

Where and how does grammatically geared processing take place—and why is Broca's area often involved. A coordinated fMRI/ERBP study of language processing

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Abstract

We address the possibility of combining the results from hemodynamic and electrophysiological methods for the study of cognitive processing of language. The hemodynamic method we use is Event-Related fMRI, and the electrophysiological method measures Event-Related Band Power (ERBP) of the EEG signal. The experimental technique allows us to approach the relation between cortical structure and cognitive function in a sophisticated way. In particular, we can formulate original working hypotheses about the language-induced changes in the ongoing brain dynamics. We show, on the basis of electrophysiological data collected in an experiment on language production, that synchronized cortical networks code cognitive processes induced by language in form of power modulations of specific frequency bands. The hemodynamic (fMRI) data collected in the same task point to the existence of a central processor for the phrase structure assignment. We conceptualize such a central processor as a *frequency scanner*, a cortical device designed to pick up synchronized brain activity over a specific range of frequencies. We discuss the experimental designs which result from this set of hypotheses and show their relevance for the models of language processing. © 2003 Elsevier Inc. All rights reserved.

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1. Introduction

Language faculty in the narrow sense (cf. Hauser, Chomsky, & Fitch, 2002) is characterized by processes of phrase structure generation and reserialization. The computations of the narrow syntax are independent of semantic operations like naming, predication, and reference. So, for example, have patients with agrammatism no problem in naming gender in the following queries: “Brother—male or female?” “Mother—male or female?” However, they are lost if the same task is expressed with a simple sentence: “My mother's brother—male or female?” In this case it is only the grammatical computation of the phrase structure matrix which can offer a solution. It has been argued that syntactic computations may be disturbed or inhibited by lesions of the

classical prefrontal language areas (cf. Dogil, Haider, Schaner-Wolles, & Husmann, 1995; Grodzinsky, 2000).

Normal subjects process the phrase structure of sentences independently, or at least quasi-independently, of its meaning. Marslen-Wilson and Tyler (1980) have shown that meaningless sentences that are syntactically well-formed (the notorious “colourless green ideas...”) are parsed differently (faster!) than a meaningless word sequence with no language specific phrase structure. Meaningless sentences also formed a basis for another landmark discovery in neuroscience. Kutas and Hillyard (1980) found a temporal signature of semantic violations in the EEG signal. The discovery of the N400 has led to a long and fruitful series of experiments in which temporal signatures for separate stages of linguistic processing could be established (cf. Friederici, 2003; Friederici & Alter, this volume; Osterhout & Holcomb, 1992).

Most EEG studies of syntactic (and other linguistic) processing are perception based. They have assumed the

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averaged event-related potentials (ERPs) evoked by brief (mostly ungrammatical) stimuli to reflect neural activity within discrete cortical regions (cf. early-left-anterior-negativity [ELAN]; left-anterior-negativity [LAN]; P600/syntax-positivity-shift [SPS]). In this research, response averaging removes background EEG activity, which is assumed to be noise and whose temporal and spectral components are assumed to be independent of the brief experimental events. In the EEG experiment discussed in this study we follow a complementary research tradition for the study of brain dynamics (cf. Basar, Basar-Eroglu, Karakas, & Schürmann, 1999; Bressler & Kelso, 2001; Haken, 1996). In this view, ERP features arise at least partly from stimulus-induced frequency modulations (for example, synchronization, desynchronization, and phase resetting) of ongoing brain activity which is not sensitive to brief experimental events and which can be traced both in perception and in production.

The high-quality spectral and temporal data generated by EEG-based techniques suffer from its limited usefulness as far as the localization of functionally defined cortical processing regions is concerned. Here, the hemodynamic-based brain imaging methods such as PET and fMRI provide substantial evidence. In his review of the results of 28 PET/fMRI experiments on syntactic comprehension, Indefrey (2003) identifies 110 cerebral activation sites for syntactic processing. While most of the areas were activated in only a few studies, all studies reported a strong activation of the Broca Area (BA 44/45) across all syntactic conditions. Also the few existing studies of controlled syntactic production (cf. Dogil et al., 2002; Indefrey et al., 2001; Indefrey, Hellwig, Herzog, Seitz, & Hagoort, this volume) support the central role of this area in syntactic processing. Given the strong assumptions about the role of Broca's area in aphasiological literature (cf. Grodzinsky, 2000), there are reasons to believe that syntactic processing is subserved by a discrete neural substrate of the human brain. However, other review studies of cognitive processing have identified high levels of activation in Broca's area during image grasping, direction discrimination, multi-modal short-term memory, chewing, etc. (cf. Cabeza & Nyberg, 2000; Müller & Basho, this volume). It is puzzling that the brain area which seems to be the locus of real-time compositional syntactic processes (in the sense of Phillips, 2003) is also involved with so many disparate cognitive processes.

