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Perceptual Discrimination of Vowels in Aphasia

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Summary. In the present study 3 hypotheses were investigated: first, the notion that an aphasic impairment of vowel perception is not associated with particular aphasic syndromes or lesion sites, second, that it is a disorder comparable to a general impairment of perception in a normal speaker caused by some form of interference, and third, that perceptual phonemic discrimination is a separate process from the phonemic discriminative function necessary for speech production.

The hypotheses were tested by means of a vowel discrimination test administered to 50 German-speaking aphasic patients (roughly equally divided between Broca's, mixed non-fluent, Wernicke's and mixed fluent groups); the same test, masked by white noise at −10 dB was also administered to 20 normal native speakers of German.

Results were in support of all 3 hypotheses. First, aphasic patients' error patterns were similar across fluent and nonfluent groups and for all lesion sites. Second, the error distributions of aphasics with slight auditory impairment resembled those of normal subjects in the −10 dB white noise condition, while distributions of aphasics with severe auditory impairment were indicative of an added component of guessing behaviour. And third, the patients' performance on the discrimination task differed from that shown on a comparable repetition test. (It was argued that repetition involves a patient's expressive capacity in addition to his perceptual capacity.) The differentiation of perceptual and expressive phonemic discrimination was further supported by an analysis of the speech errors occurring in the spontaneous (purely expressive) speech and in the repetition (expressive plus perceptual) tasks of 16 French Canadian and 5 English Canadian aphasics.

Key words: Aphasia – Perception – Phoneme discrimination

Zusammenfassung. Mit der vorliegenden Studie wurden drei Hypothesen untersucht: (1) die Möglichkeit, daß eine aphasische Störung der Vokalperzeption nicht mit spezifischen aphasischen Syndromen oder lokalisierten

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Hirnschäden verbunden ist, (2) daß diese Störung vergleichbar sei mit einer generellen Störung der Perzeption bei Normalpersonen, die durch Interferenz mit z. B. anderen auditiven Reizen erklärt werden kann, und (3) daß die perzeptive Phonemdiskrimination ein andersartiger Prozeß ist als die Phonemdiskrimination, die in der Sprachproduktion gebraucht wird.

Die Hypothesen wurden mit Hilfe eines Vokal-Diskriminations-Tests geprüft. Fünfzig deutschsprachige Aphasiepatienten (zu etwa gleichen Teilen Gruppen von Broca's, gemischten nichtflüssigen, Wernicke's und gemischten flüssigen Aphasikern) wurden untersucht. Der gleiche Test, allerdings mit Maskierung durch weißes Rauschen, wurde mit 20 deutschsprachigen Normalpersonen durchgeführt.

Die Ergebnisse unterstützten alle drei Hypothesen. Die Fehlerart und -verteilung war bei allen Aphasiegruppen und für alle Läsionsschwerpunkte ähnlich. Die Fehlerverteilung der Aphatiker mit leichter rezeptiver Störung glichen der von Normalpersonen unter der Bedingung mit weißem Rauschen bei −10 dB. Aphatiker mit schwerer rezeptiver Störung zeigten des weiteren Resultate, die auf zusätzliches Ratverhalten schließen lassen. Weiterhin unterschieden sich die Leistungen der Patienten, wenn man eine auditorisch-sprachlich nicht expressive mit einer auditorisch-sprachlich expressiven Aufgabe verglich. Daß eine Unterscheidung zwischen perzeptiver und expressiver Phonemdiskrimination zu machen ist, wurde weiter unterstützt durch eine Analyse von Sprachfehlern während spontanem Sprechen und beim Nachsprechen, durchgeführt bei 16 französisch-kanadischen und 5 englisch-kanadischen Aphasikern.

Schlüsselwörter: Aphasie - Perzeption - Phonemdiskrimination

Introduction

The present experiment addresses a number of related issues in the study of impairment of auditory perception in aphasia. First, it examines whether impairments of vowel discrimination can be predicted on the basis of aphasia syndrome, lesion site or age. Second, an attempt is made to characterize more closely the nature of impairment of phoneme discrimination through aphasia. And finally, the relation between expressive and perceptual impairments of phoneme discrimination is studied.

At present, there exists relatively little empirical evidence concerning lesion sites and aphasia syndromes associated with perceptual discrimination impairments. Traditionally, such disorders have been described as part of the classical aphasia syndromes, which are themselves typically distinguished on the basis of expressive disorders. In the Boston Diagnostic Aphasia Examination (Goodglass and Kaplan 1972), for instance, the distinction between Broca's, Wernicke's, conduction and anomic aphasics is in large part made on the basis of the patients fluency of speech, the typical length of his phrases, the presence of agrammatic ("telegraphic") or paragrammatic (incorrect) grammatical structures in his speech, the presence or absence of phonemic or semantic paraphasias or jargonized speech, and on his performance in naming tasks. All of these are criteria concerned with expressive tasks.

Yet it is not clear whether syndromes recognized on the basis of speech production impairments also represent adequate groupings for his receptive impairments. In some respects, such as the impairment of lexical items, a parallelism between the two modalities does seem to prevail. For instance, Whitehouse et al. (1978) found that on a naming task, anterior patients behaved much like normal subjects when shown a series of pictures of food containers varying from prototypical to atypical shapes. Subjects named objects with prototypical features in a consistent fashion, and those with atypical features inconsistently, while posterior patients did not establish a clear naming pattern.. This parallels aphasic impairments in comprehension, where posterior patients are also marked by slow and inconsistent responses to the presentation of lexical items in multiple-choice tasks, while anterior aphasics are relatively unimpaired in these respect (Zurif et al. 1974; Goodglass and Baker 1976; Baker and Goodlass 1979).

