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Impaired speech perception in aphasic patients: event-related potential and neuropsychological assessment

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Abstract

The mismatch negativity component (MMN) of auditory event-related potentials (ERP) was recorded in four aphasic patients and in age, gender and education matched controls. The MMN changes elicited by tone, vowel, voicing stop consonant and place-of articulation contrasts were recorded over both hemispheres. The results of MMN amplitude, latency and distribution differences between aphasics and controls were analyzed in detail. An extensive neuropsychological investigation was performed in order to highlight the assumed dissociation and possible interactions between the impaired acoustic/phonetic perception and deficient comprehension in aphasic patients. Our principal finding was that MMN elicited by pitch deviations is not enough sensitive to distinguish between patients and age-matched controls. The MMN elicited by consonant contrasts was found to be the most vulnerable in aphasic patients investigated. The MMN elicited by voicing ([ba:] vs. [pa:]) and place-of-articulation ([ba:] vs. [ga:]) could be characterized by total lack, distorted or very limited distribution and correlated with the patients' performance shown in the behavioral phoneme discrimination task. The magnitude of the deficient phoneme (vowel and consonant contrasts) processing shown by MMN anomalies was proportionally related to the non-word discrimination and did not interact with the word discrimination performance. The impact of deficient speech sound processing on higher level processes may depend on the type of aphasia, while the presence of perceptual deficits in processing acoustic/phonetic contrasts seems to be independent of the type of aphasia. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Extended research on studying a neuronal response to stimulus change, called mismatch negativity (MMN), shows how the MMN may reveal processes underlying the perception of acoustic contrasts. The fact, that MMN can be elicited by numerous contrasting features of auditory stimuli, further indicates that this event-related potential (ERP) component may be useful to investigate acoustic features having a fundamental role in perceiving speech [1,21,22,30,32]. Furthermore, results of positron emission tomography (PET) studies indicate that there is a distinctive processing of pure tones (pitch) and phonetic features of speech stimuli [16,17,35].

In accordance with the PET results, the first MMN study on aphasic patients [2] showed a significant difference between pitch and vowel processing. Two patients with left posterior lesions failed to show any MMN to contrasting vowels, whereas in the two other patients with predominant anterior lesions on the left side a rather normal MMN to deviating vowels could be recorded. This finding was in accordance with the hypothesis of the authors that is the discrimination of synthetic vowels is impaired by left posterior damage. The fact that all four patients showed a pitch-MMN indicates that the pitch and spectral contrast processing is different and, furthermore, different cortical areas might take part in their generation.

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Sharma and her colleagues [33] also reported a similar difference between pitch and phoneme processing. Their case study on a 42-year-old patient, classified as residual mild fluent aphasic, revealed intact processing of pitch contrast (fundamental frequency) and impaired processing of phonemic changes (spectral contrast in formant transition). The presence and absence of the MMN to contrasting feature correlated with the behavioral discrimination results; the pitch discrimination was normal (88%). However, the discrimination of the phonetic contrast used in the experimental paradigm did not exceed the chance level (50%). Contrary to these results Aaltonen and his colleagues [2] found the vowel discrimination above chance level only in one patient (left frontal cortical lesion). The striking difference between the MMN results and language comprehension scores let the authors conclude that the auditory discrimination is not directly related to language comprehension.

According to the classical view on aphasia the language comprehension deficit of Wernicke's aphasia is due to impairments in the 'sound images' of words [18]. Furthermore, the original idea of Luria [23] was that impairment in 'phonemic hearing' resulting in perceptual defects might be responsible for severe comprehension disorders found in aphasic patients. While speech perception studies with aphasics supported the view that misperception was due to perceptual deficits, the hypothesis of a strong correlation between perceptual deficits and language comprehension impairments of Wernicke's aphasics could not be proven by the latter investigations.

Results of phonological discrimination studies aiming to explore the role of speech perception deficits in auditory comprehension impairments led to a different view on the role of speech perception. Several studies have proven that nearly all aphasic patients show some problem in the phoneme contrast discrimination [10,19,25,26] or in consonant labeling or identification [6]. Interestingly, the perception of place of articulation as contrasting feature was found especially vulnerable [5,25]. However, speech perception and auditory language comprehension do not seem closely related. Patients with intact auditory comprehension may show impaired speech sound processing and vice versa [12]. Furthermore, Blumstein [8,9] has demonstrated that impairments of auditory comprehension in aphasic patients are mainly related to impaired analysis of speech input at both phonetic and lexical or semantic levels.

The aim of our present study was to reconcile some contradictions due to differences in the assumed role of auditory perception of various phonological feature contrasts in language comprehension. Results of speech perception and speech comprehension studies have shown an interesting dichotomy in the performance of aphasic patients. The dichotomies seen both in Wernicke's and in Broca's aphasics suggest that the language impairment of these patients do not correlate with the perceptual deficits per se. However, it does not mean there are no particular stages of language processing that may correspond to an impaired speech perception as responsible factor for higher level language processing deficits. There are experimental evidences suggesting that the patients' impairment reflect a deficient interaction of the sound structure and the phonological input lexicon. Furthermore, speech perception impairments are not restricted to patients with left posterior brain damage [11,24,27].

Although several MMN studies investigating normal perception of changing phonetic contrasts [3,31,34] has recently been published, the number of studies on aphasic patients are very limited. In order to highlight the role of perception supposedly playing a different role in various stages of speech comprehension, a detailed analysis of MMN changes and that of the results obtained by neuropsychological assessment has been applied in our study. We attempted to investigate some of the most important features of an impaired speech perception and its possible interactions with the main types of deficient comprehension in aphasic patients as compared with normal processing in age matched controls. The main questions of our study to be answered were: (a) Does the MMN to different auditory stimulus attributes such as speech and non-speech, selectively show the impaired contrast sensitivity? (b) Is the impairment of contrast sensitivity related to a general deficit in phoneme processing or related only to particular phonetic features such as voicing or place of articulation? (c) Are there any dissociation between automatic (pre-attentive) and controlled (behavioral discrimination) processing of contrasting features of vowel and consonants? (d) Is there any dichotomy in auditory perception and higher-level language processes in aphasic patients? (e) Are speech perception impairments restricted to patients with left posterior brain damage, i.e. Wernicke's aphasics or a deficient phoneme processing occurs in Broca's aphasics as well but its contribution to a higher level language processing is different?

2. Methods

2.1. Subjects

Four aphasic patients with neuroradiologically verified (CT) lesions and four control subjects were selected for this study (patients' data are presented in Table 1). The patients were prospectively selected on the basis of a neurological examination and an extensive neuropsychological assessment. The controls were neurologically unimpaired subjects who were matched to the patients on age (± 1-year difference), gender, handedness and years of education. All persons investigated gave their intent consent. All subjects were dominantly right handed as judged by the modified Annette handedness inventory. The control subjects had normal hearing; their audiological investigation revealed no larger threshold changes than 10 dB. In three of four patients an increased hearing threshold (change larger than 15 dB) was found on the right ear. It might be due to a neglect or to a real threshold change contralateral to the cerebrovascular incident also influencing the functional ear preference [28]. Therefore, we chose left side stimulation both in patients and in controls.

2.2. Patient selection

The four patients investigated in this study were chosen from a larger sample of 12 aphasic patients, based on the neuropsychological profile representing the two main diagnostical categories of aphasia, that is Broca's and Wernicke's aphasia. Although the four patients exhibited very different lesions of the dominant hemisphere, moreover, the size and site of the lesions were different, varying from limited temporoparietal infarct to large fronto-temporo-parietal lesion and multiple infarcts, they represented the same diagnostic category in pairs. However, both the Wernickes's and Broca's patients of unilateral or bilateral lesion in the larger sample had different performance in the neuropsychological assessment, so that we chose to oppose unilateral and bilateral lesions in order to follow if a contralateral lesion contribute to further dissociations assumed to be exhibited. The data below describe four case studies, that is the results of an extensive neuropsychological and psychophysiological investigation of four patients as compared with their age, gender and education-matched controls.