Our experiment described below combines EEG and fMRI data induced by an identical set of stimuli. The results of the experiment, and the model that we develop to interpret them, will help to solve this puzzle. At least it will help us formulate a set of assumptions about language-induced brain dynamics to be tested in future research.

2. Methods

2.1. Participants

Ten subjects (5f, 5m, age med. = 27) were examined in the hemodynamic experiment, and 22 subjects participated in the EEG study (14f, 8m, age med. = 23). All participants were native speakers of German, they were right-handed as determined by standardized inventory, and none of them had a history of neurological disorders. Informed consent had been obtained from each subject. Subjects were paid for the participation in the experiment.

2.2. Methods

In the fMRI experiment the subjects lay supine in the MR scanner (1.5 T whole body scanner, Siemens Vision), their heads being secured by means of a foam rubber in order to minimize movement artifacts. fMRI data were obtained across the whole brain volume (28 slices, 4 mm thickness, 1 mm gap) of each subject using Echo Planar Imaging (1.5 T, TR 3 s, matrix 64 × 64). Spatial transformation of images and statistical analysis were performed using SPM99. The results are based on a random effects analysis of the group data.

The EEG data were recorded referentially against a common linked earlobe reference with a 64-channel NeuroScan-system (frequency response: 0.16–50 Hz), by using a 64-channel Ag/AgCl-electrode cap (58 scalp electrodes, two earlobe electrodes, and four Electrooculogram electrodes). Sampling rate was 250 Hz.

The measurement of band power changes is based on a method originally proposed by Pfurtscheller and Aranibar (1977) and is described in detail in Klimesch, Russegger, Doppelmayr, and Pachinger (1998) and Röhm, Klimesch, Haider, and Doppelmayr (2001). The different steps for calculating event-related changes in band power (ERBP) are the following. First, over the entire length of the experimental session, the EEG data are bandpass filtered and then the filtered data are squared. Segmentation into single trials is done after bandpass filtering. Second, the obtained data are averaged over the number of artifact-free epochs. Third, within consecutive time windows of 100 ms the squared data are averaged. Fourth, *z*-values were computed for each subject, recording site and experimental condition to obtain data that are Gaussian distributed.

Frequency bands were determined individually for each subject, by using individual α frequency IAF(i) as a cut-off point between the lower and the upper α band.

Statistical analysis is based on the calculation of confidence intervals. For each subject, lead and task condition and averaged over all trials, the mean *z*-value for the reference interval was determined. These values were taken to calculate sample means and standard

deviations for 99.9% confidence intervals. For topographical maps only significant z -values exceeding the lower or upper confidence intervals were used. The level at which a z -value exceeds the confidence interval reflects the extent of a band power change with respect to the reference period.

2.3. Stimuli

The stimuli were presented visually as lines of text on a computer screen. For the fMRI experiment the test items consisted of German sentences ($n = 16$) with three syntactic constituents (the test task) and German word lists ($n = 16$) containing three elements (the control task). The length of the stimuli was balanced. In the test task the subjects were asked to read the sentence silently (reading task), to manipulate the word order of the sentence (reserialization task), and to replace the subject NP with a hyperonym (semantic task). In the control task the subjects were asked to read the word list, to move the second element of the list to the first position, and to replace one of the list elements with a (pre-specified) hyperonym. One of the 16 word lists used in the experiment is given below:

Kaffemaschine Waschmaschine Bügelmaschine
Coffee machine washing machine ironing machine

In contrast to the general cognitive task of list reordering and list element substitution, word order manipulation and hyperonym substitution in sentences are grammatical tasks.

