Hemispheric specialization for the perception of speech sounds: The influence of intonation and structure*

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The present report investigates the effect of various cues to phrase structure upon the hemispherically lateralized processing of phonetic structure. Meaningless sequences were paired for dichotic presentation and were delivered under two different conditions termed structured and semistructured. The dichotic sequences in the two conditions contained the same nonsense syllable stems, English bound morphemes, and English function words. Also each of the sequences in both conditions were grammatically ordered in the sense that if the nonsense stems were replaced by English stems, a grammatical sentence would result. The conditions differed with respect to prosody, however: the structured sequences were characterized by the acoustic correlates of constituent structure; the semistructured sequences were delivered in a monotone. A significant right-ear superiority was observed in the structured condition, but not in the semistructured condition. These perceptual laterality differences are discussed in relation to cerebral dominance for language and in relation to speech processing generally.

In a dichotic listening situation, Ss are simultaneously presented with two different auditory messages, one to each ear. When the dichotic material is verbal, such as two competing lists of spoken numbers, the majority of normal adult Ss identify the stimuli delivered to the right ear more accurately than those delivered to the left ear (Kimura, 1961; Bryden, 1963; Dirks, 1964). In contrast, if the dichotically presented stimuli are of a nonverbal nature, such as musical patterns or environmental sounds, recognition is better for the material directed to the left ear (Kimura, 1964; Curry, 1967). These response asymmetries have been interpreted as a manifestation of hemispheric differences for the perception of verbal and nonverbal stimuli (Kimura, 1961). This interpretation is consistent with the evidence that the contralateral connections from ear to hemisphere are stronger than the ipsilateral pathways (Rosenzweig, 1951; Hall & Goldstein, 1968) and also with the neuroclinically derived concept of hemispheric specialization, the left and right hemispheres subserving language and nonverbal functions, respectively (e.g., Millikan & Darley, 1967; Milner, 1962). In the dichotic listening situation, then, verbal material has better access to the left-hemispheric speech processing mechanisms when delivered via the

right-ear route, while with nonverbal material, since processing is more dependent upon right-hemispheric functioning, the left-ear/right-hemisphere pathway is functionally prepotent.

Dichotic presentation has now become an established technique in the study of hemispheric differences in the normally functioning brain and has been used to find out precisely which aspects of speech perception depend upon the mechanisms of the language-dominant hemisphere. For example, one concern has been with whether or not cerebral dominance extends only to the processing of meaningful words. It would seem not. Recent findings of a right-ear superiority in the recognition of dichotically presented nonsense syllables have suggested that the lateralized language mechanisms also process the sounds of speech (Kimura, 1967; Kimura & Folb, 1968; Shankweiler & Studdert-Kennedy, 1967). Moreover, it appears that hemispheric specialization at the level of phonetic structure is linguistically based and not due to asymmetrical auditory capabilities. This latter viewpoint arises from a study carried out by Studdert-Kennedy and Shankweiler (1970) in which Ss were presented with, and then attempted to recall, dichotically paired CVC syllables contrasting in only one phone. Based on a detailed analysis of correct responses and errors (the latter, mostly "blends" of subphonemic features from each of the opposing inputs), they argue that both hemispheres are equipped to extract the auditory parameters of

speech but that only one hemisphere contains mechanisms capable of extracting linguistic features at the phonetic level from these parameters.

The sounds of speech, however, are inextricably linked to other units within the hierarchical structure of language. Specifically, at the level of phonetic representation, there are also the structurally determined prosodic contours (stress, pitch) of an utterance to be considered. In this respect, the theory of transformational grammar (Chomsky & Halle, 1968) specifies an intricate relation between phonetic shape and the surface structure of an utterance. Namely, the constituent makeup of the surface structure underlies the acoustic pattern exhibited by the phonetic description: it determines how the phonological rules (e.g., rules of stress assignment) assign phonetic values. Thus, Chomsky and Halle (1968) propose that their linguistic model relates to speech perception as follows: using certain cues, the perceiver first tries to capture syntactic structure, in particular surface structure, and then uses the internalized phonological principles to determine phonetic representation.

