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LEFT EAR PERFORMANCE IN DICHOTIC LISTENING FOLLOWING COMMISSUROTOMY

SALLY P. SPRINGER, JOHN SIDTIS, DONALD WILSON and MICHAEL S. GAZZANIGA

State University of New York at Stony Brook, New York 11794, U.S.A. and
Dartmouth Medical School, Hanover, New Hampshire, U.S.A.

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Abstract—Contribution of the left ear stimulus to dichotic listening performance following commissurotomy was studied in five patients. In two tasks, subjects were asked to identify in writing both members of a pair of competing stimuli, either digits or CV syllables. A third task required subjects to integrate high and low frequency components of a single word presented dichotically. Left ear performance was at chance level for CV syllables but exceeded 80% for four out of five patients on the digit stimuli. All patients showed evidence of being able to utilize left ear information in the dichotic fusion task. Results indicate that apparent supression of left ear material in the dichotic task is a function of spectral-temporal overlap between competing stimuli.

KIMURA's [1, 2] neurological model of the mechanisms underlying ear asymmetries observed during dichotic listening has subsequently generated a vast quantity of research involving dichotic listening as a tool for investigating functional brain asymmetries (for reviews, see BERLIN and MCNEIL [3] and HAGGARD [4]). Much of the utility of the dichotic paradigm in this context is predicated upon the assumption that it provides a means of lateralizing an auditory input to one hemisphere, in spite of the fact that the auditory pathways project bilaterally from the level of the superior olivary nucleus upward [5]. KIMURA [2] proposed that ipsilateral ear-cortex projections are partially occluded during dichotic presentation so that the most functional routes are from each ear to the contralateral hemisphere. She attributed the right ear advantage observed among neurologically intact right handed subjects to the superior connections from the right ear to the hemisphere specialized for speech and language. In contrast, the left ear input would be projected to the left hemisphere along the occluded ipsilateral pathways, placing it at a disadvantage relative to the right ear.

While KIMURA [2] did not consider the role of the commissural pathways in mediating identification of the left ear inputs, SPARKS and GESCHWIND [6] subsequently suggested that the most likely route for the left ear items was first to the right hemisphere followed by callosal transfer to the left hemisphere speech centers. They cited two pieces of evidence in support of their argument. First, temporal lobe lesions in the nondominant hemisphere had been shown to produce deficits in the report of material presented to the contralateral ear [7]. If left ear projections to the left hemisphere were primarily ipsilateral, they noted, left ear performance would not be expected to decrease as a consequence of right hemisphere damage. Second, a patient tested by SPARKS and GESCHWIND [6] who had undergone sectioning of the corpus callosum for relief of intractable epilepsy showed a right ear advantage considerably greater than that reported for neurologically intact subjects. Sparks and Geschwind used the term "extinction" to refer to the very low level of performance for left ear inputs in this patient. Again, disruption of left ear performance would not be expected if the ipsilateral pathways were the major source of information from the left ear. These two pieces of data thus implicate the role of the corpus callosum in the identification of left ear inputs and argue that ipsilaterally transmitted information plays a minor role in the dichotic task.

Subsequent research with other patients has verified the SPARKS and GESCHWIND [6] finding that the right ear advantage is greatly magnified following commissurotomy [8–10], and it is these observations that are primarily responsible for widespread acceptance of a modified version of Kimura's seminal model. Split-brain research is frequently cited (e.g. [11–13]) as support for almost complete supression or extinction of ipsilaterally transmitted information under dichotic presentation, in lieu of the partial occlusion postulated by KIMURA [2].

In the course of our investigations of dichotic listening following commissurotomy, however, we observed that patients would occasionally perform in a manner that this model of the dichotic task would not allow. For example, we noted in earlier papers [9, 14] that patients were able to identify, with a spoken response, the left ear members of dichotically presented pairs of animal names. Since extensive testing of these patients had indicated that they lacked the ability to initiate speech from the right hemisphere, the extent to which they could incorporate the left ear inputs into a verbal report reflected the availability of the left ear items to the left hemisphere. With the region of the corpus callosum believed to be responsible for interhemispheric transfer of auditory material sectioned in each case [9], it seemed reasonable to attribute report from the left ear to ipsilateral transmission of information.

A closer examination of some of the earlier split brain findings revealed signs of a similar phenomenon. SPARKS and GESCHWIND [6] report that upon retesting with dichotic digits, their patient's left ear score rose from 0 to 35% correct identification. MILNER *et al.* [8] note that while five of the patients tested in their study had near zero scores in the left ear, the remaining two reported about 1/3 as many items from the left ear as from the right ear.