We take advantage of the fact that German grammar allows a fairly free choice as to which syntactic constituent is followed by the finite verb. The critical point is that only a syntactic constituent can be moved to the pre-verbal position. We instructed the subjects to start the test sentences differently, which to them meant that they had to replace the initial constituent. An example of the test task requirement is illustrated by the transformation below:

[_{PP}An den Gitterzaun] [_{VP}hat sich [_{NP}ein Aktivist] gekettet]

Ein Aktivist hat sich an den Gitterzaun gekettet
 (reserialization)

An den Gitterzaun hat sich *ein Mensch* gekettet
 (substitution)

An activist/man chained himself to the fence

In the EEG experiment 54 sentences of this type were presented in four chunks. The first chunk contains the subject (or object), the second the finite verb and a reflexive pronoun, the third the object (or subject) and the fourth the verb. Each chunk was presented at the center of a computer monitor for 800 ms. A single trial lasted for 12 s and consisted of a reference interval of 1 s, a blank interval of 300 ms, a warning signal (300 ms), a

blank interval of 300 ms, the presentation of four chunks ($4 \times 800 = 3200$ ms), a blank interval of 1 s, the presentation of the question mark for 3 s and a blank interval of 2900 ms.

The word order variation induced in the task is grammatically (and stylistically) neutral in standard German. This task is grammatically geared as it requires the identification of an alternative syntactic constituent, which in turn pre-supposes a syntactic analysis of the sentence. The comparison with the list reordering task (in the fMRI experiment) serves to differentiate a general symbol manipulation activity (list reordering) and a syntactically grounded reordering activity. All tasks involve other linguistic (e.g., lexical search) and cognitive subsystems (visual processing, grapheme–phoneme conversion, speech motor control) that will be neutralized by the fMRI subtraction design, with only genuine phrase structure processing activities remaining.

3. Results¹

The hemodynamic response obtained in the fMRI experiment shows activation of the classical prefrontal language areas across all experimental conditions. Broca's area was activated in reading, in the substitution, and in the reserialization task, both for word lists (which contain syntactically complex compounds) and for syntactically structured sentences. The subtraction design used in this study led to some variation in the activation level of parts of Broca's area (cf. Dogil et al., 2002, 82ff). However, the differences in activation patterns in the left prefrontal cortex were much less striking than the similarities. Whenever the general cognitive task was subtracted from the grammatical task Broca's area was prominently present. When two grammatical tasks were subtracted from one another, the activity in Broca's area disappeared. Other areas, in particular the anterior cingulate cortex, were activated as well.

There are hardly any differences in the hemodynamic processes activated by substitution and by reserialization of grammatical constituents (Figs. 1A and B). The activation of Wernicke's area in the substitution task (Fig. 1A) can be explained by the semantic specificity of the hyperonym search and semantic replacement characteristics of this task. However, the almost identical hemodynamic answer of Broca's area to the narrow syntactic constituent reserialization task and the broad semantic hyperonym replacement task is unexpected

¹ The richness of the neuroimaging data generated in the experiment cannot be properly treated in this study, which has its natural space limitation. We refer the reader to Dogil et al. (2002, 80–85) the dissertation project of Frese and to Röhm (2003), where details are discussed. Here, we discuss only those aspects of data which are most immediately relevant to the model that we propose.

