure. On the one hand "the two tasks (linguistic, non-linguistic) are able to evoke a late positivity in responses to the unacceptable elements, which, indeed, joins them on the neurophysiological level". But in the same time, the distribution of this late positivity is not the same one, a left lateralization being exclusively obtained in the linguistic syntactic structure task. The non-linguistic abstract structure task evoked a late positivity with rather a right lateralization even if this right lateralization was not significant, whereas the left was. Therefore, some aspects of the processing of the non-linguistic abstract structure and the linguistic syntactic structure are likely dissimilar. The P600/SPS noted during linguistic syntactic structure processing [12, 22, 24, 25] has a centro-parietal distribution and increases to frontal areas of the left hemisphere. The fact that in this and previous experiments late positivities have been observed during both linguistic syntactic and non-linguistic abstract processing [13, 17] as well as during music phrase structure processing [26] suggests that all these processes might share a common neurophysiological basis [6, 7, 18], an interesting possibility that remains open to further investigation.

REFERENCES

1 Caplan D, Baker C, Dehaut F. Syntactic determinants of sentence comprehension in aphasia. Cognition 1985 ; 21 : 117-75.
2 Caplan D, Hildebrandt N, Makris N. Location of lesions in stroke patients with deficits in syntactic processing in sentence in sentence comprehension. Brain 1996 ; 119 : 933-49.
3 Damasio AR. Aphasia. New Eng J Med 1992 ; 326 : 531-609.
4 Dominey PF. An anatomically structured sensory-motor sequence learning system displays some general linguistic capacities. Brain Lang 1997 ; 59 : 50-75.
5 Dominey PF, Georgieff N. Schizophrenics learn surface but not abstract structure in a serial reaction time task. NeuroReport 1997 ; 8 (13) : 2877-82.
6 Dominey PF, Lelekov T. Non-linguistic Transformation Processing in Agrammatic Aphasia. Comment on Grodzinsky "The Neurophysiology of Syntax: Role of Broca's Area". Behav Brain Sci 2000 ; 23 (1) : 30.
7 Dominey PF, Lelekov T, Ventre-Dominey J, Jeannerod M. Dissociable processes for Learning the Surface Structure and Abstract Structure of Sensorimotor Sequences. J Cognit Neurosci 1998 ; 10 (6) : 734-51.
8 Dominey PF, Ventre-Dominey J, Broussolle E, Jeannerod M. Analogical transfer is effective in a serial reaction time task in Parkinson's disease: Evidence for a dissociable form of sequence learning. Neuropsychologia 1997 ; 35 (1) : 1-9.
9 Friederici AD, Hahne A, Mecklinger A. Temporal Structure of Syntactic Parsing: Early and Late Event-Related Brain Potential Effects. J Exp Psychol Learn Mem Cognition 1996 ; 22 (5) : 1219-48.
10 Friederici AD, Opitz B, von Cramon DY. Segregating Semantic and Syntactic Aspects of Processing in the Human Brain: an fMRI Investigation of Different Word Types. Cerebral Cortex 2000 ; 10 : 698-705.
11 Friederici AD, Pfeifer E, Hahne A. Event-related brain potentials during natural speech processing: effects of semantic, morphological and syntactic violations. Cognit Brain Res 1993 ; 1 : 183-92.
12 Hagoort P, Brown C, Groothusen J. The syntactic positive shift (SPS) as an ERP measure of syntactic processing. Lang Cognit Process 1993 ; 8 : 439-84.
13 Hoen M, Dominey PF. ERP analysis of cognitive sequencing: a left anterior negativity related to structural transformation processing. NeuroReport 2000 ; 11 (14) : 3187-91.
14 King JW, Kutas M. Who did what when? Using Word- and Clause-level ERPs to monitor working memory usage in reading. J Cognit Neurosci 1995 ; 7 (3) : 376-95.
15 Kutas M, Hillyard SA. Brain potentials during reading reflect word expectancy and semantic association. Nature 1984 ; 307 : 161-3.
16 Lelekov T, Dominey PF, Chosson-Tiraboschi C, Ventre-Dominey J, Labourel D, Michel F, Croisile B. Selective Deficits in Processing Syntactic and Abstract Sequential Structure in Agrammatic Comprehension. Europ J Neurosci 2000 ; 12 (s11) : 168.
17 Lelekov T, Dominey PF, Garcia-Larrea L. Dissociable ERP Profiles for Processing Rules vs. Instances in a Cognitive Sequencing Task. NeuroReport 2000 ; 11 (5) : 1129-32.
18 Lelekov T, Franck N, Dominey PF, Georgieff N. Cognitive Sequence Processing and Syntactic Comprehension in Schizophrenia. NeuroReport 2000 ; 11 (10) : 2145-9.
19 McCarthy G, Nobre AC, Bentin S, Spencer DD. Language–related field potentials in the anterior-medial temporal lobe: I.

Intracranial distribution and neural generators. J Neurosci 1995 ; 15 (2) : 1080-9.
20 Mesulam MM. Large-scale neurocognitive networks and distributed processing for attention, language, and memory. Ann Neurol 1990 ; 28 : 597-613.
21 Münte TF, Szentkuti A, Wieringa BM, Matzke M, Johannes S. Human brain potentials to reading syntactic errors in sentences of different complexity. Neurosci Lett 1997 ; 235 : 105-8.
22 Neville HJ, Nicol J, Barss A, Forster KI, Garrett MF. Syntactically based sentence processing classes: Evidence from event-related brain potentials. J Cognit Neurosci 1991 ; 3 : 151-65.
23 Nobre AC, McCarthy G. Language-Related ERPs: Scalp distributions and modulation by word type and semantic priming. J Cognit Neurosci 1994 ; 6 (3) : 233-55.
24 Osterhout L. On the Brain Response to Syntactic Anomalies: Manipulations of Word Position and Word Class Reveal Individual Differences. Brain Lang 1997 ; 59 : 494-522.
25 Osterhout L, Holcomb PJ. Event-related brain potentials elicited by syntactic anomaly. J Mem Lang 1992 ; 31 : 785-806.
26 Patel AD, Gibson E, Ratner J, Besson M, Holcomb PJ. Processing syntactic relations in language and music: An event-related potential study. J Cognit Neurosci 1998 ; 10 (6) : 717-33.
27 Stromswold K, Caplan D, Alpert N, Rauch S. Localization of syntactic comprehension by positron emission tomography. Brain Lang 1996 ; 52 (3) : 452-73.
28 Tucker DM. Spatial sampling of head electrical fields: the geodesic sensor net. Electroencephal. Clin Neurophysiol 1993 ; 87 : 154-63.
29 Tucker DM, Liotti M, Potts GF, Russell GS, Posner MI. Spatiotemporal Analysis of Brain Electrical Fields. Hum Brain Map 1994 ; 1 : 134-52.
30 Zurif E, Swinney D, Prather P, Solomon J, Bushell C. An on-line analysis of syntactic processing in Broca's and Wernicke's aphasia. Brain Lang 1993 ; 45 : 448-64.