In the present report we present a more systematic set of findings which suggest re-examination of the assumption that dichotic presentation of speech stimuli results in the extinction of ipsilateral information. Three different dichotic tasks were employed with five commissurotomy patients to determine the extent to which left ear material would be utilized. In two of the tasks, subjects were required to identify both members of a competing pair of messages. Consonant–vowel (CV) syllables and digits were the stimuli used. In the third task, the two simultaneous inputs were complementary in that each formed a different part of the spectral information comprising a single stimulus. It is a well established result that two separated frequency bands presented to the same ear produce a higher level of intelligibility than would be expected when each is presented alone [15]; neurologically intact subjects show the improvement in intelligibility with dichotic presentation as well [16, 17]. A similar "dichotic fusion" effect in commissurotomy patients would indicate that these subjects are able to integrate information from the left and right ears under conditions of simultaneous presentation.

METHOD

Subjects

Five right-handed male subjects, operated on by Dr. Donald Wilson of the Dartmouth Medical School in an attempt to prevent the interhemispheric spread of epileptic seizures, were included in the present study. J. H., age 26 at the time of surgery, had complete forebrain commissurotomy that included the anterior commissure. J.Kn., operated on at age 16, was originally believed to have had a complete section of the corpus callosum and anterior commissure, although subsequent behavioral testing has indicated the existence of remaining fibers capable of interhemispheric transfer of visual information. Detailed neurological histories of J.H. and J.Kn. may be found in WILSON, REEVES, GAZZANIGA and CULVER [18]. D.H. underwent complete sectioning of the corpus callosum sparing the anterior commissure at the age of 15. D.S. had frontal callosotomy that included the rostrum, genu, and anterior half of the corpus callosum at the age of 23. One year later posterior callostomy was performed. D.H. and D.S. are discussed in further detail by WILSON, REEVES and GAZZANIGA [19]. T.C. is the most recent surgical case in the Wilson series. No signs of neurological disorder were evident in this patient until seizures began at age nine. The seizures were controlled with medication for 6 yr until T.C. experienced a hairline linear skull fracture after falling off a diving board. From that point seizures became intractable, with the EEG revealing no consistent focal or lateralizing features suggesting that the epileptic activity arose from a deep midline source. Complete section of the corpus callosum sparing the anterior commissure was performed on this patient.

J.H., J.Kn., and D.H. were each tested in the present study 1 yr or more following surgery. D.S. was tested three months after this last operation while T.C. was seen on day 11 of the postoperative recovery period. Audiometric testing of each patient indicated bilaterally normal hearing in the speech range.

Control subjects were undergraduates fulfilling an introductory psychology course requirement at SUNY Stony Brook. Each was right handed and had bilaterally normal hearing at the speech frequencies.

Stimuli

The dichotic CV syllable test in this study consisted of stimulus pairs selected from among the following six syllables: /pa, ta, ka, ba, da, ga/. These syllables were produced by a female speaker, edited to a duration of 300 msec, and aligned for simultaneous onset and offset on two channels of audio tape using the PCM system at the Haskins Laboratories. Pairs of digits were created in a similar fashion. Produced by a female speaker, the digits one through nine (omitting seven) were edited to a duration of 450 msec and aligned for simultaneous dichotic presentation on two channels of audio tape using the VOCAL system at the Waisman Center for Mental Retardation at the University of Wisconsin. VOCAL was patterned after the Haskins system and produces dichotic stimuli of comparable high quality. For both the CV syllables and digits, a trial consisted of the presentation of a pair of different items (no item was ever paired with itself). The CV syllable test consisted of four blocks of 30 trials with each block representing a complete randomization of CV pairs while the digits test contained 56 trials. In each test, the inter-trial interval was 6 sec.