At the same time, divergences between expressive and receptive disorders have also been reported. For instance, Gainotti et al. (1975) found that confusions in a multiple-choice comprehension test, which could be ascribed to errors in phonological or semantic receptive processing, occcurred in all of their aphasic groups, even though some of the groups were characterized by phonological or semantic expressive disorders, while others were not. Although Goodglass et al. (1979) showed that Broca's aphasics comprehend expanded sentences (e.g. "the fireman is strong and the policeman is not") more easily than encoded sentences ("the fireman is stronger than the policeman"), a phenomenon which is parallel to the Broca's aphasics tendency to replace encoded sentences by expanded sentences (Gleason et al. 1975), Goodglass et al. failed to show a difference between aphasic groups with respect to the percentages of errors on the comprehension of encoded sentences (p. 206). On the basis of typical aphasic expressive behaviour, one would have predicted a decreased performance for Broca's aphasics.

Such findings suggest that certain receptive disorders may neither parallel related expressive disorders, nor can necessarily be predicted on the basis of expressive syndrome groupings. It is possible that they should rather be seen as processing disorders in their own right, potentially related to typical lesion sites of their own.

In the present experiment, these concepts will be tested with respect to the phonemic discrimination of vowels. This psycholinguistic process offers the possibility of a direct assessment of the relation between receptive and expressive impairments in aphasia, since it is a process required in both speech reception and speech production. Perceptually, phonemes must be discriminated to permit the correct identification of acoustic stimuli (e.g. sun/fun), and productively, motor programs corresponding to phonemes must be distinguished during the planning and the execution of speech events.

Historically, it has been assumed that a perceptual impairment of phonemic discrimination is characteristic of Wernicke's aphasia, and even that it may form the basis of the usually profound comprehension disorder associated with the syndrome (Luria 1970, pp. 112). On the expressive side, paradigmatic aphasic phoneme substitutions (an impairment of phoneme discrimination in production, or "literal paraphasias") are more typically seen in anterior types of aphasia (Broca's and conduction aphasia; Goodglass and Kaplan 1972; Blumstein 1973; Keller 1978).

A few years ago, Blumstein and her colleagues presented some evidence contradicting Luria's claims concerning perceptual phoneme discrimination. Blumstein et al. (1977) found, for instance, that on a same–different discrimination test for consonants (e.g. "pear"-"bear" vs. "pear"-"pear"), a sample of 6 Wernicke's aphasics performed somewhat better than did a group of 6 mixed anterior patients, even though the Wernicke's aphasics were more severely impaired in verbal comprehension than were the mixed anterior patients. Blumstein (1981) suggests that Luria's tasks probably involved the ability to make phonemic judgements, and were not merely a "... disturbance of auditory analysis and synthesis ..." (Luria 1970, p. 115), which may account for the reported differences between her results and Luria's. Furthermore, an analysis of the results of Blumstein et al. actually shows that with the exception of the 6 Broca's aphasics, who did particularly well in the discrimination task, the remaining 19 patients (mixed anterior, Wernicke's and residual posterior) all scored at roughly the same level. A further study involving perceptual discriminations of voice onset time (Blumstein et al. 1977), also failed to produce clear differences between groups of aphasics (Broca, mixed anterior, anomic, Wernicke and conduction), though the 16 patients showed varying degrees of impairement on the task.

In view of these considerations, 3 hypotheses concerning aphasic impairment of perceptual phoneme discrimination will be tested here. (a) The first hypothesis is that aphasic perceptual impairments are not associated with a particular expressive syndrome or a specific site within the left hemispheric speech cortex. The alternative hypothesis is that phoneme discrimination impairments can be predicted on the basis of specific syndromes or lesion sites. (b) The second hypothesis is that aphasic impairments of perceptual phonemic discriminations are comparable to an impairment of phonemic perception in normal subjects, caused by some form of interference. The alternative hypothesis is that aphasic discrimination deficits are of a different nature than impairments of normal subjects. (c) The third hypothesis is that the reception and production of speech operate independently of each other, and affect vowel discrimination differentially. Alternatively, their operations are closely related, in which case they should be affected in similar manner by an aphasic impairments.

The hypotheses will be tested with respect to the distinction of the feature height in vowels. This distinction appears to pose differential problems in the reception and the production of speech. It has been established by studies in various languages that high-mid distinctions are perceptually closer than mid-low distinctions (cf. matrices in Lafon 1972, p. 303 [French]), Singh and Woods (1971, p. 1863 [English]), and Pols et al. 1969, p. 462 [Dutch]). Such perceptual distances derive from studies of subjective judgements of similarity and from perceptual errors made under noise conditions, and correspond to distances on Terbeek's (1977, p. 122) low–non-low dimension of vowel perception, 1 of 6 dimensions derived by a multi-dimensional scaling technique.

These perceptual distances are in apparent contrast to phonemic discrimination distances in speech production. A vowel substitution matrix for the spontaneous speech and repetition task performance of 5 English-speaking aphasics had shown a greater tendency to substitute low and mid vowels than mid and high vowels (cf. Keller 1978). We may thus assume that in production, high-mid contrasts are greater than mid-low contrasts.

If the 3 hypotheses apply, it is expected (a) that on a perception test, aphasia will impair high-mid distinctions more than mid-low distinctions, and that high-low distinctions would be least impaired, (b) that all aphasic groups will show a similar degree of severity and pattern of impairment on a perceptual vowel discrimination task, and (c) that his pattern will differ from that found in expressive tasks with respect to the differentiation of vowels.

Method

Subjects. The 50 aphasic patients, all native speakers of German (Table 1), were tested with a German version of the Boston Diagnostic Aphasia Examination. On the basis of the diagnostic rating scale of the battery, 4 types of aphasics were distinguished: 12 Broca's aphasics (non-fluent speech with relatively intact auditory comprehension), 12 mixed non-fluent patients (non-fluent speech with severely impaired auditory comprehension, patients that could also be classified as "global aphasics"), 11 Wernicke's aphasics (fluent speech with severely impaired auditory comprehension), and 15 mixed fluent aphasics (fluent speech with relatively intact auditory comprehension, patients that could for the main also be classified as "anomic aphasics"). These groupings resemble the sample subdivisions chosen in Blumstein et al. 1977. Standardized *z*-scores for auditory comprehension, similar to those of the English version of the Boston Diagnostic Aphasia Examination and needed to place patients into various syndrome groups, were derived from the sample itself.

