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Auditory temporal-order judgement is impaired in patients with cortical lesions in posterior regions of the left hemisphere

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Abstract

Auditory temporal-order judgement was investigated in patients suffering from unilateral focal brain lesions, localized in anterior or posterior regions of the left hemisphere (LH) (resulting in non-fluent or fluent aphasia, respectively), or in predominantly subcortical regions of this hemisphere (without aphasic syndromes) and in anterior or posterior regions of the right hemisphere. The temporal order threshold was measured as the minimum time interval between two clicks presented consecutively and binaurally via headphones (one to each ear) that was necessary for a subject to indicate the temporal order of the two stimuli. Only the patient group with fluent aphasia showed a significantly increased mean temporal-order threshold as compared to the controls. Our results indicate that fine temporal resolution for auditory stimuli is predominantly associated with posterior regions of the LH. © 1999 Elsevier Science Ireland Ltd. All rights reserved.

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The association of fine temporal resolution with processes of the left hemisphere (LH) and, especially, with those associated with language functions has long been known ([2,14] for an overview see Ref. [8]). In a typical experimental task on auditory temporal-order judgement, the subject indicates which of two binaurally and consecutively presented clicks or brief tones appeared first – the stimulus to the left or to the right ear. Repeated findings show that the order threshold in healthy young volunteers is around 20–40 ms [10]. The temporal discrimination of rapidly changing stimuli is impaired in patients with injuries to the left hemisphere and aphasia [2,14,18], in children with language-learning impairments [17], and in children [3] and adults with dyslexia [4]. In the temporal-order judgement task, thresholds of many aphasic patients are elevated, sometimes by as much as a factor of two or more [2,14].

The concurrent impairment in temporal-order judgement tasks and language functions can be understood as a general temporal-processing deficit that underlies aspects of the language deficit occurring on the phonological level. The ability to identify consonant-vowel syllables is based on the temporal analysis of rapid formant transitions in the speech signal that occur during the voice onset. To discriminate, for example, between the syllables /pa/, /ta/ and /ka/, or between /ba/ and /da/, the order of occurrence of the spectral components in the signal has to be processed [1,18]. In syllables like /da/ and /ta/ [13] or /ba/ and /wa/, a temporal analysis sensitive to the duration of the voice-onset time is required for correct identification. Many patients with aphasia are impaired in the discrimination of these syllables [13,18].

Since patients with aphasia show a deficit in temporal resolution, it looked promising to design therapeutic training that aims at improving fine temporal processing and to thereby improve language function at the phonological level – the ability to discriminate consonant-vowel syllables. In a previous study of ours [13], after behaviourally orientated feedback training for auditory-order discrimination was applied an order threshold similar to that of healthy control subjects was achieved. The patients' ability to discriminate the syllables /da/ and /ta/ also improved, even though the training procedure had used non-verbal material. Neither of these effects were obtained in patients with aphasia and prolonged auditory order threshold when they received

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Table 1
Clinical characteristics of the patient groups

Group	Lesion site	No. of patients	Aphasic syndrome	Age mean (SD)	Gender (male/ female)	No. of sessions (three per patient)[a]
1	Left hemisphere, anterior (LH.pre)	7	Broca	57.0 (7.4)	6/1	20
2	Left hemisphere, posterior (LH.post)	14	Wernicke, amnestic, transcortical-sensory	55.5 (8.7)	8/6	37
3	Left hemisphere, predominantly subcortical without aphasic symptoms (L.noAph)	9	No	48.7 (14.7)	6/3	26
4	Right hemisphere, anterior (RH.pre)	9	No	48.2 (12.6)	5/4	25
5	Right hemisphere, posterior (RH.post)	6	No	54.0 (8.4)	6/0	16
6	Orthopaedic control group (Controls)	17	No	49.5 (12.0)	10/7	47

[a] Due to logistical problems, not all patients participated in all three sessions. Analysis was based on data from the number of subjects and sessions listed (less than 1.2% of the data were recognized as outliers).

control training that was not directed at fine temporal resolution. In another training study on children with language-learning impairments, language competence increased with the improvement of fine temporal resolution [7].

From accumulated research, there is strong evidence for an association of temporal processing with left-hemispheric function. However, research on temporal processing in patients with cortical lesions is still underrepresented [5]. In particular, the question of a more detailed localization of temporal processes requires further research. Therefore, we investigated the effect of anterior vs. posterior cortical focal lesions in the left hemisphere on language and timing functions in patients with aphasic syndromes. These patients were compared with three other patient groups with lesions in areas not primarily associated with language functions, namely patients with predominantly subcortical left hemispheric lesions and patients with lesions in anterior and posterior cortical areas of the right hemisphere (Table 1).