Table 1
Main results of the neuropsychological assessment (see text for explanation)

	H.E.	M.G.	D.K.	S.P.
Raven IQ	112	91	99	97
WAB				
Information	7	8	9	9
Fluency	4	4	7	9
Comprehension	5.8	6.7	6.6	8.9
Repetition	5.9	7.9	6.6	5.3
Naming	5.1	7.1	8.7	8.1
AQ	55.6	67.4	75.8	80.6
Token test	10	no	24	13.5
Results in %				
Sentence compr.	58.3	41.6	87.5	70.8
Picture naming	51.6	35	73.3	50
Lexical decision				
Word	100	86.6	100	90
Nonword	85	75	71.6	83.3
Word comprehension				
Spoken nouns	94	92	92	82
Spoken verbs	95	95	97.5	90
Written nouns	90	88	95	95
Written verbs	89.4	92.5	100	100

2.3. Patient description

2.3.1. Case 1: H.E.

H.E. was a 42-year-old secretary. She was admitted to the hospital 1.5 year before the neuropsychological and psychophysiological investigations. She suffered a sudden onset of severe headache and by the neurological investigations an aneurysm of the left middle cerebral artery was revealed. The aneurysm was clipped. The onset of aphasia was due to a post-operative infarct, which also led to a right-sided hemiparesis.

On her CT scan a large hypodense region can be seen (Fig. 1A) corresponding to the infarct in the territory of the left middle cerebral artery involving the cortex and white matter in the temporoparietal area, which extends towards the frontal lobe as well. The outlines of this hypodense region are sharply defined. The left lateral ventricle is enlarged.

The patient's spontaneous speech is nonfluent consisting of isolated words and short phrases without grammatical morphemes. Due to word-finding difficulties her speech is hesitant but without initiation problems. Semantic and phonological paraphasias are rare, the articulation is clear, no signs of verbal apraxia can be observed. According to her speech characteristics and the Western Aphasia Battery, H.E is diagnosed as Broca's aphasic.

2.3.2. Case 2: M.G.

M.G. was a 48-year-old operator with an onset of aphasia 1.5 year before the investigations. His aphasia and right-sided hemiparesis appeared after a second cerebrovascular incident. His first admission to the hospital was 6 years prior to the second cerebrovascular incident. He suffered an aneurysmal subarachnoid hemorrhage in the territory of the right carotis interna. The aneurysm was clipped in open craniotomy. On discharge from the hospital he was fully recovered and started to work again. On discharge from the hospital after the second incident some weeks later, the hemiparesis had mildered, but he was still aphasic.

On his CT scan the enlarged third and left lateral ventriculi can be observed (Fig. 1B). Hypodense areas are seen in the regions corresponding to the left caudate nucleus and left lentiform nucleus. Moderately hypodense regions are seen in the left frontal and parietal cortical and subcortical areas. The picture is probably caused by multiple infarcts corresponding mainly, but

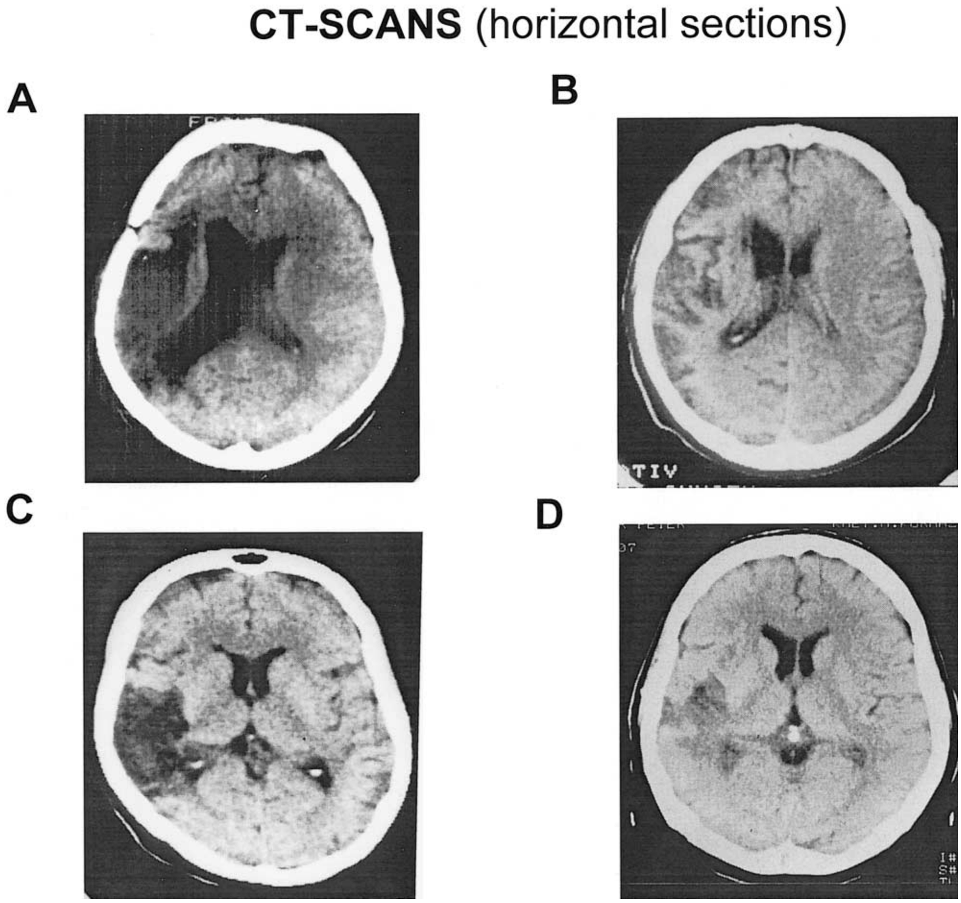


Fig. 1. CT scans of the four patients investigated (for details see text).

not exclusively to the area of the left middle cerebral artery.

His spontaneous speech is nonfluent; it is mainly consisted of one-word utterances. Impaired comprehension can be shown only under special conditions, mainly in tasks on comprehension of sentences of complex structures. He is diagnosed as Broca's aphasic. In case of further progress he can be classified as transcortical motor aphasic.

2.3.3. Case 3: D.K.

Patient D.K. was a 42-year-old secretary. About 1.5 years before our investigations she was admitted to the hospital when she suffered a sudden onset of headache and neck pain. Neurological examination revealed a cerebral arterial thrombosis accompanied by temporary motor symptoms. On her CT-scan (Fig. 1C) a large, homogeneously hypodense area could be seen in the left temporal lobe involving the cortex and the white matter extending towards the lentiform nucleus. The ventricles are slightly, symmetrically enlarged. On the right side of hemispheres a smaller hypodense area in the temporal region can be seen.

Her spontaneous speech was fluent and syntactically well formed. However, her speech was overwhelmed by phonological errors and conduite d'appproche symptoms. Her speech comprehension shown during her daily activities was well retained. On the contrary, her performance in understanding complex instructions was rather deficient, and she was well aware of this deficit. She was diagnosed as Wernicke's aphasic, though her speech disorder was developing into conduction type aphasia.