Neuropathologically, the groups did not always reflect results on the Boston Diagnostic Aphasia Examination as expected. Though mixed non-fluent (global) patients did show the expected extensive left hemispheric lesions (established on the basis of CT scan evidence and/or their etiologies), patients with the functional syndromes of Broca's and Wernicke's aphasia often had well documented localization information different from what had been expected. Of the Broca's aphasics, for instance, 3 showed CT scan and operational evidence of apparently exclusive parietal and temporal damage (IK, BM and JS), while a Wernicke's aphasic (WR) had a CT–documented precentral impairment. In view of these findings, the "anterior"-"posterior" distinction is replaced by the functionally–defined "fluent"-"non-fluent" distinction. None of the patients showed functional or neuropathological signs of brain stem or cerebellar lesion.

The patients ranged in age from 23 to 75 years (mean 48.9 years, s.d. 12.9, Broca's: mean 49.8 years, s.d. 10.9; mixed non-fluent: mean 51.1 years, s.d. 14.7; Wernicke's: mean 48.1 years, s.d. 12.0; mixed fluent: mean 47.1 years, s.d. 14.2). The relatively low average age, and the age distribution which differs from that reported for American populations (Obler et al. 1978), may reflect differences in sample composition; a large proportion of our patients were tested in outpatient clinics and rehabilitation centers, and not in chronic care institutions, as were the patients of Obler et al. (1978). There were 10 professionals in the sample, 18 patients had been white collar workers, and 18 patients had been in blue collar occupations. Types of occupation were well-distributed throughout the sample. All patients were tested at least 2 months post insult. The mean time of testing was 31 months (s.d. 47 months) post insult with group means as follows: Broca 34, mixed non-fluent 33, Wernicke 18, and mixed fluent 35 months. All patients were right-handed according to self-report and immediate familial history. The patients were screened for hearing deficiencies in either ear at 40 dB with 250 Hz pure tone, and at 30 dB with 500, 1000, 1500, 2000, and 3000 Hz pure tone.

Table 1. Neuropathologies of the patients in the sample

Patient		Sex	Age	Etiology	Localization	Procedure
BRO*	IK	M	54	CVA	Left temporal-parietal focus	CT scan, EEG
BRO	UV	F	47	CVA	Left frontal focus	Scintiscan
BRO	NB	F	68	CVA	Left temporal focus	EEG
BRO	WK	M	43	Trauma	Theta in speech areas	EEG
BRO	BM	F	60	Meningioma	Left temporal	Operation
BRO	JS	F	52	CVA	L. partial low density	CT scan
BRO	DK	M	46	Aneurysm	Unknown	
BRO	ES	M	33	CVA	Left hemispheric focus	EEG
BRO	JR	M		CVA	Unknown	
BRO	AW	M	34	Trauma	L. precentral low density	CT scan
BRO	AE	F	61	CVA	Unknown	
BRO	FK	M	50	CVA	Unknown	
MNF	WG	M	73	CVA	L. parietal-temporal focus	EEG
MNF	RB	M	41	CVA	Deep. L. parietal-insular lesion	CT scan
MNF	HK	M	46	CVA	Deep L. parietal-insular lesion	CT scan
MNF	WS	M	60	CVA	Extensive left infarct?	Arteriogram
MNF	WK	M	58	Thrombosis	Extensive left infarct?	Arteriogram
MNF	WB	M	32	Unknown		
MNF	JT	M	35	CVA	Left temporal focus	EEG
MNF	PH	M	37	Trauma	Unknown	
MNF	KH	M	40	CVA	L. anterior temporal dysrythmia	EEG
MNF	MW	F	62	Aneurysms	L. and R., operation L.	Operation
MNF	JS	M	54	CVA	Extensive left infarct	Operation
MNF	KR	M	75	CVA	L. peri-insular infarct	CT scan

WER	RR	F	32	Trauma	Left temporal lesion	Operation
WER	EB	M	52	Unknown		
WER	EB	F	55	Trauma	Left temporal lesion	Operation
WER	CK	F	47	CVA	Left temporal focus	Scintiscan
WER	RK	M	52	Trauma	Lesion L. front and occ. poles	CT scan
WER	GP	M	63	CVA	L. temporal-precentral focus	EEG
WER	RK	F	41	Embolus	Unknown	
WER	HU	M	64	CVA	Left hemispheric lesion	Scintiscan
WER	HB	F	37	Trauma	Left hemispheric lesion	Arteriogram
WER	WR	M	29	Trauma	Left precentral lesion	CT scan
WER	HK	M	57	CVA	Postero-temporal lesion	CT scan
MFL	AM	F	44	CVA	L. temporo-basal lesion	CT scan
MFL	BH	F	23	CVA	Left hemispheric lesion	Arteriogram
MFL	FJ	F	28	Angioma	Left temporal bleeding	Operation
MFL	GF	M	25	CVA	Left hemispheric lesion	Arteriogram
MFL	GK	F	53	CVA	Unknown	
MFL	HH	M	64	CVA	Unknown	
MFL	HJ	F	38	Tumor	L. temporal pole resection	Operation
MFL	HM	M	57	CVA	Unknown	
MFL	JM	M	55	Abscess	Left hemispheric focus	EEG
MFL	KF	M	64	CVA	Small peri-insular lesion	CT scan
MFL	KK	M	34	CVA	L. temporal and precentral delta	EEG
MFL	RE	F	52	Angioma	L. parietal bleeding, temporal focus	Operation, EEG
MFL	RJ	M	63	CVA	Unknown	
MFL	KK	M	53	CVA	Slight anormalities left	EEG
MFL	WT	F	54	Embolus	Unknown	

* BRO = Broca's aphasics, MNF = mixed non-fluent aphasics, WER = Wernicke's aphasics, MFL = mixed fluent aphasics

Tasks. Patients were tested on the portions of the Boston Diagnostic Aphasia test dealing with fluency, auditory comprehension, naming, oral reading, repetition, paraphasias, and automatized speech. Furthermore, they were tested with a vowel discrimination task lasting about 12 min. It consisted of a random presentation of 72 pairs of existing German lexemes distinguished solely by a phonemic height difference in the stressed vowel (e.g. lieben–leben "love–live"), and of 72 distractor pairs of the same lexeme given twice (e.g. lieben–lieben "love–love"). We chose existing stimuli over nonsense stimuli for optimal comparability to real speech situations, and because the results for the 2 types of stimuli in Blumstein et al. (1977) had been essentially parallel. Order within pairs was randomized. The stimuli were presented to the patients over earphones at a confortable listening volume at the rate of 1 pair every 5 s. All subjects received the same sequence of stimuli.