All patients, male and female, were right-handed and had unilateral focal lesions predominantly due to infarction ($n = 44$); one patient had a brain lesion after tumour resection. Groups 1 and 2 had lesions to the LH. More specifically, in group 1 patients had lesions in regions anterior to the central sulcus (pre-central) resulting in non-fluent aphasia (LH.pre; $n = 7$). In group 2, patients had lesions in posterior regions (post-central) resulting in fluent aphasia (LH.post; $n = 14$). Group 3 patients had left-sided, predominantly subcortical lesions (L.noAph; $n = 9$). Groups 4 and 5 patients had lesions in the right hemisphere, anterior (pre-central) in group 4 (RH.pre; $n = 9$) and posterior (post-central) in group 5 (RH.post; $n = 6$). The control group consisted of patients having orthopaedic problems but without brain lesions (Controls, $n = 17$). The patients were between 20 and 70 years old. The time between the infarction and our testing was from 3 months to 4 years. The classification of lesion sites was carried out by two experienced neuroradiologists, using MRI or CT imaging. The

aphasic syndromes were assessed by the Aachener Aphasie Test. Patients showing severe memory or attention deficits or a history of any other neurological disease were excluded from the study. The patients included in each group were matched according to age, educational level, and non-verbal IQ (Raven Standard Progressive Matrices, minimum IQ = 85). They had normal hearing and did not receive any medication known to influence the speed of neural processing.

Clicks (rectangular pulses of 1-ms duration) were produced by a standard AD/DA-converter card, fit to a portable computer. A pair of consecutive clicks, one to each ear, were presented by headphones at 100 dB SPL. The binaural paradigm was chosen over monaural paradigms with pitch or intensity serving as order cues, to assure that the temporal characteristics of the stimulation were indeed used for the identification of temporal order. The time interval between the two clicks and their order was controlled by a PC-based software system [6] which implements an adaptive psychophysical staircase (YAAP) for the estimation of the threshold [19]. Adaptive staircases represent optimized methods for fast and reliable threshold measurement by making the stimulus parameter in each trial dependent upon previous subject responses. YAAP is a latest-generation algorithm based on stochastic principles [20]. The subjects' task was to indicate which of the two binaurally presented stimuli they perceived first. The answers were given by pointing to the respective ear, or to the forehead when clicks were perceived as simultaneous. The program calculates a running estimate of threshold and threshold reliability. It stops the stimulus presentation when a certain stochastic criterion is reached (a stochastic criterion serves to keep the reliability of obtained thresholds constant across a set of measurement conditions. The criterion was set such that thresholds were within a ± 10 ms confidence interval at the 75% probability level; the calculations are based on a-priori set psychometric-function para-
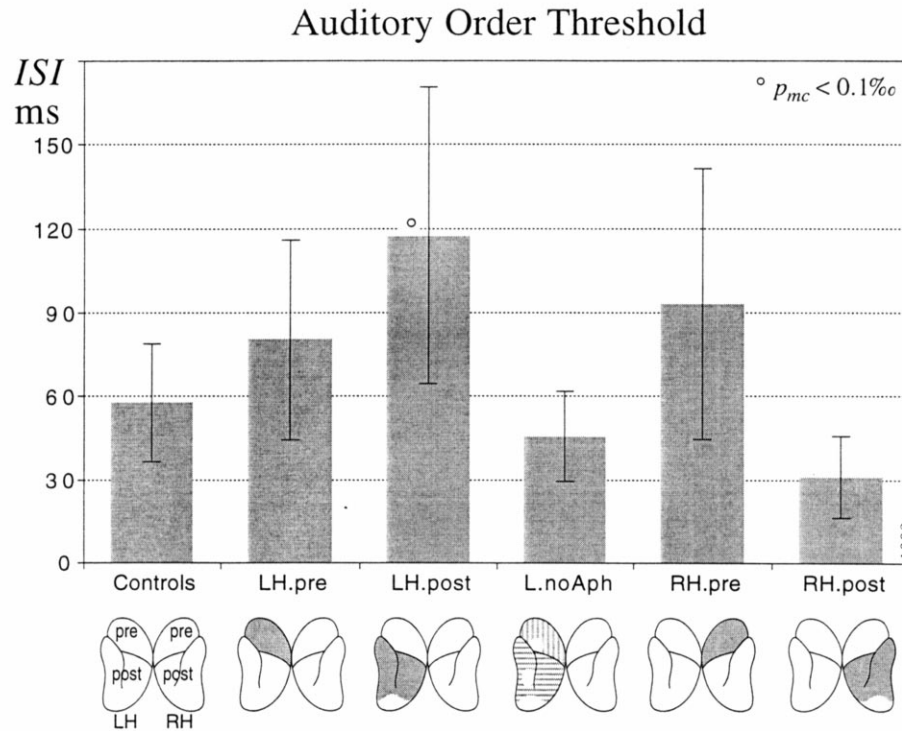
Auditory Order Threshold