2.3.4. Case 4: S.P.

S.P. was a 49-year-old clerk who had a long history of hypertonia. He had experienced sudden right-sided hemiparesis and sensorimotor aphasia and was admitted to the local health center ward 9 months before our investigation. On discharge from the ward 3 weeks later, the hemiparesis had completely disappeared but the neurological examination showed aphasia. On his CT scan (Fig. 1D) a hypodense region could be seen in the area of the left middle cerebral artery involving a large part of the temporoparietal cortical area. The lesion involves both the cortex and underlying white matter but spares the basal ganglia. The left lateral ventricle is enlarged. His speech comprehension was normal during conversation although with numerous misunderstandings. His spontaneous speech was fluent and consisted a lot of phonological errors, conduite d'approche symptoms, literal and verbal paraphrases and neologisms of which the patient was well aware. In task situations, however, deficit in speech comprehension was expressed. His bad performance in the naming tests was based both on semantic and on phonological errors. With the Western Aphasia Battery he was diagnosed as conduction aphasic. According to the results of neuropsychological investigation the patient was originally Wernicke's aphasic.

2.4. Neuropsychological assessment (relevant to this study)

For diagnosing the types of aphasia the Hungarian version of Western Aphasia Battery (WAB) [20,29] was used.

The speech sound perception was measured with traditional discrimination and identification tasks. The speech sound discrimination test consisted of four stimulus series designed as same-different judgement task. In the first two series consonant-vowel (CV) syllables were used. The first block included CV-pairs contrasting in place of articulation, while in the second block voicing was used as distinctive consonant feature. In the third stimulus block vowel pairs differing in place, rounding and height were applied, while the fourth one was composed from pairs of meaningful words differing only in one consonant (minimal pairs). During the stimulus discrimination tasks the patients were performing a same/different judgement, deciding whether the stimulus pairs (CVs, vowels and words) heard were same or different. For further comparison the patients' identification performance was also measured. In the identification task the CV syllables were given via loudspeaker one by one, and the patients' task was to choose one among three written syllables matching with the one heard. Each one of the fouls differed from the target in one of the discriminative phonemic features investigated.

The lexical decision task consisted of 30 real words and 60 legal non-words. The non-words were constructed from real words retaining the original segmental structure of the given word (legal pseudo-words). The patients were asked to decide right after every spoken item whether the stimulus delivered was a real word with meaning or not.

The patients' word level comprehension was measured by using a picture-word-matching task. The test consisted of four series where pictures had to be matched with spoken and written forms of nouns and verbs.

The sentence comprehension as well as the verbal short term memory was screened by applying a shortened version of the Token Task (De Renzi, 1962). In a picture/sentence matching task the processing of some types of sentences with relative clauses was checked.

For assessing the patients' semantic discrimination performance, pairs of nouns, verbs and adjectives were used. The items used in a word pair differed in four different semantic distance categories. The test items have equally represented pairs of synonym words, pairs with slight differences in meaning, pairs from the same semantic category, and pairs of words with completely different meaning. The patients' task was to decide whether the words put together in pairs have the same or a different meaning.

2.5. Event-related potential study

2.5.1. Stimuli

Stimulus sets were designed to determine which characteristics of the acoustic perception was influenced, and whether the type of lesion led to a specific impairment in phonetic perception. Three different types of stimuli were presented in a passive oddball paradigm delivered in separate blocks: pure tones, front vowels and consonant-vowel (CV) syllables. Within each type there were three different stimuli: one frequent stimulus serving as standard and two rare stimuli representing a small or large deviation. The pure tone standard was 1000 Hz and the deviants were 1050 and 1200 Hz. The standard of the vowel block was the [e:], and the [i:] and [ø:] served as deviants. Each deviant contrasted with the standard in one phonetic dimension (rounding and height). The CV blocks were composed of a [ba:] sound given frequently and used as standard (Std) and two other CVs given with lower probability were used as deviants. One of the deviants differed from the standard in voicing ([pa:]) and the other one in place of articulation ([ga:]).

The pure tones were computer-generated stimuli. The spoken syllables used in the speech sound paradigm were digitized speech stimuli matched for amplitude and duration. The speech stimuli were based upon parameters obtained from exemplars produced by a young female native speaker of literary Hungarian. The tape-recorded productions where filtered at 8 kHz and digitally sampled at 16 000 samples per s. The stimulus duration where adjusted to a uniform 240 ms by removing portions of the center of the steady-state vowel, and resplicing at the zero-crossing line. The [ba:] – [pa:] voice onset time (VOT) difference was 80 ms.

In all stimulus blocks, the standard appeared with 70% probability and the probability for deviants' occurrence was 15–15%. The stimuli were given in a random order with the exclusion that two deviants follow each other without having a standard in between. The stimulus intensity was set to 70 dB nHL, the interstimulus interval (ISI) was onset-to-onset 1 s. In one experimental block 400 stimuli were delivered, and a block was repeated three times in random order for each stimulus type. The stimuli were given monaurally (left side) through a TDH-49 headphone.

2.6. Distraction

During the auditory stimulus presentation the subjects' attention was distracted by a visuo-motor task in an easy computer game. They were instructed to keep a slowly moving bright point in the middle of a double circle by moving a trackball with the intact hand (in control subjects with the dominant hand). The visual stimuli were displayed on a high-resolution monitor, placed about 1 m in front of the subjects in the middle of their field of view.

2.7. Data acquisition and analysis

The recording were made between 6 months and 1 year after the onset of aphasia in all patients. The ERPs were recorded over 21 (F1, F2, Fz, Cz, Pz, F3, F4, F7, F8, C3, C4, T3, T4, T5, T6, P3, P4, O1, O2, M1, M2) electrodes linked to the nose as reference. Using a 32 channel SynAmp amplifier and the SCAN program of the Neuroscan software package (Neurosoft Inc.) the brain electric activity was acquired in continuous mode. The sampling rate was set to 250 Hz, with a bandpass of 0.1–200 Hz. The acquired samples were sliced into epochs, lowpass filtered at 30 Hz, sorted and selectively averaged. The epochs contaminated with muscle, movement or eye-movement artifacts were discarded from further analysis. The presence of the N1 response on the standards and deviants was visually inspected. The different parameters of the MMN component of the deviant-standard difference curves were measured for every stimulus and deviant type. The difference curves were computed by subtracting the ERPs to standards from those to the deviants. For further qualitative analysis of the MMN peak amplitude, latency, and onset as well as offset (baseline-crossings) latencies were measured on the averaged individual responses. The MMN parameters of the four patient and four controls were compared by using a cluster analysis program of the BMDP software package. Color-coded amplitude distribution maps (Neuroscan) were also computed and compared.

3. Results

3.1. Results of the MMN measures

In all control subjects a reliable MMN could be elicited by all the contrasting parameters used. The mean latencies of the MMN (over Fz) to small (5%) and large (20%) pitch deviations were 199 ($\pm$ 54.2) and 152 ($\pm$ 37.2) ms, respectively. The MMN elicited by the consonant deviations in the CV condition peaked at 224 ($\pm$ 8.5) ms (voicing) and at 221 ($\pm$ 16.1) ms (place of articulation). The mean latencies of the vowel deviation elicited MMN were 187 ($\pm$ 12.6) ms to the [i:] and 172 ($\pm$ 8.9) ms to the [o:]. In the V and CV conditions, the MMN latencies have shown a good across subject stability as it was reflected by the lower S.D. values.

The peak amplitude values of the MMN were in the same range (1.1–3.3 μV over Fz) for all sound deviations. The individual amplitude distribution maps were visually inspected. The MMN amplitude and latency values were measured over the maximum area (Fz, Cz, F3, F4, C3, and C4) for further analysis. All of our four patients showed some anomalies of the MMN, irrespective of which stimulus type was used. However, the observed changes of the MMN showed characteristic differences as compared with the variations of the MMN of the matched controls.