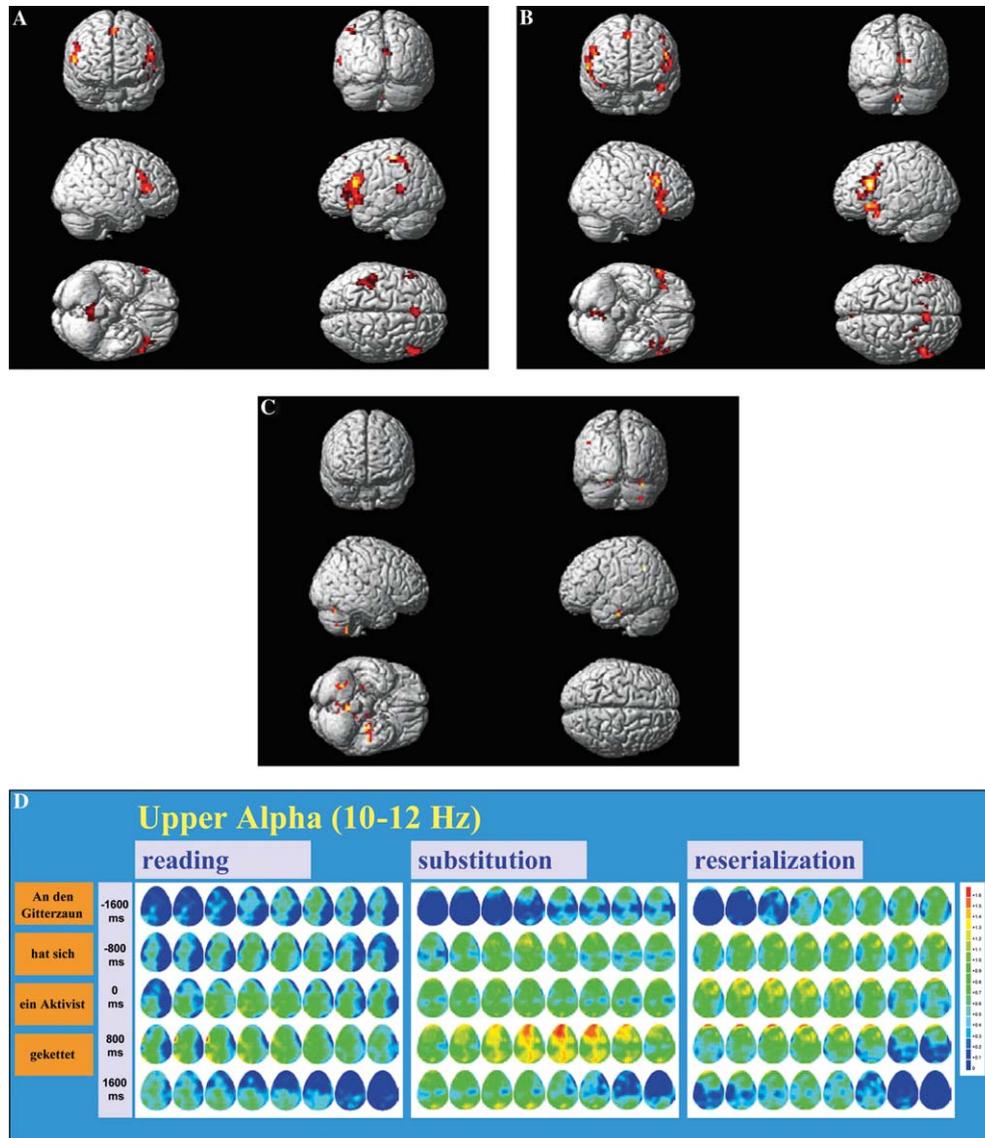


Fig. 1. Statistical Parametric Maps of the group ($n = 10$) random effects analysis of the paired image cognitive subtractions: *semantic processing—reading of the word list* (A) and *syntactic processing—reading of the word list* (B), *semantic processing—syntactic processing* (C), and topographical maps (D) showing z-transformed event-related band power (ERBP) changes with respect to a reference interval of 1 s (preceding the presentation of the warning signal by 300 ms). Hot colors reflect a decrease in ERBP. Sentences were presented in four consecutive chunks. Each row with eight maps (covering a time window of 100 ms each) represents one chunk. The z-levels in (D) correspond to the color scale and indicate the extent of a band power change exceeding the confidence interval. The German text in (D) is identical with the example discussed in the text:

[_{pp}An den Gitterzaun] [_vhat sich [_Nein Aktivist] gekettet]
Ein Aktivist hat sich an den Gitterzaun gekettet (reserialization)
An den Gitterzaun hat sich ein Mensch gekettet (substitution)
An activist/man chained himself to the fence

(Figs. 1A and B). It is just as unexpected that the activation in Broca's area disappears when syntactic processing is subtracted from semantic processing and vice versa (Fig. 1C). In 4 of this paper, we provide an explanation of this result which is rooted in our assumptions about general principles of language processing and brain dynamics. We also suggest that the activations of the right prefrontal areas, of cerebellum and the anterior cingulate cortex displayed in Fig. 1 might be explained by general principles of cortical synchronization.

The analysis of the neurophysiological correlates of the same tasks presents a more differentiated picture. We investigated the task-induced changes in the EEG signal. In particular, we looked at changes of band power (ERBPs) in the critical frequency bands. The measure of the band power in the neurophysiological signal is traditionally determined by the power effect of the EEG signals in the δ (0.5–3.5 Hz), θ (3.5–7.5 Hz), α (8–13 Hz), β (13–30 Hz), and γ (30–70 Hz) frequency bands (cf. Basar, 1998; Bressler & Kelso, 2001; Röhme, 2003;

Schack, Rappelsberger, Weiss, & Möller, 1999). Whereas no significant correlates of our tasks were induced in the lower frequencies, the band power starting at the upper α (10–12 Hz) shows interesting, and significant, desynchronization patterns. Fig. 1D illustrates the changes in this band power across the sentence reading (left panel), the constituent substitution (central panel), and the constituent reserialization (right panel) tasks.