The patient's task was to indicate, after each stimulus pair presentation, whether the pair had consisted of two different words or whether it was the same word given twice. He was asked to indicate his answer by pointing either to the word *"verschieden"* (different), printed to one side of a 30 × 21 cm-sized cardboard below a symbol consisting of a red circle and a blue square, or to the word *"gleich"* (same), printed to the other side of the cardboard below a symbol consisting of two red circles. Sides were reversed randomly, so that roughly half the patients had *"verschieden"* to their left, while the other half had it to their right.

There was an initial training period on 10 trial pairs which could be repeated if the patient failed to understand the task. During the presentation of the task stimuli, a single repetition of a stimulus pair was permitted if the patient had missed its first presentation. Patients were scored on whether they had correctly identified the pairs as same or different. All patients tested were capable of performing the task.

Exactly half the patients (25) had sufficient expressive capacity to be tested on an additional repetition task. They were asked to repeat the presented stimulus pair after pointing to the card. They were then scored on whether they had pronounced the first vowels of the stimulus pair correctly, in addition to being scored on the pointing task. Incorrect vowels were noted down and form the basis of the repetition task results.

Stimulus Pairs. The 72 stimulus pairs represent the 3 height distinctions possible in the basic German vowel triangle consisting of the vowels i, e, a, o, u, with both long and short variants (cf. Table 2): high–mid, mid–low, and high–low. Each distinction was represented by 4 sets of 6 stimulus pairs, with each set exemplifying one type of distinction, such as i:–e:, i–e, u:–o:, and u–o for high–mid. The six stimulus pairs for i:–e: were for instance: bieten–beten (offer–pray), lieben–leben (love–live), liegen–legen (lie–lay), siegen–Segen (win–blessing), wieder–weder (again–nor), and Mieter–Meter (tenant–metre). Organized in this manner, half of the 72 stimulus pairs exemplified high–mid distinctions and half are mid–low distinctions. Also, half of the distinctions involved short vowels (/i, e, a, u, o/), while the other half involved long vowels (/i:, e:, a:, u:, o:/). Furthermore, half the distinctions involved front vowels, while the other half involved back vowels. Items for the 72 distractor pairs were chosen from among the 72 stimulus pairs, and from lexemes that satisfied the same /ˈCVCən/ form. Presentation of stimulus and distractor pairs was totally randomized.

Some of stimulus pairs show a semantic similarity in addition to their phonological similarity: "liegen" (lie) and "legen" (lay) are for instance semantically related verbs, differing

Table 2. The basic German vowel triangle, excluding front round vowels /y, ø, œ/ and diphthongs /aj, aw, oj, uj/. Examples: /i:/ lieben (love), /i/ sitzen (sit), /e:/ leben (live), /e/ setzen (set), /a:/ raten (counsel), /a/ fallen (fall), /o:/ Rosen (roses), /o/rosten (rust), /u:/ Buden (booths), /u/ Stunden (hours)

High vowels	i:	i			u:	u
Mid vowels	e:	e			o:	o
Low vowels			a:	a		

only in transitivity, or "sehen" (see) and "sahen" (saw) are the same verb differing only in tense. No effort was made to control for this factor, with the result that pairs with semantic similarity were more or less equally distributed throughout the sample; they represent 25% of the sample, and account for 26.8% of the errors made by aphasic patients. This difference between proportions is not significant at $P<0.05$ by binominal test ($z=0.29$), indicating that the proportion of errors associated with semantic similarity was not different from the proportion of semantically similar word pairs in the stimulus set.

Similarly, the pairs were not controlled for the frequency of occurrence of their constituent lexemes, in part because for many German words, modern frequency measures are not available. However, an informal analysis of errors committed on a number of lexeme pairs for which frequency counts were listed in Kaeding (1898) also indicated no connection between errors made by aphasic patients and the presumed frequency of occurrence of the lexemes in the language. Stimulus pairs consisting of 2 low frequency lexemes did not appear to be associated with more discrimination errors than stimulus pairs consisting of 2 high frequency lexemes (few clear-cut cases of high or low frequency pairs were observed, however).

Another uncontrolled factor was the patients' native dialect. German dialects differ somewhat with respect to phonemic distinctions between various vowels, which could conceivably have influenced the results of the test. The errors obtained from 30 patients who were native speakers of north German dialects were compared to those obtained from 17 patients who were speakers of south German and Austrian dialects. No significant differences were observed between groups with respect to the distribution of errors in the 3 height distinctions ($X^2(2)= 2.58$). An effort had also been made to make the stimuli particularly easy to distinguish: the speaker was a native of the Mainz area with an excellent command of standard German pronunciation and a person familiar with the technique of recording stimuli, and the stimuli were recorded and played back using high quality equipment.

Control Study with Normal Subjects. In order to be able to test the hypothesis of a similarity between an aphasic's auditory perception problem and a normal phonemic discrimination impairment through interference, we produced a second set of stimuli with a midstimulus dB level of 60, masked by a constant white noise of 70 dB. This second set of stimulus pairs was presented to 10 younger (mean age 25.5 years, s.d. 4.9) normal speakers, and to 10 older (mean age 51.7 years, s.d. 7.5) normal speakers, all with hearing levels tested at the same limits as were those of the aphasic patients. The task was the same, except that instead of pointing to a card, subjects were asked to verbally indicate whether a stimulus pair was the same or different. Results from the younger and the older sample were combined, since no significant difference was found with respect to the distribution of discrimination errors in the 3 height conditions ($X^2(2)=1.55$).