Cluster analysis was applied in order to group together cases (i.e. individual response patterns) with similar profiles on a set of dependent variables (MMN amplitude over six recording sites) and distinguish groups that differ in their mean profile. Each of the dependent variables was included in the analysis. The 288 individual MMN response amplitudes (i.e. 36 responses per participant × eight participants = 288 cases) were than analyzed using the hierarchical clustering method. A four-cluster solution was adopted as the best account for the data. The global results of the cluster analysis are presented in Table 2.

All four clusters are readily interpretable. All cases grouped in Cluster A are speech-sound elicited MMN responses of control subjects, but four (V2 responses in one patient). Cluster B comprises responses elicited by tone deviations, both in control subjects and in patients. Clusters C and D involve a high proportion of speech-sound elicited MMN responses recorded in patients. While the responses elicited by CV deviations are grouped into Cluster C, most of the responses grouped into cluster D are vowel contrast elicited responses. Moreover, Cluster C and D group together and are distinct from cluster A and B.

As it is revealed by the global results of the cluster analysis, there is a clear difference between controls and

Table 2
Cluster assignment as a function of stimulus type

Condition	Clusters			
	A	B	C	D
T1	0	36	0	12
T2	0	45	0	3
V1	24	0	4	20
V2	28	3	0	17
CV1	24	0	24	0
CV2	24	0	24	0

T1: tone/50 Hz difference, T2: tone/200 Hz difference, V1: [i:], V2: [ø], CV1: VOT, CV2: place.

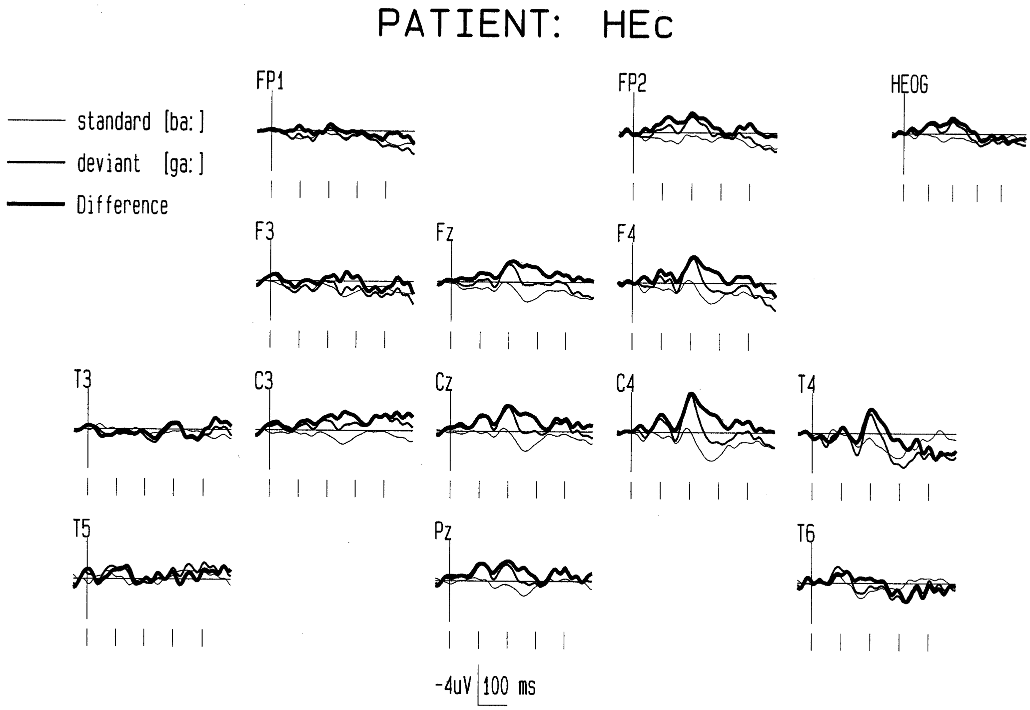


Fig. 2. Typical waveform anomalies of the CV elicited ERPs seen in Broca's aphasic patient of unilateral lesion. Superimposed ERPs elicited by standards and deviants and their subtraction curves in the CV paradigm. Contrasting feature: place ([ba:] vs. [ga:]).

patients. This separation allowed us to make a reliable subgrouping of the responses of patients and controls based on the speech-sound elicited MMN abnormalities as well. Although a deficient processing both of vowels (cluster D) and of CVs (cluster C) could be demonstrated in the patients investigated, only one of them that is CVs were found to be the most vulnerable characters. Interestingly, no striking difference between patients and controls could be found when the comparison (see Cluster B) was based on tone elicited MMN differences. The only exception was the somewhat smaller amplitude of the MMN elicited by the smaller tone pitch deviation in two patients (D.K. and M.G.).

The figures shown demonstrate the most characteristic consonant- and vowel-contrast elicited MMN anomalies.

One of the typical waveform anomalies found in patients is a changed distribution of the MMN. This type of MMN variation is shown in Fig. 2. The MMN shown in this figure was elicited by the [ba:] versus [ga:] contrast in our Broca's aphasic patient of unilateral lesion (H.E.). Superimposed responses evoked by the 'standard' [ba:], the 'deviant' [ga:] and the difference wave resulted from the 'deviant-standard' subtraction, are shown. In contrast to the MMN recorded in the control subjects the MMN appears with a large amplitude in the normal latency range (peak latency: 200 ms) on the right recording sites and absent or dramatically attenuated over the left recording sites. Parallel with the disappearance of the MMN the N100 is vanished or dramatically attenuated.

A second type of waveform anomaly, that is the lack or total depression of the MMN can characterize a general processing deficit of the contrasting phonetic feature as it is shown in Fig. 3. In Fig. 3 responses elicited by the standard [ba:] and deviant [pa:], recorded in the Wernicke's patient of bilateral lesion (D.K.) are shown. As it can be seen on the averaged responses and on the subtraction curve neither the MMN nor the other components occur. The only exceptions are some wave-like complexes of very low amplitude on two recording sites, Cz and C4.

A third variation of the characteristic processing alterations is a complex change of the MMN and N100 waves. A modified distribution of these components could be best observed in the Wernicke's patient of unilateral lesion whose responses to the 'standard' [e:] and 'deviant' [i:] vowels are shown in Fig. 4. As it can be seen the difference waves consist of two peaks, an early and a late one. The first negativity is a rather early deflection of about 100 ms and seems to result from the amplitude differences of the N100 of the standard and the deviant. The second negativity of the difference wave, however, peaks about 280 ms and it is about 80–100 ms longer than that of the MMN elicited by the same vowel contrast in controls. The most striking difference of the waveforms can be seen on the N100 component. In comparison with the responses recorded over the left side an N100 wave of two times larger amplitude can be observed over the right side.

Variations in the amplitude and distribution of the MMN elicited by two deviations of the three different stimulus types are demonstrated on the amplitude maps shown for a representative control subject. In Fig. 5 variations of the normally distributed MMN evoked by different stimulus types are shown on gray-scale-coded amplitude maps. While the spatial distribution of the tone MMN (1000 vs. 1050 Hz) shows an asymmetry towards the right, the spatial distribution of the speech-sound elicited MMN shows only a slight variation with the type of contrast. While the MMN to vowel contrast show a slight shift towards the left; there is no noticeable difference over all areas but one (left frontal) when VOT and place of articulation served as contrasting features.