The semantic processing of a presented stimulus (here hyperonym search and substitution) is significantly correlated with desynchronization in the upper α band (Fig. 1D, mid panel). The electrophysiological modulation of this frequency band does not appear to be correlated with syntactic processing (here constituent reserialization, Fig. 1D, left panel) or the general cognitive process of reading a sentence (Fig. 1D, right panel).

4. Discussion

The results of the hemodynamic experiment show that linguistic processing, be it syntactic or semantic, is concentrated in the classical prefrontal left areas of the brain, which are distributed around the left peri-sylvian cortex. These areas disappear when the subtraction is applied to two linguistic tasks involved in compositional linguistic computation. The results of the electrophysiological experiment suggest that there are indeed differences in cognitive processing of syntactic and semantic computations and that these differences are correlated with band power changes within specific frequency bands. These data serve as an illustration for the notion that EEG band-power analyses may help to distinguish among (almost) identical fMRI patterns. For example, the semantic processing of a sentence, which is undistinguishable from the syntactic processing of the same sentence in the fMRI analysis appears to be correlated with desynchronization in the upper α band in the EEG band-power analysis (Fig. 1). Despite this result it seems rather unlikely that the band-power effect is due to specific linguistic processing activities. Results from non-linguistic experiments indicate that the upper α might reflect semantic processes of a more general type (cf. Röhm et al., 2001). Bastiaansen, Van Berkum, and Hagoort (2002), who investigated agreement-related changes in induced band power in frequency bands, argue for the selectivity of the α and the θ rhythms during the processing of number and gender in words and sentences. They assume, however, that some of the observed changes (e.g., a slow increase in θ power as the sentence unfolds) are possibly related to episodic memory and verbal memory load. In order to be able to further disentangle the possible functional role of stimulus-induced brain oscillations, it is necessary to contrast linguistic processing with appropriate control tasks

which facilitate the separation of single processing stages.

The research program of assigning separate stages of language processing to specific brain oscillations appears to be promising. Given the complexity of brain oscillations themselves, and the intricacies of mathematical models for studying them, this program also appears to be quite ambitious. Is such a research program feasible? How shall we ever predict which frequencies can be correlated with which linguistic functions at which processing stages? Why should, for example, upper α and not θ reflect semantic processing? Why should the phrase structure assignment at phrasal level be correlated with high frequencies (β and γ), and the wh-movement trace assignment with the low frequencies (θ and δ)? Can we ever construct a predictive model for language specific band power changes? We suggest using the results of the previous EEG research to constrain the parameters of such a model. In particular, we want to propose a procedure which will let us read out information from unfiltered “noisy” EEG data obtained under variable experimental conditions.

Most EEG studies of language have assumed that the separation of single processing stages can be explained by the temporal properties of the signal which are coded as averaged ERPs. The important temporal signatures of language processing that can be derived from the post-stimulus ERPs have been discussed in detail by Friederici and Alter in this volume (cf. also Friederici, 2003).

It has been argued, however, that poststimulus ERPs arise from alternations in the dynamics of ongoing neural synchrony generating the EEG signal (Bressler & Kelso, 2001; Haken, 1996). This relation between ongoing brain dynamics and temporal signatures registered by averaged ERPs has been proposed for auditory responses by Sayers, Beagley, and Hanshall (1974) (cf. also Poeppel, 2003). Most recently this relation has been established for visual ERPs, like N1, as well (cf. Makeig et al., 2002). The causality of the relation implicated by Makeig et al. is unimportant, because both signals are very abstract as far as the neurophysiological reality is concerned. It is more important to find a model which makes use of the observed parallelism between the changes of band power within a frequency band and the peak latency. A simple account for the correlation between unaveraged EEG signals and averaged ERP responses could be a matched filter model. Please note that this is a model of the observed EEG signals and has nothing to do with the neurophysiological sources of these signals or the localization of these sources.²

² The left anterior EEG patterns (be it ERP components or changes in band power) do not necessarily point to neural generators in that part of the brain (cf. EEG’s “inverse problem”). However, some of the language specific EEG activity has been clearly linked to Broca’s area (Friederici, 2003).