Fig. 1. Auditory order thresholds (mean and standard deviations) for the five patient groups with focal brain injuries and for an orthopaedic control group (Controls) are shown: LH.pre – anterior left hemisphere (pre-central) with non-fluent aphasia; LH.post – posterior left hemisphere (post-central) with fluent aphasia (*P < 1% for group differences as compared with Controls and L.noAph; statistical calculation with Scheffé post-hoc test); L.noAph – left-sided subcortical lesions without aphasia; RH.pre – anterior right hemisphere (pre-central); RH.post – posterior right hemisphere (post-central).

meters). Three order-threshold measurements (sessions) per subject were conducted on 3 consecutive days.

A two-way ANOVA with between-subject factor 'group' and within-subject factor 'session' revealed that only the factor 'group' had a significant main effect ($P < 0.001$; $F(5, 43) = 6.76$). A Scheffé post-hoc test for group differences, over the mean order threshold of the three sessions, revealed that the group with posterior left-hemispheric lesions differed significantly not only from the control group ($P < 0.001$), but also from the non-aphasic patient group with predominantly subcortical, left-sided lesions ($P < 0.001$) and the group with right-hemispheric posterior lesions ($P < 0.001$). The patients with left-hemispheric anterior lesions and aphasia, in contrast, had much less elevated thresholds, and these did not differ significantly from the controls.

Fig. 1 indicates the order-thresholds (mean and standard deviation) averaged over the three sessions per person for the five patient groups and the control group. The mean order threshold for the control patient group is 57.7 ms, a value higher than that usually found for healthy young adults of 20–40 ms [10,13,14]. As can be seen in Fig. 1, the neurological patient group with posterior left-hemispheric lesions and fluent aphasia showed the highest thresholds (a mean of 117.5 ms), twice that of the controls.

Our results confirm an association between the left-hemi-

sphere's involvement in language processing and fine temporal resolution [2,14,18]. Similar to Swisher and Hirsh [14] we found that patients with fluent aphasia, in particular, show deficits in the temporal ordering of events. In the study presented here, however, we more strictly controlled the patients' lesion sites: In the selection of patients, we ensured that those with fluent aphasia had damage mainly in posterior regions and those with non-fluent aphasia had damage mainly in anterior regions. Our main finding was that only patients with fluent aphasia who have left-hemispheric lesions to the cortex that are posterior to the central sulcus were impaired in their temporal-order judgement. Patients with left-hemispheric lesions in anterior regions who were non-fluent aphasics did not show a significant increase of auditory-order threshold. Also, patients with subcortical left-hemispheric injuries without aphasia did not show prolonged order thresholds. One can infer that sequential processing in the range of some tens of milliseconds is predominantly controlled by neural mechanisms of the left posterior cortex, which are also involved in language processing.

Independent evidence suggests that posterior regions are also those that are involved in the temporal analysis of phonemes. Poeppel et al. [9], for example, studied neural activity during the perception of phonemes using MEG recording in healthy subjects. The authors found increased

neuronal activity in the left temporal cortex when subjects discriminated between the stop consonant-vowel syllables /dae/ and /tae/, that differed by the duration of the voice-onset time.

Our findings complement experimental results obtained in the same patient groups with further experimental paradigms. In separate reports we have shown that temporal-information processing in the 2–3 s range, the integrating of sensory information [15], or the perception of ambiguous figures [13], are differentially controlled by anterior regions, both left- and right-hemispheric [11,16]. In contrast, the processes of temporal-order judgement are associated with posterior LH lesions. Our present finding of prolonged temporal-order thresholds in patients with posterior LH lesions adds to the growing evidence that specific timing functions are associated with different brain areas: temporal processes represent a necessary prerequisite for mental function and behaviour [10,12].

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