Figs. 6 and 7 show the amplitude distribution of the MMN waves elicited by the two CV contrasts, voicing and place of articulation. In Fig. 6 the complete disappearance of the MMN to voicing is demonstrated by the distribution map computed from the responses of the Broca's patient of unilateral lesion and for the Wernicke's patient of bilateral lesion. In spite of the unilateral lesion the MMN was apparent in the Wernicke's patient whose map is shown on the top right panel. Though the distribution differs from that shown in the control subjects, the MMN is elicited by the contrasting phonetic feature over a limited area, demonstrating that the lesion has contributed to the lack of MMN only over the damaged area. A somewhat different distribution of the MMN could be observed in the Broca's patient of bilateral lesion; MMN of attenuated amplitude over the right and middle frontocentral recording sites.

The MMN amplitude distribution maps computed from the difference responses when place of articulation was used as contrasting phonetic feature are shown in Fig. 7. Although MMN or MMN-like waves could be recorded in all patients studied, different amplitude distribution abnormalities were found as it can be well seen on all maps. While in the Wernicke's patient of unilateral lesion and in the Broca's patient of bilateral lesion the MMN disappears over the left side, it occurs, though over a very limited area of the right recording sites, in both patients. The MMN is present over the frontal area in the Wernicke's patient of bilateral lesion, and over a circumscribed fronto-central area in the Broca's patient of unilateral lesion. However, comparing the distribution maps of MMN to CV contrasts (Figs. 6 and 7) an expressed similarity of the two patients can be observed, that is the disappearance of the MMN to voicing and the presence, though abnormal, of the MMN to place of articulation deviations. A noticeable difference between the occurrence of the MMN to VOT and place of articulation contrasts can be observed especially in Case 1 (H.E., Broca's patient of unilateral lesion) and to a lesser extent in Case 3 (Wernicke's patient of bilateral lesion).

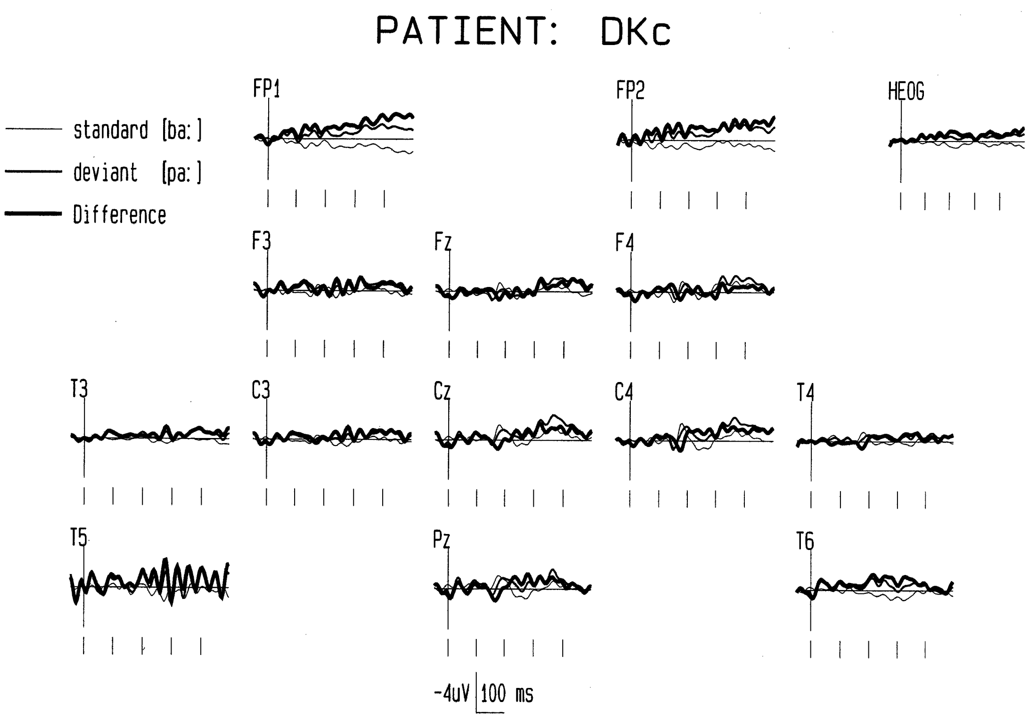


Fig. 3. Processing deficit-related changes of the scalp recorded ERPs observed in Wernicke's aphasic patient of bilateral lesion. Contrasting feature in the CV condition: voicing ([ba:] vs. [pa:]).

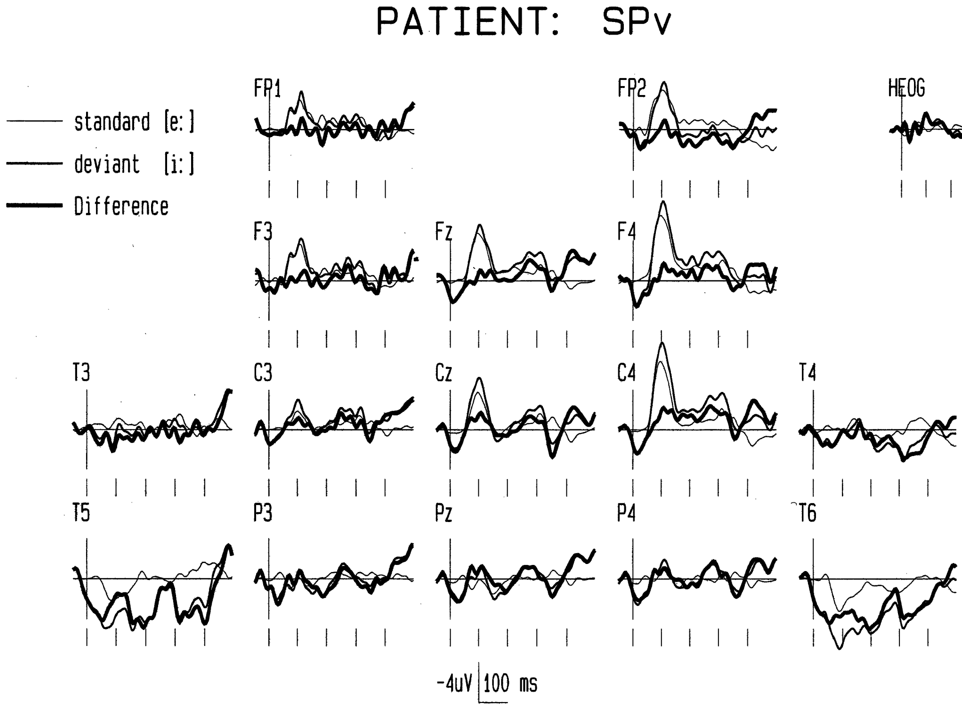


Fig. 4. Unilateral suppression of the N100 and MMN waves in Wernicke's aphasic of unilateral lesion. Contrasting feature in the vowel condition: height ([e:] vs. [i:]).

3.2. Results of the neuropsychological investigations

3.2.1. Speech sound discrimination

Results of the speech sound discrimination tasks are presented in Fig. 8. The test score comparisons indicated in all patients a better discrimination performance in the vowel- than in the CV-pair judgment tasks. Two of the patients investigated, H.E. and S.P., had lower scores in one of the consonant discrimination blocks that is voicing.

A closer look at the CV discrimination performance pattern of the two patients with bilateral lesions (M.G's. and D.K's.) reveals a striking difference, that is a reversed pattern as compared with the other two patients. These patients of bilateral lesion achieved better results when voicing was the contrasting phonetic feature, although the difference as shown in Fig. 8 is quite modest. Although a relative better performance is valid for D.K. as well, her scores were found to be the lowest (slightly over 60%-hit rate). Furthermore, when these stimuli were used as distinctive features in the word-pair discrimination task the patients' performance did not improve except for one (unilateral Broca's aphasic, H.E.).