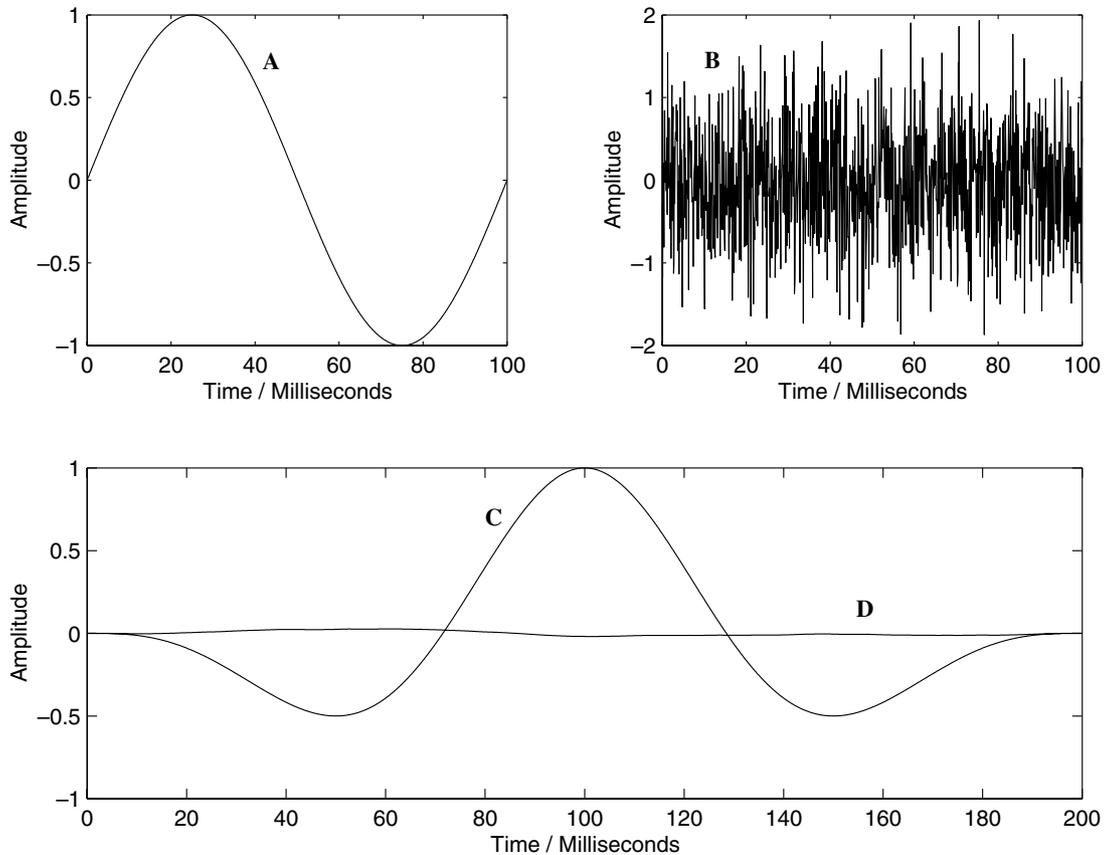


Fig. 2. Input signals to the matched filter: (A) information-carrying sinusoidal signal of 100 ms duration and (B) 'white' noise with the same RMS amplitude $1/\sqrt{2}$. Response of the matched filter to (C) the sinusoidal signal and (D) the noise. Note that the peak in (C) occurs exactly at the end of the signal (A) and the response to the noise is weaker by about 30 dB.

The matched filter model employs a signal detection scheme successful in communication engineering. If an information carrying signal $m(t)$ is to be detected, the noisy mixture containing m is processed by a filter matched to m . This matched filter is completely specified by its impulse response $h(t) = m^*(T - t)$,³ which is the complex conjugated and time-reversed m . This matched filter produces a peak at time T , the duration of m . The peak is maximal for m compared to all other signals with the same energy but different shapes.