Results

Analysis 1: Relationship Between Perception Task and Auditory Comprehension

The initial question was whether the perception task in fact tested phonemic discrimination. This process is presumably part of a larger set of processes mediating the auditory comprehension of linguistic material. A correlation was thus expected between performance on the vowel discrimination task and performance on those tasks in the Boston Diagnostic Aphasia Examination that presuppose phonemic discrimination, such as auditory comprehension and repetition. The question was tested by calculating Pearson *r*'s between aphasic error scores for the 72 stimulus pairs of the phonemic discrimination test and performance on each of the subtests of the aphasia battery. Against expectations, none of the discrimination test–aphasia battery subtest correlations reached significance at the 0.05 level.

Despite this result, it was considered unlikely that the present test did not measure phonemic discrimination. Rather, it was assumed that the discrimination test results were contaminated by factors other than auditory discrimination.

Preliminary analyses of false positive responses (indicating "same" for different stimuli) had revealed a number of systematic differences between patients with severe auditory comprehension impairment and those with slight auditory comprehension impairment. Results for patients with heavy impairment seemed to be marked by excessive guessing behaviour, which was not the case with patients with slight impairment. For instance, patients with heavy auditory impairment tended to give high numbers of false negative responses (responding "different" to same stimuli) and they tended to have similar scores for easy and difficult vowel discriminations. By contrast, patients with slight auditory impairment tended to have low numbers of false negative responses and were seen to show systematic differences with respect to easy and difficult test items.

This difference between patients with slight and severe auditory comprehension impairment could have affected the relation between perceptual discrimination and aphasia battery measures of auditory comprehension. Under this hypothesis, scores from heavily impaired patients would be expected to be distributed somewhat randomly and show no significant correlation to auditory comprehension scores, which would also tend to be randomly distributed. By contrast, slightly impaired patients would be expected show a correlation between vowel discrimination scores and auditory comprehension test scores, since both tests are expected to measure at least in part the same impairment.

To test this hypothesis, two subsamples were constituted one with $N=22$ who scored half a standard deviation or more above the mean in auditory comprehension in the aphasia battery (z-score>0.5), and one with $N=13$ who scored half a standard deviation or less below the mean (z-score<0.5), thus excluding about 30% of the sample closest to the mean. Results of the linear correlation analysis supported our hypothesis. None of the Pearson r's between discrimination errors and performance scores on the aphasia battery subtests of the heavily impaired group reached significance. But in the slightly impaired group, significant correlations were evident for those subtests that imply phoneme discrimination (auditory comprehension: $r=0.43$, $d.f.=20$, $P<0.05$; repetition: $r=-0.57$, $d.f.=20$, $P<0.01$). Subtests that do not imply perceptual phoneme discrimination, such as fluency, naming, oral rading, paraphasias, and automatized speech, did not show any significant correlations with the vowel discrimination test. We may thus conclude that the present vowel perception task probably does test a patient's ability to discriminate between vowels, but only if the patient is not severely impaired in auditory comprehension.

The lack of correlation for the scores of patients with severe auditory comprehension deficits provides some support for the notion that these patients from a different test population, marked by excessive guessing behaviour and grossly insufficient phonemic discrimination. It is possible that this form of neurolinguistic processing has its origin in differential neurological adaptation to the lesion causing the pathology; it has recently been demonstrated that severely impaired aphasic patients show different blood flow patterns than slightly impaired patients (Meyer et al. 1980, p. 67). Patients with severe infarctions were observed to decrease blood flow to the affected left hemisphere areas when performing speech tasks, while normal subjects and patients with moderate or slight infarctions in speech areas show increased of blood flow. As in our findings, slightly impaired patients show behaviour similar to that of normal subjects, while severely impaired patients show abnormal patterns of behaviour.

Analysis 2: The Severity of the Perceptual Impairment

In this analysis, the hypothesis that the severity of impairment on the vowel discrimination test is associated neither with a particular expressive syndrome nor a specific site within the left hemispheric speech areas was investigated. This is tested with reference to the severity of the discrimination deficit found with different syndromes and lesion sites. Both false positive and false negative responses are evaluated in this analysis, since both types of response are assumed to be indicative of the severity of the discrimination impairment (Table 3).

Aphasics made relatively few errors on the discrimination test. Still, only 5 of the 50 patients showed a perfect score. (Normal subjects experienced no difficulty at all under similar test conditions.) Such comparable ease of discrimination for vowels (as against consonants) is also apparent in normal hearing under white noise conditions (Lafon 1972, p. 303).

A Kruskal-Wallis test of the 4 aphasia groups showed no significant difference among the error distributions of the groups ($H=4.43$ with $d.f.=3$ and corrected for rank ties, approximating X^2 (3)). (The Kruskal-Wallis rank test was chosen because of considerable skew in the data distribution.) All the same, it was observed that 2 aphasia groups showed a relatively great impairment, mixed non-fluent (global) aphasics (mean errors 13.5, s.d. 15.3) and Wernicke's aphasics (mean errors 8.6, s.d. 2.94), in contrast to Broca's aphasics (mean errors 4.7, s.d. 6.05), and mixed fluent aphasics (mean errors 4.3, s.d. 3.7). The 2 more heavily impaired groups share the criterion of a depressed score on the auditory comprehension subtests of the Boston Diagnostic Aphasia Examination, while they differ with respect to the expressive criteria making up to composite index of fluency.

The patient's error scores were thus rearranged to reflect the criteria of fluency and comprehension. Differences between fluent and non-fluent aphasics were not significant (as measured by the Kruskal-Wallis test; $d.f.=1$, $H=-6.86$), while they were significant for the performance on the auditory comprehension criterion (H 4.06, $d.f.=1$, $P<0.05$). Patients who scored low on the auditory comprehension subtest of the aphasia battery did significantly worse in phoneme discrimination than those who scored high.

Aphasic performance on auditory reception tests has also been related to age (Sheehan et al. 1973). An analysis of this factor showed a trend towards decreased performance with increasing age (20–45 years mean 5.5, 46–55 years mean 7.81, 55–80 years mean 10.13). However, differences between age groups were not significant when measured with the Kruskal-Wallis test ($H=-4.58$, $d.f.=2$).