The fusion test was prepared by first recording words read by a female speaker from the CID auditory tests [20] W-1 (list A) and W-22 (lists 1A–4A) on two channels of audio tape. This recording contained 224 words. Each channel was then simultaneously played through separate bandpass filters (Rockland Model 1042–F) with characteristic attenuation of 48 dB/octave. The output from the filters was recorded on a second audio tape resulting in a simultaneous representation of the high and low frequency spectra on separate audio tape tracks. For the low frequency channel, the nominal pass band had a range of 560–760 Hz, with a center frequency of 656 Hz and 3 dB down points of 773 and 543 Hz. For the high frequency channel, the nominal pass band had a range of 3350–3450 Hz with a center frequency of 3392 Hz and 3 dB down points of 3030 and 3776 Hz. These channels were selectively gated and recorded on a third audio tape such that 112 of the trials consisted of both channels presented dichotically, while the remaining 112 trials were presented monaurally with half consisting of information presented to the right ear, the remaining half to the left ear. Spectral information was also counterbalanced across ears. Fifty-six of the dichotic trials were made up of low frequency information presented to the left ear and high frequency information presented to the right ear. The remaining 56 dichotic trials consisted of the reverse spectrum–ear combinations. In the monaural condition, there were 28 trials of each combination of frequency spectrum and ear (i.e. low–left, low–right, high–left, high–right). Two such tapes were made by gating high and low frequency channels to control for possible differences between words selected for dichotic or monaural presentation. Words presented dichotically on one form of the test were used as monaural items on the other. In both forms of the test, the order of dichotic and monaural trials was randomized with each trial separated by a 5 sec interval.

Each of the test tapes were presented to subjects on a Revox A77 stereo tape recorder through matched earphones (Telephonics TDH-39) equipped with MX 41/AR ear cushions. Audio channels were calibrated using the A scale on a sound level meter (General Radio Company Type 1565-A) and earphone coupler (Type 1560–P83). The CV syllables and digits were played at approximately 80 dB SPL while the fusion items were played at approximately 60 dB SPL.

Procedure

Patients were generally tested first with the digits stimuli, followed by the CV syllables and the two forms of the fusion test. In two cases, D.S. and T.C., testing was carried out in a single day. For the other patients, the tests were administered in several sessions on different days. The digits test was initiated by having subjects verbally identify each of the eight digits from a list which remained in front of them during testing. They were then told that they would hear two of these digits played simultaneously and were instructed to write the digits they heard on a response sheet. All subjects were encouraged to enter two responses after every trial even if the second response required a guess.

The CV syllable test was begun in a similar fashion. A list of the six syllables was placed in front of the subject who was then required to verbally identify each one. This was followed by binaural presentation of the syllables one at a time in a random sequence. Each subject met the criterion of correctly identifying 10 out of 10 syllables. Subjects were then told that they would hear two different syllables at once and that they should write both syllables on the response sheet. Two responses per trial were encouraged.

The fusion test began with instructions stating that a list of common words would be played, although some of them might be difficult to hear. Subjects were asked to identify each word out loud immediately following its presentation; they were told to guess if they were uncertain about the identity of a particular word.

In each of the tests, all subjects with the exception of T.C. were able to respond during the standard inter-stimulus intervals. Because of mild post-operative dysphasia present in T.C. at the time of testing, the stimulus tapes were stopped after each trial until either a response was made or the subject indicated that he wished to go on to the next trial.

Earphone orientation was counterbalanced within subjects for each test to control for any possible imbalances between audio channels or side of earphone.

RESULTS

Results from the CV syllable and digits tasks are given in Table 1. All subjects completed the digits test. Normal subjects were given eight blocks of CV syllable trials (240 trials) as was D.S. Patient D. H. completed four blocks of CV syllables, J. H. and T. C. completed two blocks, and J. Kn. completed one. For each patient, identification of left ear digits is higher, in most cases considerably so, than identification of left ear syllables. Right ear performance is roughly comparable for the two stimulus types, approaching a performance ceiling of 100%. The index of laterality we employed, (R—L)/(R+L), reflects this difference in left ear performance as the relative advantage of one ear over the other.

TABLE 1. Per cent correct identification and laterality indices for the digit and syllable dichotic tests

	Digits			CV syllables		
Subjects	Left ear	Right ear	Laterality index	Left ear	Right ear	Laterality index
J.H.	84	100	0.087	22	97	0.630
J.Kn.	82	98	0.089	03	93	0.937
D.H.	91	100	0.047	37	93	0.431
D.S.	88	100	0.064	21	93	0.632
T.C.	23	96	0.613	15	75	0.667
Normals ($N = 10$)	100	100	0.000	65	78	0.091

Data from the dichotic fusion task are given in Table 2. All scores represent the mean of the subject's performance on the two forms of the fusion test. The percentage of correct identifications for monaurally presented items as a function of ear of presentation and frequency are given in the first four columns. Since no effort was made to equate the high and low frequency information in terms of their contribution to total performance, we were not surprised to find that monaural identification rate in the control subjects is significantly higher for the high frequency information in comparison to the low pass information ($F = 177.75$; $df = 1, 18$; $P < 0.001$). While this difference also appears in the split-brain subjects ($F = 20.20$; $df = 1, 4$; $P < 0.05$), the increased effectiveness of the high frequency information is due to a significant interaction with ear ($F = 36.21$; $df = 1, 4$; $P < 0.005$). Identification is better on high frequency information only when that information is presented to the right ear.