For the shape of m we propose a single period of a sinusoidal wave $m(t) = \sin(2\pi Ft)$, $0 \leq t \leq T = 1/F$. The signal duration is T and its spectrum is concentrated around $F = 1/T$. The corresponding matched filter has the impulse response $h(t) = -\sin(2\pi Ft)$, $0 \leq t \leq T = 1/F$. If the original wave m starts at the stimulus time $t = 0$, the matched filter for m produces a maximal peak at T , the end of m . Conversely, this behavior can be used to estimate the model wave duration as T , if a peak is observed at T . Furthermore, m can easily be located in the frequency domain at frequency $F = 1/T$ because the

sinusoidal shape of m is already the base for the Fourier spectrum.

If the instant of the peak T is known but the model wave m is only known not to begin before the stimulus, i.e., non-causal behavior is not allowed, the duration of the model wave m is restricted to be T or shorter. Shorter model waves simply start delayed with respect to the stimulus, possibly due to phase reset. In the frequency domain this simple model restricts stimulus-related ERP peaks to frequency bands higher than $1/T$, with T being the ERP peak latency.

Fig. 2 shows example input and output waveforms of a matched filter. The waveform $m(t)$ that the filter is matched to is the sinusoidal wave (Fig. 2A), the target signal. The impulse response of the filter is not shown but it is simply the time-reversed, i.e., a sinusoidal wave starting with the negative halfwave. The response of this matched filter to its target signal is shown in Fig. 2C. It is a wave with ascending and descending amplitude reaching its peak value in the middle exactly at the end of the input wave. The matched filter responds much less to inputs deviating from the target signal. An extreme example is the white noise signal shown in Fig. 2B. The matched filter's response is the weak lowpass noise

³ * denotes complex conjugation, which is necessary only for complex valued signals $m \in \mathcal{R}$.

shown in Fig. 2D. Even though both inputs have the same RMS (root mean of squared values) amplitude of $1/\sqrt{2}$, the response to the noise amplitude is weaker by a factor of 30 (about 30 dB, by incident). Is it likely that some areas of the brain evolved to play a role of a matched filter in the system of brain oscillations? Could the strong fMRI response of left peri-sylvian cortex to linguistic processing be correlated with its strong response to certain types of signals (like the response 1C of the matched filter illustrated in Fig. 2) but not to other types of signals (cf. response 1D in Fig. 2 to the signal of the same strength).

The core idea embodied in this matched filter model is the type of integration that occurs in the convolution operation of a filter. At each instant the filter output is the result of the integration of the product between the input signal and the time reversed impulse response of the filter. This operation yields maximal results if both shapes match exactly. Whereas the integration operation is the limit of a sum, we do not claim that our model's summands are equal or even similar to the summands that yield the EEG potential. The matched filter model for ERP peaks is expected to be as meaningful as viewing the EEG potential in the spectral domain, i.e., in terms of frequency bands. From the point of view of a cognitive model, we can assume that some areas of the brain, in particular those that evolved to perform complex cognitive activities like language, developed a specific type of neural function, not dissimilar to the one of a matched filter.

This model has a potentially strong predictive power for experimental neuroscience of language. Taking the ERP results as a basis, we can approximate the range of frequency bands that may be correlated with ERP peaks. The matched filter, which is calculated on the basis of the ERP peak, represents both temporal and band power properties of the signal. A by-product of this calculation is the prediction that the so-called "early" phases of processing are coded at relatively high-frequency bands (they show short ERPs), whereas the "late" processes will be expected to be found at low frequencies (their ERPs have long latencies). If the assumptions of our model are correct, the stipulated distinction between early and late processing can be called into question, too. We could assume, as it has been suggested for strictly grammatical reasons by Phillips (2003), that syntactic processing is a real-time ongoing incremental adventure. All processes responsible for syntactic computation start at the same time and are followed online. Because the critical aspects of these computations are represented by different matched filters, their temporal signatures are *expected* to appear early for high-frequency bands and later for low frequencies.