The scores were furthermore related to documented and suspected lesion site. Since a preliminary analysis of discrimination error scores associated with neurological lesions verified by CT scans and operational evidence had revealed

Table 3. Summary statistics for auditory discrimination errors[a]

Factor	Mean errors	s.d.	Median	N	Kruskal-Wallis value and *d.f.*	Significance
Aphasia Group						
Broca	4.7	6.1	2	12	4.43	N.S.
Mixed non-fluent	13.5	15.3	9	12	$d.f.=3$	
Wernicke	8.6	2.9	8	11		
Mixed fluent	4.3	3.7	3	15		
Fluency[b]						
Good fluency	6.3	5.1	6	25	−6.86	N.S.
Bad fluency	8.8	12.1	7	25	$d.f.=1$	
Auditory Comprehension[b]						
Good comprehension	4.4	4.8	3	27	4.06	$P<0.05$
Bad comprehension	11.2	11.8	8	23	$d.f.=1$	
Age						
20–45 years	5.5	3.8	7	18	−4.58	N.S.
46–55 years	7.8	9.7	5	16	$d.f.=2$	
56–80 years	10.1	12.9	8	15		
Lesion Site						
Precentral/anterotemporal	3.3	3.3	2	7	0.11	N.S.
Parietal/parietotemporal	8.3	7.1	3	4	$d.f.=4$	
Temporal	5.4	4.8	3	8		
Peri-insular	15.6	18.8	8	8		
Unspecified, left hemisphere	6.8	3.4	7	6		

[a] Out of 144 discrimination pairs

[b] Differentiation of good and bad fluency or good and bad comprehension with reference to mean scores obtained by the entire sample ($N=50$) on subtests of the Boston Diagnostic Aphasia Battery

no systematic differences from scores related to lesions verified by EEG and scintiscan, the 2 sets of data are reported together. The group with unspecified left hemisphere lesions appears to form a heterogeneous group with respect to site and severity of lesion, as judged by patient's medical reports. A Kruskal-Wallis test revealed no significant difference among the 5 lesion site groups ($H=0.11$, $d.f.=4$,).

These results again suggest that performance on an auditory comprehension test is the only reliable predictor of the severity of a patient's vowel discrimination deficit. Neither fluency, age, nor lesion site appears to relate directly to performance on the vowel discrimination test. On the basis of the results of the previous analysis, this result can be interpreted in the sense that at least in patients with slight auditory comprehension impairment, auditory comprehension presupposes relatively good performance in vowel discrimination.

Table 4. Chi-square distributions of discrimination errors[a]

Group compared with normal subjects	N errors	X^2 (2)	P
All Aphasics	214	9.27	<0.01
Fluency[b]			
Good fluency	94	9.04	<0.01
Bad fluency	120	11.16	<0.01
Auditory Comprehension[b]			
Good comprehension	82	4.15	N.S.
Bad comprehension	132	14.13	<0.001

[a] Comparisons of distributions of false negative responses in the high-mid, mid-low, and high-low conditions for normal subjects under a −10 dB white noise condition and for various groups of aphasic patients with the same stimuli, but without noise

[b] Differentiation of good and bad fluency and good and bad auditory comprehension with reference to mean scores obtained by the entire sample ($N=50$) on subtests of the Boston Diagnostic Aphasia Battery

Analysis 3: Perceptual Impairment on Vowel Height in Aphasics and Normals

The next analysis addresses the hypothesis that aphasic impairment of vowel discrimination is comparable to a general impairment of vowel perception in normal speakers, caused by some form of interference. This was tested by comparing aphasic false positive responses for high-mid, mid-low, and high-low vowel distinctions to those made by normals when tested on the same stimuli masked by white noise. Under the "noisy channel" hypothesis, there should be no significant difference between aphasics and normals with respect to the error distribution in the different conditions. On the basis of previous findings for normal subjects (see Introduction), we expected that aphasic performance would parallel a relatively high perceptual impairment shown by normals on high-mid distinctions and a relatively low impairment on mid-low distinctions. Minimal impairment was expected for the relatively great high-low distinctions.

Discrimination test results from the normal sample involving a −10 dB S/N midstimulus white noise condition were used to estimate typical noise impairment for normal subjects on the 3 discrimination conditions. The resulting error proportions ($N=70$) of 77% for high-mid distinctions, 20% for mid-low distinctions and 3% for high-low distinctions compare well with proportions reported in other studies at this S/N ratio.

These proportions were compared to error proportions from the complete aphasic sample, from fluent and non-fluent groups, and from patients with slight and severe auditory impairment. No meaningful comparison was possible with individual aphasic syndromes, since there were too few error scores in the mid-low and high-low vowel discrimination conditions.

Chi-square tests indicate that only patients with slight auditory impairment show the expected error distribution (Table 4). Results from the complete aphasic sample and from the 2 subsamples constituted on the basis of the fluent/

non-fluent distinction showed significant differences from normal error distributions (normal/all aphasics: $X^2(2)=9.27$, $P<0.01$; normal/fluent: $X^2(2)=11.16$, $P<0.01$; normal/non-fluent: $X^2(2)=9.04$, $P<0.01$).

However, when the error distributions of normal subjects were compared to those of patients who had scored above and below the mean on the auditory comprehension test, the patients with scores above the mean behaved much like normals under noise condition; the distribution of their errors in the 3 discrimination conditions ($N=82$) was not significantly different from that of normals ($X^2(2)=4.15$). Patients with scores below the mean in auditory comprehension ($N=132$) showed significant differences in their error distribution ($X^2(2)=14.13$, $P<0.001$).

Pairwise aphasic-normal comparisons for individual conditions revealed that errors in the high–low condition can account for the reported difference between patients with slight and severe auditory comprehension deficit. None of the pairwise X^2 comparisons in the high-mid and mid-low conditions for slight and severe aphasics reached significance. In the high-low condition, however, severely impaired patients showed significantly more errors than normals. While a nonsignificant $X^2(1)$ of 1.976 was found for slightly impaired aphasics, a significant $X^2(1)$ of 11.423 ($P<0.001$) was observed for the severely impaired patients.