As it is shown on the upper panel of Fig. 9, the spoken version of the word/picture matching task revealed higher performance scores in all patients for verb matching than for noun matching (generally not typical for Hungarian speaking aphasics). The two patients with Broca's aphasia (H.E., M.G.) attained better results in the spoken variant of the test than in its written version, while patients with conduction or Wernicke's aphasia showed again a reversed pattern. The results of the lexical decision task, shown on the right panel of Fig. 9, revealed a better real word discrimination performance in all patients as compared with judging on legal non-words. The lexical decision performance scores correlated with the WAB repetition index and with the percentage of correct responses given in the speech sound perception tasks measuring the discrimination performance on contrasting features of consonants. The most striking performance score difference was shown by the Wernicke's patient of bilateral lesion, D.K., whose impairment was also extreme in the consonant discrimination task.

As it is shown in Fig. 10 the semantic discrimination task revealed a comparatively better performance in judging on pairs without common semantic features than on synonyms in all patients but one, H.E. However, all the patients showed difficulties in discriminating words of slightly different meaning. Word pairs of common semantic features were more difficult for Broca's than for Wernicke's or conduction aphasic patients, and this difficulty was well shown by their low achievement scores expressed in percentage. Furthermore, H.E. (Case 1) showed a deficiency effect of meaningfulness on speech sound discrimination (Fig. 9) and a reversed performance ratio in semantic distance, such as lower scores for words of different meaning and a very low score for words sharing common semantic features. (Fig. 10). The lowest score in discriminating between word pairs of common features was achieved by the Wernicke's patient of bilateral lesion (Case 3, D.K.).

4. Discussion

A primary goal of this study was to determine if the MMN component of ERPs reflected selectively processing deficits in the preattentive change detection of various contrasts of speech and non-speech stimuli. To test this idea, we examined MMN waveforms and distributions to tonal and speech stimulus clusters such as vowels and initial consonants of syllables. The deviations used were either smaller (tone), 'difficult to discriminate' (acoustic differences related to phonetic variations) or larger, 'easy to discriminate' stimulus contrasts. Although some studies have already suggested [8,13] that disorders in input analysis at both phonetic and lexical, semantic level may contribute to impairments of auditory comprehension in aphasic patients, it remained poorly understood, how the lesion topography is related to perceptual analysis and lexico-semantic performance.

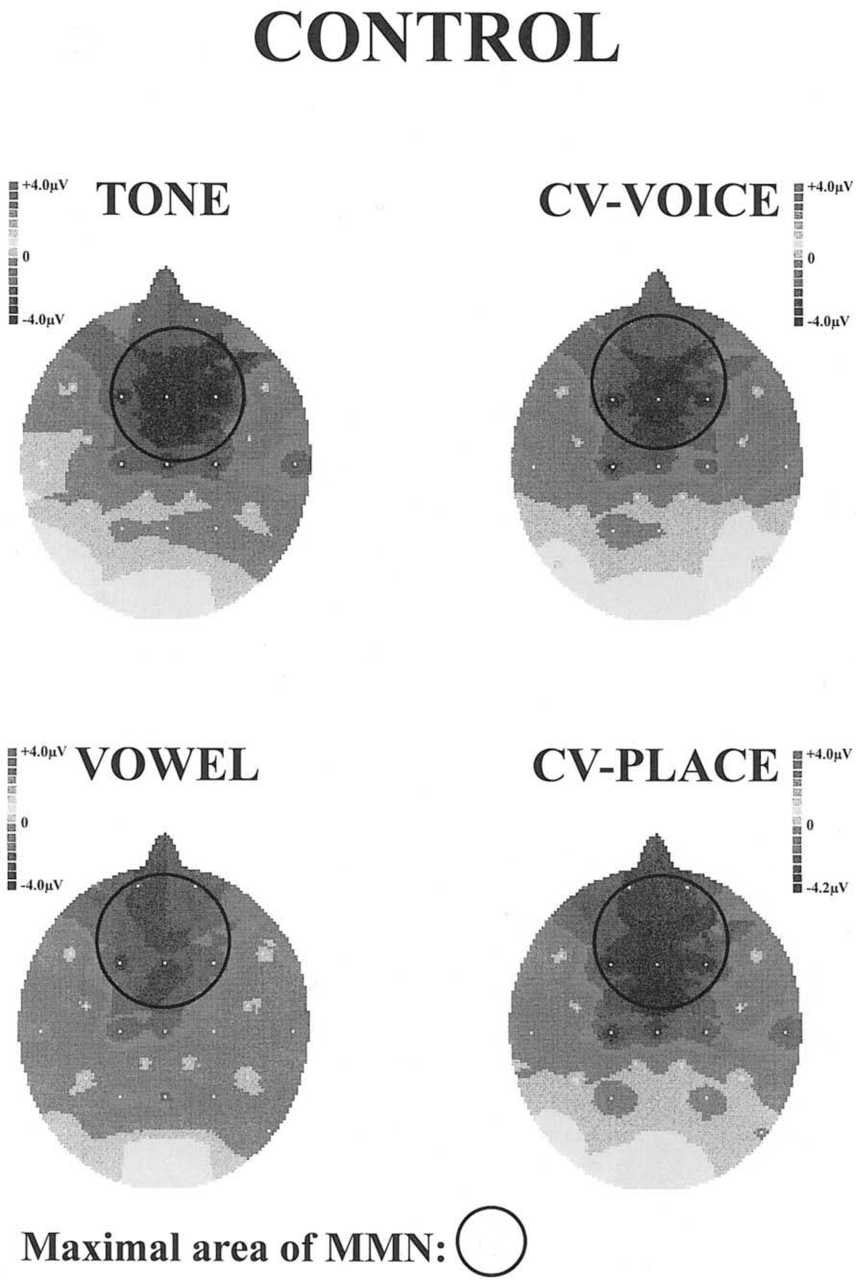


Fig. 5. Color-coded amplitude distribution maps computed for the MMN peak in one of the age matched control subjects (see text for details).