TABLE 2. Per cent correct identification on dichotic fusion test

	Monaural				Dichotic	
	Left ear		Right ear		Predicted	Obtained
Subject	Low	High	Low	High	dichotic	dichotic
J.H.	12.50	14.29	21.43	55.36	47.42	70.54
J.Kn.	8.93	8.93	7.14	33.93	27.81	46.43
D.H.	5.43	16.27	17.86	37.50	36.08	56.02
D.S.	37.50	39.29	21.43	48.21	59.60	79.47
T.C.*	35.71	25.00	21.43	35.71	49.87	62.50
Normals (N=20)	18.93	53.39	17.50	51.25	61.08	81.24

* The scores for T.C. represent his performance on one form of the fusion test only. The second form was not administered to this patient.

The predicted identification rate on fusion trials assuming no integration of information from the two ears was obtained from the identification probabilities for each band pass under monaural presentation using a probability summation calculation. This is simply the sum of the probabilities of correctly identifying a stimulus on the basis of monaural information minus the product of those probabilities. The predicted values thus generated and the actual obtained per cent correct identification for the fusion trials are given in the last two columns of Table 2. The obtained value exceeded the predicted score in every case indicating that integration of information from the two ears had occurred.

DISCUSSION

Results of the present investigation indicate that the extent to which subjects show apparent extinction of the left ear member of dichotically presented stimulus pairs varies quite dramatically as a function of the type of stimulus used. Dichotically presented CV syllables displayed a massive right ear advantage for each patient, while the ear asymmetry with digits as stimuli was considerably reduced. In four out of five cases, report of digits presented to the left ear was over 80% correct.

While one may at first be tempted to explain these results in terms of the differential ability of the right hemisphere to process digits as opposed to CV syllables, it is important to remember that written report was obtained in the digits task as well as the CV task, thereby restricting output to the left hemisphere. Thus, while there may well be differences in the capacity of the right hemisphere to deal with these stimuli, such differences cannot be reflected in the present data.

Although the dichotic CV and digit stimuli were aligned according to similar criteria to achieve simultaneity of onset and offset within each stimulus pair, the acoustic structure of the CV syllable pairs permits a considerably greater degree of spectral-temporal overlap within a stimulus pair than does the digit stimuli that are quite heterogeneous in terms of phonetic composition. The degree of apparent "suppression" of the left ear input may well be a function of the extent to which that stimulus competes, cortically or subcortically, on an instant by instant basis with a right ear stimulus similar to it both spectrally and temporally.

Additional support for the importance of acoustic parameters in dichotic listening research has been provided by BERLIN and his colleagues [18]. In an interesting set of experiments, BERLIN *et al.* [18] studied temporal lobectomies and hemispherectomies who typically show very poor identification of dichotically presented CV syllables in the ear contralateral to the lesion (the weak ear). Monaural identification, however, is generally found to be good for both ears in these subjects. Berlin *et al.* sought to determine the acoustic characteristics of stimuli which, when delivered to the ear ipsilateral to the lesion, could disrupt identification of CV syllables delivered simultaneously to the weak ear. Bleat stimuli, composed of isolated second and third formants of the three formant synthetic CVs, produced greater interference with weak ear identification of CVs than did vowel stimuli. Thus the stimulus type most like the CV syllables produced the greatest suppression, leading BERLIN *et al.* [21] to conclude that "suppression of the weak ear was in part a consequence of the interaction of the auditory features of the dichotic signals" (p. 189).

Performance of commissurotomy patients in the fusion test also supports this analysis. Spectral overlap between left and right ear stimuli was minimal in the fusion task as a consequence of the way in which the items were generated. In the absence of such overlap both ipsilateral and contralateral pathways would be expected to contribute to performance, a prediction verified by a comparison of predicted and obtained fusion performance.

In their paper detailing the results of intensive dichotic studies of one commissurotomy patient, SPARKS and GESCHWIND [6] report that their subject was unable to identify similar fusion items. They tentatively suggested that the corpus callosum may be necessary for such fusion to take place. Our investigation indicates that the performance of their subject was atypical of callosally sectioned patients. Subjects in the present study, without exception, showed evidence of dichotic fusion. These results fit nicely with a report of dichotic frequency fusion in patients who have undergone surgical removal of one hemisphere [22]. The commissurotomy and hemispherectomy data are thus consistent with the interpretation that frequency fusion occurs at the brain stem level [16, 17].