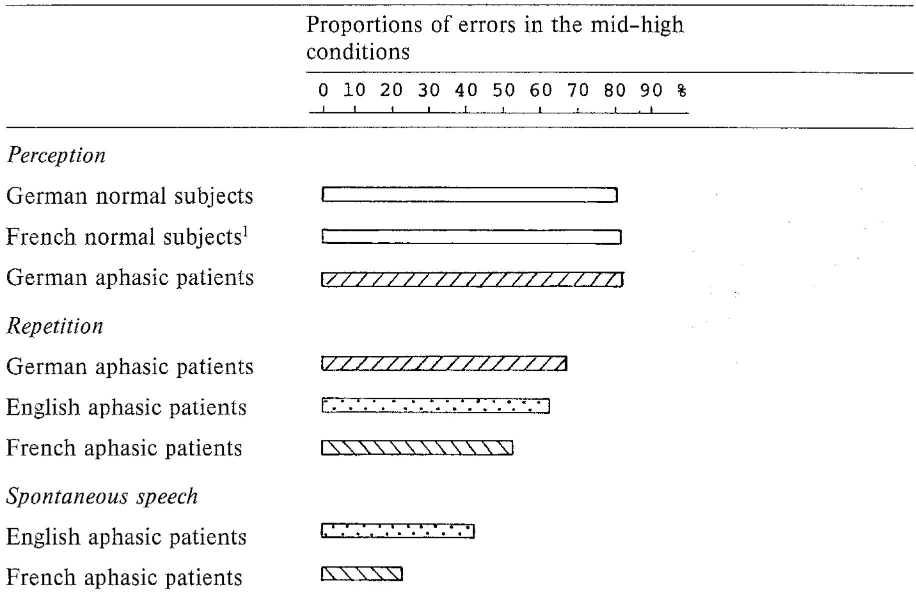
To sum up, aphasic patients with slight auditory comprehension deficit behave in all conditions like normal subjects with white noise impairment at −10 dB S/N, while aphasic patients with severe auditory comprehension deficit behave as normals in high–mid and mid–low conditions, but show an extraordinary impairment in the high–low condition. This last condition is marked by a relatively great phonemic difference between stimuli.

The present findings can be interpreted within the "noisy channel" hypothesis. Although the test was not performed directly, it can be assumed that aphasics with a serious impairment of auditory comprehension behave as normals would if the levels of white noise were increased even more, i.e. they engage in considerable guessing behaviour. This is evident from the usual effects of manipulating S/N ratios. As an example, Miller and Nicely's (1955) subjects had very little difficulty in distinguishing voiced from unvoiced stops at $S/N=-6$ dB, a noise condition which led to considerable confusions between unvoiced stops and unvoiced fricatives. Yet at $S/N=-18$ dB, this advantage had all but disappeared. Confusions between voiced and unvoiced stops were nearly as frequent as those between unvoiced stops and fricatives presumably because the subjects' guessing behaviour had increased. Therefore, differences between slight and severe auditory comprehension impairments probably reflect first, that the S/N level chosen for the normal sample (−10 dB) corresponds best to the discrimination difficulty of slightly impaired patients, and second, that patients with severe impairment probably engage in increased guessing behaviour.

Analysis 4: Patterns of Breakdown in Perception and Production

The last analysis concerns the hypothesis that vowel discrimination is a separate process in speech reception and production. If the phonological impairments measured by the present perception task disturb a single phonological process subserving both perception and production, there should be no difference be-

Table 5. Proportions of errors in the high-mid condition when high-mid confusions are compared to mid-low confusions between the vowels /i:, I, e:, ε, a, o:, c, u:, ζ/. A variety of samples testing perceptual discrimination, repetition, and expressive discrimination as measured by phoneme substitutions from anumber of sources and languages are presented (see text)



[1] From Lafon (1972)

tween perception and production tasks with respect to proportions of errors on high-mid and mid-low distinctions. But if the patterns systematically, we may assume that aphasia can impair perceptual processes independently of production processes.

The difference between perceptual and productive processes was first assessed by examining false positive response distributions on the discrimination task and those on the repetition task of those patients who had performed both tasks. A significant difference in distributions was assumed to be due to the added expressive difficulty in performing the repetition task. Since a group of English-speaking aphasics had previously shown a higher proportion of excessive paradigmatic vowel substitutions in the mid-low condition than in the high-mid condition (see Introduction), it was expected that repetition would show a smaller proportion of errors in the high-mid condition than would phoneme discrimination.

The various samples used for this analysis were constituted as follows (see Table 5): (1) A sample of 177 errors for German aphasic perception is based on the vowel discrimination errors of the 25 patients in our study who had made repetition errors in addition to discrimination errors. The sample's distribution of errors in the various height conditions is comparable to that of the complete sample ($X^2(2)=2.73$). (2) For comparison, 2 normal discrimination samples for German and French are reported. They are based on the 70 errors of the 20 normal subjects of our sample and on the 957 discrimination errors on unrounded and non-nasal vowels of 26 normal French subjects reported by Lafon (1972). (3) A sample of 205 errors for German repetition was derived from the 25 patients of our study who had made repetition errors in addition to discrimination errors.

The results of the comparison between vowel perception (discrimination) and repetition agreed with our expectations. 82.5% of the aphasics' 177 errors on the vowel discrimination task occurred in the high-mid condition (vs. 17.5% in the mid-low condition), but only 70% of the aphasics' 205 repetition errors occurred in the high-mid condition (30% in the mid-low condition). The patterns differed reliably, ($X^2(1)=20.5$, $P<0.001$). Furthermore, the difference between impairments in the repetition and discrimination tasks is in the predicted direction.