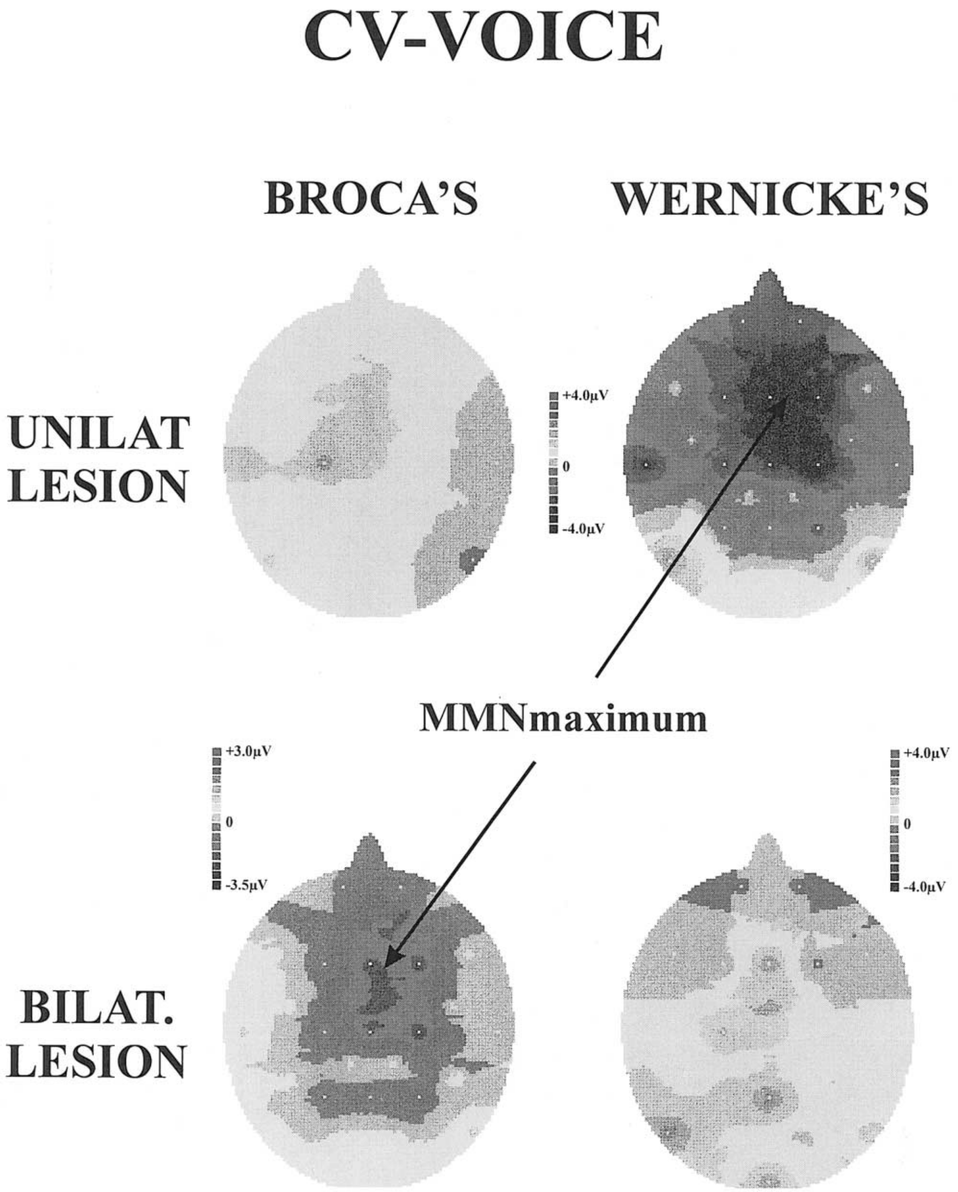


Fig. 6. Amplitude distribution maps of MMN to voicing as contrasting phonetic feature, shown for all four patients investigated. Note the total lack of response in Broca's aphasic of unilateral and Wernicke's aphasic of bilateral lesion.

Our principal finding was that the MMN elicited by pitch deviations is not sensitive enough to distinguish between patients and age-matched controls. The relative intactness of the tone-deviation elicited MMN in aphasic patients' was also shown by Aaltonen and his coworkers [2]. Furthermore, the speech-sound elicited MMN waves recorded in patients and controls were well distinguishable in distribution. The CV-elicited MMN was found to be the most vulnerable in the aphasic patients investigated. The MMN elicited by voicing and place of articulation as contrasting phonetic features could be characterized by total lack, distorted or very limited distribution. The preattentive change detection failed, as reflected by the absence of MMN, when the contrasting phonetic feature was voicing and it was correlating with the performance shown in the behavioral phoneme discrimination task. The patients' (H.E. and D.K.) phoneme discrimination performance (for all possible voicing contrasts in Hungarian) was about 70%. This processing abnormality, however, was not specific to the aphasia type. It is rather probable, however, that the lesion site might involve areas that are crucial in detecting these acoustic differences (VOT). Although the place of articulation contrast elicited MMN showed an abnormal distribution in all patients but one, it was present even in those patients whose behavioral discrimination performance was slightly over 60%. Again, the anomalies found in

MMN distribution were not related to the aphasia type, as it was also found in the vowel paradigm. The MMN to both vowel contrasts was in the normal range in three patients, and was found to be disturbed to both deviants in the Wernicke's patient of bilateral lesion, D.K. This one is the only finding which corresponds to the results of Aaltonen et al. [2] using very short vowels.

The deficient change detection as revealed by the MMN was neither related to the type of aphasia nor restricted to the Wernicke's aphasia type. This independence of the speech-sound elicited MMN anomalies seems to correspond to the behavioral data [8] revealing perceptual deficits both in Wernicke's and in Broca's aphasics. This could be explained if distributed representations of change detection of acoustic/phonetic variation were taken into account or the aphasic patients investigated being different according to the neuropsychological classification shared lesioned areas. Very recent fMRI data [14] seem to underlie the later one showing in normal subjects an exclusive activation within the inferior part of the left supramarginal gyrus when initial stop consonants of syllables were contrasted. In our both patients (Case 1 and 3) lacking the MMN to voicing the cerebrovascular incident has affected deeply extended areas, so it can be assumed that similar areas are involved though the affected areas cannot be determined based on the data available.

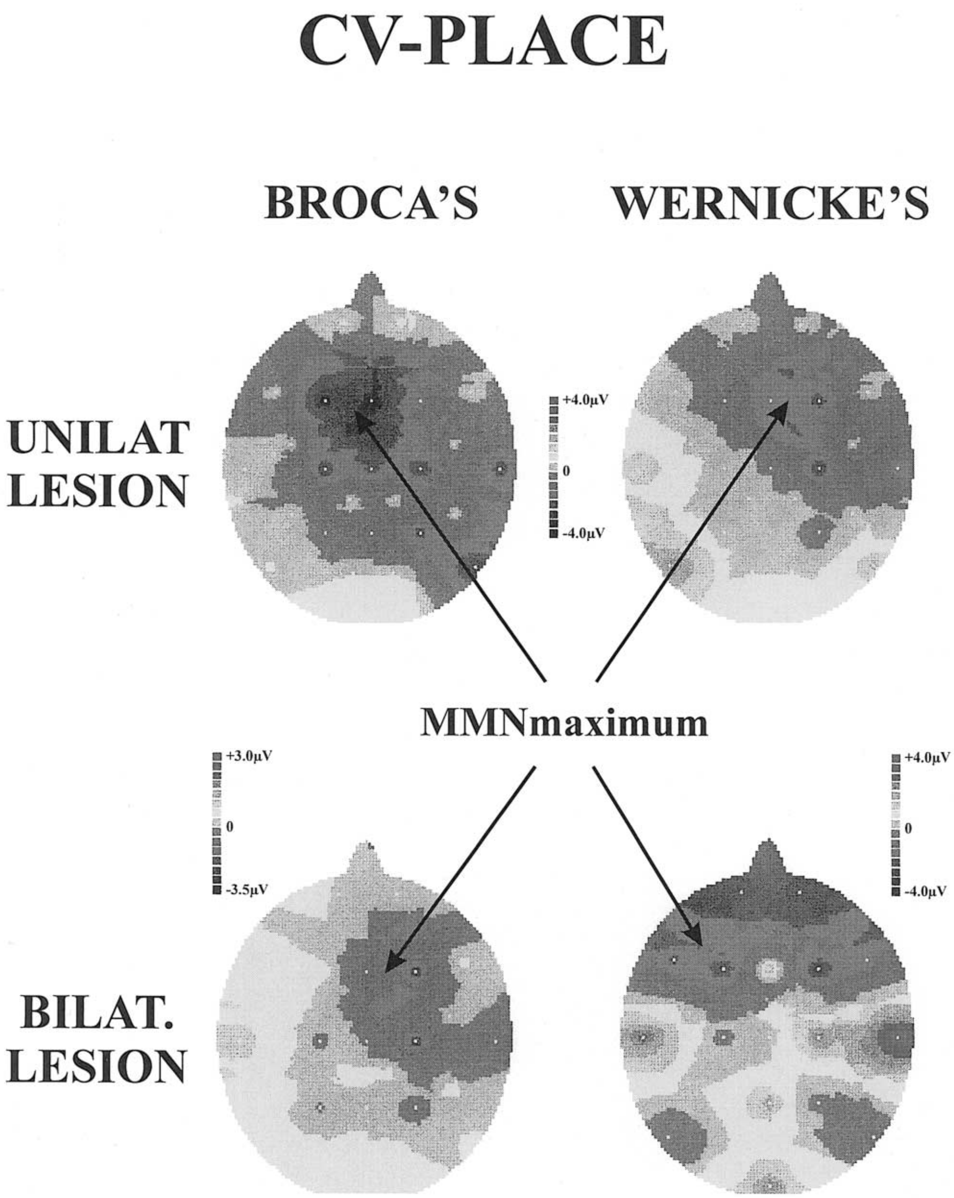


Fig. 7. Amplitude distribution maps of MMN to place of articulation as contrasting phonetic feature, shown for all four patients investigated. The MMN distribution is abnormal in all patients but one, Broca's aphasic of unilateral lesion.