An unexpected finding emerging from the fusion task was the interaction of frequency spectra and ear of presentation on monaural trials found among the commissurotomy patients. This result was surprising since monaural identification of speech had been previously shown to be equivalent for the two ears in these subjects [9, 8]. The present study, however, involved stimuli considerably degraded by filtering whereas earlier observations had been made using undistorted speech at suprathreshold levels. Several investigators have reported that patients with temporal lobe damage performed equivalently in the two ears when asked to identify normal speech, but showed a deficit in the ear contralateral to the damage when the speech was filtered [17, 23, 24]. This suggests that the speech processing task presented to the subject must be sufficiently difficult before differences between ipsilateral and contralateral auditory pathways will become discernable and that we may have tapped these differences with the high frequency stimuli. It is difficult to explain, however, why the low frequency stimuli did not manifest a similar and possibly even greater ear asymmetry in the commissurotomy patients since they appear to be even more difficult to identify when presented alone. We plan to pursue this problem in later research.

One additional point in these data is worthy of note. An examination of the performance of individual patients in the dichotic digits task reveals that T.C.'s identification of digits delivered to the left ear was considerably poorer than that of the other patients. Two possible explanations of this finding suggest themselves, with both related to the fact that T.C. was the only patient to be tested in this task shortly after surgery. First, the mild dysphasia he experienced post-operatively may have made it difficult for him to generate two responses per trial, despite adequate processing of the left ear digits. Alternatively, the utilization of ipsilateral pathways folllowing surgery may not be immediate. We plan to retest this patient at frequent intervals to chart the time course of ipsilateral utilization of information.

In summary, these investigations indicate that it is unwise to assume a comparable degree of ipsilateral suppression of information for all classes of dichotically competing speech stimuli. The results suggest that an important variable may be the degree to which inputs are similar in spectral–temporal microstructure. The systematic, parametric investigations necessary to determine with precision the limiting factors in effecting suppression remain to be done, however. We present these preliminary results in the interim to urge cautious interpretation of investigations that seek to determine the relative extent of hemispheric specialization in the processing of different stimuli from an examination of the magnitude of the ear advantage they display: differences in ipsilateral transmission of information may potentially confound such results.

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Résumé :

On a étudié chez 5 malades après commissurotomie la contribution du stimulus de l'oreille gauche dans la performance d'écoute dichotique. Dans 2 épreuves, on demandait aux sujets d'identifier en les écrivant les 2 membres d'une paire de stimulus en compétition soit des chiffres soit des syllabes CV. Dans une troisième épreuve, les sujets devaient intégrer des composantes de haute et basse fréquence d'un mot isolé présenté dichotiquement. La performance de l'oreille gauche était au niveau de chance pour les syllabes CV mais dépassait 80% pour 4 des 5 malades sur les stimulus de chiffres. Tous les malades montraient qu'ils étaient capables d'utiliser l'information de l'oreille gauche dans l'épreuve de fusion dichotique. Ces résultats indiquent que la suppression apparente du matériel à l'oreille gauche dans l'épreuve dichotique est une fonction du recouvrement spectral-temporel entre les stimulus en compétition.

Deutschsprachige Zusammenfassung:

Der Beitrag des Linksohrstimulus zur dichotischen Hörleistung nach Kommissurektomie wurde bei 5 Patienten untersucht. In zwei Aufgaben wurden die Probanden gebeten durch Niederschreiben beide Teile eines Paars von kompetitiven Stimuli, entweder Ziffern oder Silben zu identifizieren. Eine dritte Aufgabe verlangte von den Probanden die Zusammenfügung (Integration) von Hoch- und Niederfrequenzkomponenten eines einzelnen, dichotisch dargebotenen Wortes. Die Linksohrleistung lag bei Silben auf dem Zufallslevel, überstieg hingegen 80 % bei 4 von 5 Patienten bei den Zahlenstimuli. Alle Patienten waren deutlich in der Lage, Linksohrinformationen in der dichotischen Verschmelzungsaufgabe zu verwenden. Die Ergebnisse zeigen, daß offensichtliche Unterdrückung des Linksohrmaterials in der dichotischen Aufgabe eine Funktion der spektral-temporalen Überlappung zwischen kompetitiven Stimuli ist.