As a second test of our hypothesis, we examined samples of spontaneous speech and repetition errors from English and French Canadian aphasic patients. (There had not been enough time to gather a corpus of German aphasic vowel substitutions in spontaneous speech.) The first sample is based on 64 repetition and 22 spontaneous speech errors from the corpus of vowel substitutions reported in Keller (1975 and 1978; 5 Broca's aphasics). The second sample is constituted of 73 paradigmatic errors in spontaneous speech and 174 errors in repetition from a corpus of successive phonemic approximations reported in Joanette et al. (1980; 5 Broca's, 8 conduction and 3 Wernicke's aphasics). (The range of severity and age of the German, English and French patient populations appeared to be comparable.)

Vowel substitutions in the various expressive tasks were collected for the sounds bearing the closest resemblance to the German vowels of the present perception task (/i:, i, e:, e, a:, a, o:, o, u:, u/). All substitution errors along the paradigmatic axis were counted, regardless of whether syntagmatic motivation for the error was also evident or not. Substitution frequencies between high and mid vowels, between mid and low vowels, and between high and low vowels were counted, after standardization for frequency of occurrence in the language (cf. Keller 1978, p. 268). Separate comparisons of proportions of standardized errors in the high-mid condition (vs. the mid-low condition) were performed for the two languages by means of the binomial test. In both languages, the difference between proportions for repetition and spontaneous speech were significant (English: $z=1.72$, $P<0.05$; French: $z=4.77$, $P<0.001$). The direction of the difference is in the predicted direction in both languages.

Aphasia thus seems to impair phonemic discrimination in a different manner in perception from the way it impairs it in production. The high-mid distinctions tend to be the most impaired in perception, while in production, it is the distinctions between mid and low vowels that are the most confused in literal paraphasias. Repetition takes an intermediate position between the two, presumably because it is a task that involves both production and perception processes.

Discussion

Three hypotheses concerning receptive impairments in aphasia were tested with respect to the discrimination of high, mid and low vowels. Results were in support of all 3 hypotheses. First, the severity of impairment on the vowel discrimination test does not seem to be associated with particular aphasic syndromes or specific lesion sites within the left hemispheric speech areas. The degree of the general auditory comprehension deficit was the only successful predictor of the discrimination impairment. Second, proportions of false negative responses of aphasic patients with slight auditory impairment involving high–mid, mid–low, and high–low distinctions of vowels were comparable to error proportions of normal subjects under conditions of white noise. This suggests that aphasic impairments of vowel discrimination may be comparable to a general impairment of perception in a normal speaker, caused by some form of interference. And third, differences between false negative response patterns for high–mid and mid–low distinctions in perception, repetition and spontaneous speech suggest that with respect to this type of discriminative function, reception and production of speech operate independently of each other.

The 3 different analyses of our data have also shown that patients with a severe deficit in auditory comprehension perform differently in a vowel discrimination task than patients with a slight comprehension deficit. There were several indices that the performance of patients with severe auditory comprehension deficit was marked by guessing behaviour: their discrimination scores did not correlate with subtests of the aphasia battery that presuppose phoneme discrimination and they showed indiscriminantly high confusion rates on relatively easy vowel distinctions. It is likely that this difference reflects a fundamental difference in adaptation to the aphasic lesion.

Our conclusions differ somewhat from those reached by Blumstein et al. (1977) on the basis of their analysis of errors on a very similar test of consonant discriminations. They found significant differences between aphasic syndromes with respect to overall severity and impairment on place of articulation. Mixed anterior patients (comparable to our mixed non-fluent patients) performed worse –on all consonant discriminations, while Wernicke's aphasics, with a more severe comprehension deficit, did better. And only posterior (i.e. fluent) aphasics showed particular difficulties with discriminations of place of articulation. By contrast, we found that Wernicke's aphasics, like mixed non-fluent (in fact, global) aphasics, showed more impairment on vowel discrimination than either Broca's or mixed fluent (i.e. mostly anomic) aphasics. This was related to the fact that mixed non-fluent and Wernicke's aphasics share a severe auditory comprehension deficit which we found to be directly related to the vowel discrimination impairment on a number of measures.

To explain this difference between our results and those of Blumstein et al., two possibilities come to mind. First, the sample composition is somewhat different in the 2 studies. While we determined aphasic syndromes strictly on behavioural evidence (the Goodlass and Kaplan battery), Blumstein et al. based their subdivision primarily on localisation information, and only in the case of anterior aphasics, used the degree of auditory comprehension deficit as distinguishing feature between Broca's and mixed anterior aphasics. In view of their smaller total N (25 patients as against our 50), this difference could have contributed to the difference between findings.

The other possibility is that vowel discrimination is of a fundamentally different nature than consonant discrimination. It may be that vowels are perceived and distinguished in a much more diffuse area of the brain than are consonants.

This would lead to specific impairments at certain lesions sites for consonants, and to a more or less equal impairment of vowels at all aphasic lesion sites.

Despite the fairly clear results we obtained on this test, two caveats are in order. Slight, statistically nonsignificant tendencies in favour of a lesser vowel discrimination impairment were observed for patients with symptoms of Broca's aphasia and for patients with precental and antero-temporal lesions. It may thus be that patients with neurologically and functionally classic Broca's syndromes are less likely to be impaired in vowel perception than are other aphasics (as are Broca's aphasics of Blumstein et al.). Some support for this notion can also be derived from Hécaen and Consoli's (1973) findings that only 4 of their 17 patients with precentral lesions experienced any difficulty at all in phonemic discrimination.

Furthermore, it should be emphasized that the concept of "noise in the perceptual channel" is to be taken to mean any general interference with normal perceptual functioning, such as the presence of strong background noise, a deflection of attention, tiredness, or even a short-term recall condition. As an example, Wickelgren (1965) asked his subjects to listen to test words (such as /zIk/ or /lIk/), copy them down, cover them up, and recall them. Of the 579 words involving vowel distinctions between /I/, /ε/, and /a/ which produced errors in recall, 66.7% involved confusions of high and mid vowels, while 33.3% involved confusions of mid and low vowels (p. 585), essentially the same error pattern as was noted for white noise perceptual conditions. Moreover, aphasic autoreports concerning their perceptual difficulties bear greater similarity to normals reporting tiredness than to reports of strong background noise.

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