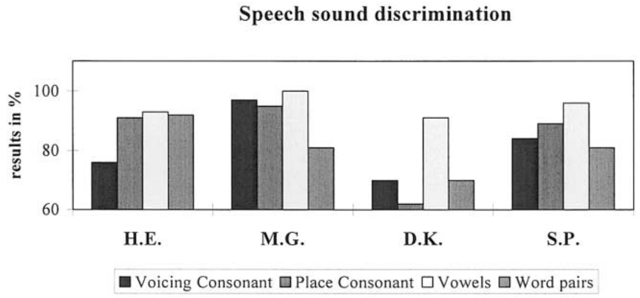
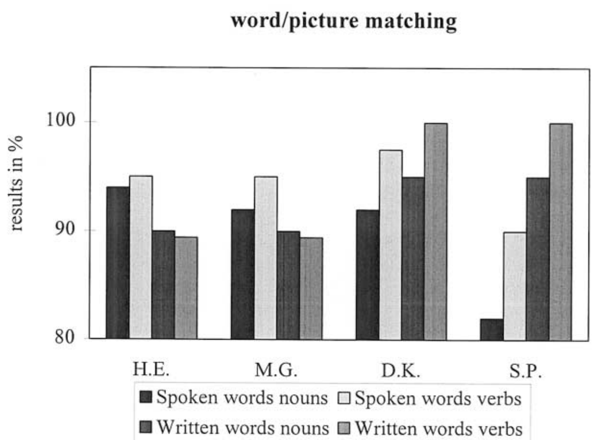


Fig. 8. Percentage of correct responses in the same/different phoneme judgment task.

However, it is interesting to oppose the difference between the occurrence of the place of articulation- and VOT-elicited MMN in patients to the relative stability of the consonant-elicited MMNs in controls. This difference speaks for a difference in MMN source location for voicing and place of articulation. However, it must be taken into account, that our assumption is based on correlative measures. The interpretation of the MMN amplitude distribution in patients with brain lesions is based on the following: (a) the total lack of the MMN is due to the lack of contrast processing, probably because of the effect of lesion on crucial generator(s). (b) The abnormal distribution can be regarded as the sign of a still well functioning generator when no response is recordable over the lesioned site and normal amplitude MMN is present over the intact areas. (c) The abnormal MMN distribution is interpreted as the sign of attenuation in the activity of the MMN generator(s) when attenuated and often delayed latency responses occur over the intact areas.



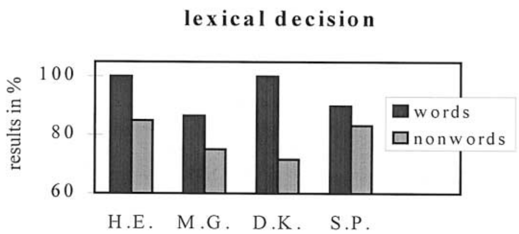


Fig. 9. Results of the word/picture matching and lexical decision tasks.

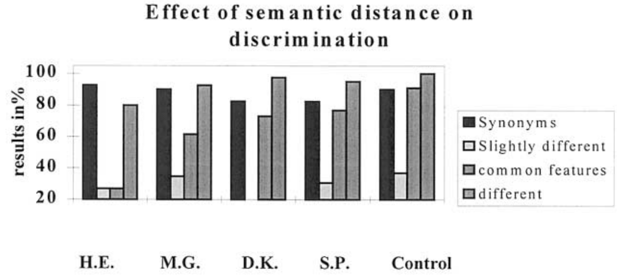


Fig. 10. Discrimination performance showed for various semantic distances of word-pairs.

Regarding the complexity of the ERP and neuropsychological findings one may expect that the traditional classification of aphasia type does not predict the deficient language processes in detail. An extensive fMRI study run on 30 subjects in language activation tasks requiring phonetic and semantic analysis of spoken words revealed activation patterns which are not fully consistent with the classical models of language processing areas [7]. These findings show a clear participation of the left frontal areas in the receptive language functions and the existence of semantic analysis outside the traditional Wernicke area. Furthermore, the functional activation revealed by fMRI measurements in patients and controls during comprehension tasks was found very much different over the superior temporal and angular gyrus regions [4]. These findings may explain our patients' performance differences in the effect of semantic distance on discrimination.

Based on a similar, more flexible functional organization of the language-processing network than that corresponding to the classical view, our aphasia type independent MMN results may be better understood as well. Moreover, the insensitivity of the pitch MMN in distinguishing between patients and controls is in agreement with the fMRI study of Celsis et al. [14] showing a strong rightward asymmetry in the primary and secondary auditory cortex and the right inferior frontal areas for tones, even for spectral changes. Furthermore, the fMRI results [14] revealed differential activation over the left and right superior temporal areas when tones or initial stop consonants of syllables were contrasted. As suggested by the authors, the left posterior superior temporal gyrus is active when acoustic changes in speech or in non-speech stimuli are processed, whereas the left supramarginal gyrus is more engaged in detecting phonological changes. These results may explain some of our own findings suggesting that the various speech contrasts be not effected in a uniform fashion.

It is notable that the MMN to voicing was more affected, at least what concerns the magnitude of deficit, while the place of articulation difference elicited MMN was present, though disturbed. An interesting finding of this study was that the automatic and controlled processing of speech sounds did not dissociate. However, the automatic and controlled processing of voicing showed a better and more reliable correlation than the place contrast or the vowel contrasts.

An interesting and subsidiary finding of this study was the dichotomy found in the relationship of MMN to perception and to lexical decision with respect to judging on legal non-words. While the automatic processing of speech sound contrasts as reflected by the MMN and the speech sound discrimination performance measured in same/different judgement tasks showed a well-defined correlation, the deficient automatic processing proportionally related to the non-word discrimination and did not interact with the word discrimination performance. While the phoneme perception deficits did not contribute to the speech comprehension in general, a strong correlation could be found between the deficient phoneme processing and deficient lexical decision.

Moreover, M.G. and S.P., (Broca's bilateral and Wernicke' unilateral) showed a low performance even for words in the lexical decision task, and this deficit did not correlate well with their phoneme perception performance. It was also well shown by our results that a deficient phoneme perception may contribute to higher level language processes and this contribution may depend on to what extent the processing of various phoneme clusters was affected by the site and size of the lesion. It is clear, however, from this study that deficits in the automatic change detection of phonetic contrasts appear both in Wernicke's aphasic patients having phonological output lexicon deficits, and in Broca's aphasics showing large differences in automatic and controlled phoneme processing.

Our data suggest that the MMN elicited by contrasting features of various phoneme clusters reflect deficient processes due to lesioned or disconnected regions of the language-processing network [15]. The impairment correlating with the controlled phoneme processing as well is more related to the affected area than to the type of aphasia. However, the impact of deficient automatic and controlled speech sound processing on higher level language processes may be more dependent on the type of aphasia as it is suggested by the dichotomies and dissociation shown by the neuropsychological assessment.

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