The final issue that we want to discuss in this paper is the language specific hemodynamic response to the

brain dynamics we have modelled so far. The hemodynamic data show that practically all human tasks dealing with real-time compositional processes for grammar activate the brain system localized in the classical prefrontal language areas. The differences in this activation site, at least in our own experiments and in the ones that have been reviewed in the literature (Caplan, Alpert, Waters, & Olivieri, 2000; Dapretto & Bookheimer, 1999; Embick, Marantz, Miyashita, O'Neil, & Sakai, 2000; Indefrey et al., 2001; Stromswold, Caplan, Alpert, & Rauch, 1996, all found activation around the left inferior frontal gyrus during syntactic processing), are much less striking than are the similarities. We presume that left peri-sylvian cortex has evolved to play a very specific role in language-induced brain dynamics. Again, we use a simple technical metaphor of a *frequency scanner* to model language specific computation. A frequency scanner is a device designed to pick up activity over a certain range of frequencies. Electronically it may be implemented as a matched filter array. The human brain could have evolved biologically in such a way that it reserves some of its dedicated areas to actively scan the ongoing activity of neuronal populations located all over the brain. Areas that react specifically to language appear to be located in the left peri-sylvian cortex. One of these 'scanning areas' could be Broca's area. In our most recent experiment Frese (to appear) found Brodmann Area 45 (Talairach coordinates $-51\ 23\ 8$) to be selectively involved in phrase structure generation.

There are cases in the fMRI literature which show that Broca's area is involved in non-syntax specific processing as well. Müller, Kleinhans, and Courchesne (2003) show an involvement of Broca's area in semantic processing. This is in accordance with the results of the fMRI experiment presented in this paper and supports the idea of a language processor which functions as frequency scanner. Meyer, Friederici, and Cramon (2000) found left temporal areas involved in the judgement of sentences' grammaticality (whereas right frontal and temporal regions were activated by a repair task). Meyer et al. suggest that the frontal activation found in other fMRI experiments on syntactic processing could be due to the visually presented stimuli. In their experiment, which is designed as an auditory comprehension experiment, the temporal activation sites found in the study could be correlated with the high demand on auditory processing, or might be due to the use of the violation paradigm (cf. also the MEG study by Friederici, Wang, Herrmann, Maess, & Oertel, 2000).

There are other cases in the fMRI literature which show that Broca's area is *not* activated during syntactic processing. Fiebach, Schlesewsky, and Friederici (2001) show that the processing of wh-based filler-gap dependencies in German is correlated with the distance

between the filler and the gap. Long distance dependencies activate Broca's area and show specific ERP patterns. Short distance dependencies have a specific ERP answer and they *do not* activate the Broca's area. Fiebach et al. suggest that Broca's area is involved only when syntactic working memory is required. Similarly, Kaan and Swaab (2003) in their recent review article, argue that the frontally distributed activity is related to syntactic ambiguity resolution and long distance dependency resolution, which involves high discourse level complexity. The models which argue that only incremental online processes are constitutive of syntax (cf. Phillips, 2003) would probably have to argue that short lag dependencies are resolved at a processing power that is below the level of the temporal resolution of an fMRI scanner. However, an asymmetry in the treatment of long distance and short distance filler-gap dependencies has been also observed in a patient suffering from transcortical aphasia whose Broca's area has been isolated due to the hemorrhage (cf. Dogil et al., 1995). The situation is unclear. On the one hand there is evidence for considering Broca's area as a central processor for syntax, on the other hand there is evidence that it is rather a co-processor, which is sensitive only to syntactic processing which is bound to specific modality and/or to specific memory demands.

Other candidates for small, designated 'scanning areas' are fusiform gyrus (visual processing, cf. Makeig et al., 2002), posterior superior temporal gyri (auditory and speech processing, cf. Hickok & Poeppel, 2000; Poeppel, 2003), and anterior insula (speech articulation, cf. Ackermann & Riecker, this volume; Dogil, Ackermann, Mayer, Riecker, & Wildgruber, 2003; Wise, Greene, Büchel, & Scott, 1999). In our view, the primary variable that is "scanned" in all those areas is the power of pre-defined frequencies. Whenever neuronal (de)synchronization leads to a change in the signal that is picked-up by a matched filter, the area will be activated. The possibilities of neural synchronization and desynchronization are infinite (Haken, 1996) and their combinations will produce frequencies that a matched filter will have to consider as likely information carriers. Language specificity is defined by the whole array of matched filters that the designated areas actively support. How this array is biologically implemented and how it is computationally used is one of the critical issues in the language-induced brain dynamics. The present paper is nothing more than a way of asking a structured set of questions about these issues. At the present stage of our knowledge we consider the simple models that allow us to ask these questions to be external to the brain. We have presented a resonance model which restricts the interpretation of cognitive data. Further research will show if this simple resonance model has a potential to evolve into a cognitive resonance model.

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