If syntactic appreciation generates detailed phonetic shape, then the presence of syntactic constraints might be expected to sharpen the lateralized processing of phonemic sequences. Whether or not this is so, a recent finding (Zurif & Sait, 1970) suggests that structural cues at least alter the hemispheric asymmetry effect associated with phonetic perception. Sequences consisting of nonsense syllables, bound morphemes, and function words were paired for dichotic presentation, both sequences of each pair being either structured (S) or unstructured (US). In the S condition, sequences were grammatically ordered in the sense that if the nonsense stems were replaced by English stems, a grammatical sentence would result. The sequences in the S condition were also characterized by the acoustic correlates of the constituent structures of the original sentences from which they had been derived. In contrast, the elements comprising sequences of the US condition were randomly rearranged and delivered in a monotone. Subjects, faced with an auditory multiple-choice problem after each dichotically presented pair, generated a greater right-ear superiority in the S condition than in the US condition.

The above study demonstrates that cues to structure can influence the laterality effect in the processing of phonemes. However, the study also raises a specific question. In essence, the question is whether it was the

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Table 1
Dichotic Stimuli for Both Structured and Semistructured Conditions

Condition		Channel 1	Channel 2
Structured and Semi-Structured	1	Hebful neasing, sej da viseltive.	Yaffing guselshug, the queffle froed.
	2	Hudly nee bul gu.	Sig the bajee wuga.
	3	Kiff zum shab for wenda.	The doos mag niffing gug.
	4	Ta hurped a geppen.	Gri nunc to sig yed.
	5	Durvendly ha flijjes rab.	Fash er a bodious siggen.
	6	Ra vip aj the lud mik.	Lo doont jeg ub shavving.
	7	Gie daggeds a wubby voom.	Quees murgy zu dakking teffs.
	8	Qua sav habbing dod.	The wak jud shendily.

syntactic arrangement of bound morphemes and function words that most influenced the lateralized speech processes or whether the asymmetrically placed mechanisms were affected more by the acoustic correlates of constituent structure. Further, the intention of providing no cues to phrase structure in the US condition was, by and large, not met. The rearrangement of the few elements in each of the US sequences still allowed the function words and bound morphemes to serve as grammatical markers for many of the sequences.

The present investigation, therefore, was designed to dissociate the intonational and grammatical cues to phrase structure, at least insofar as they bear upon speech processing in the dominant hemisphere. To accomplish this aim, a dichotic listening test termed semistructured (SS) was constructed containing sequences characterized by the grammatical ordering of bound morphemes and function words but delivered in a monotone. Lateralization was tested in both the S and SS dichotic listening situations, and comparisons were drawn.

METHOD

Stimulus Materials and Procedure

Both the S and SS sequences were derived from the same set of five-to-six-word English sentences found in a primary school reader (Table 1). The sequences in each condition were constructed by substituting a single nonsense syllable for each syllable contained in the formatives of the original sentences, except for some bound morphemes and some function words which were not replaced. The nonsense syllables used were easily pronounceable.

The same nonsense syllable substitutions were used for both conditions. Thus, for each S sequence, there existed an SS sequence containing in an identical order the same English function words, the same nonsense syllable stems, and the same English bound morphemes. In each of the sequences in the two conditions, the ordering of bound morphemes and function words was not changed from

the original sentences from which they had been derived.

The two conditions were, therefore, identical in terms of structure and distinguishable only along the dimension of prosody. The S nonsense strings contained the overt rhythms of speech. In contrast, the sequences in the SS condition were recorded in a monotone.

Two separate dichotic listening tests were constructed, one consisting of eight pairs of the S sequences and a second consisting of eight pairs of the SS sequences. The members of each pair were recorded on different tracks of a dual-channel tape recorder so that, for any one pair, one sequence could be delivered to the left ear at the same time that the other sequence was being delivered to the right ear via earphones.

Following each dichotic pair, four binaurally presented nonsense sequences were delivered in succession, one of the four being identical to one of the two preceding dichotically delivered sequences. The alternatives were numbered, and the subject's task was to identify by number which one of the four he had heard presented dichotically. For each condition, on half of the eight trials and in a random order, the correct alternative corresponded to the left-ear stimulus; on the other half, the correct alternative was a stimulus that had been delivered to the right ear. Further, the correct alternative was distributed in each of the four sequential positions equally often. Of the remaining three alternatives following each dichotic pair, one was somewhat similar to the left-ear stimulus, one was similar to the right-ear stimulus, and one was dissimilar to both of the dichotically presented stimuli.

Since no attempt was made to match the two sequences of each dichotic pair with respect to the number of function words and bound morphemes, it was necessary to balance ears and channels. Accordingly, for each condition, there were 16 trials for each subject; after the first eight trials, the same eight pairs were played over again but with the earphones reversed. In this way,

each sequence of each pair was delivered once to the left ear and once to the right ear, and any difference in the recording of either channel could have no biasing effects on the results. Further, since it was possible that the correct alternative was not equally distinguishable from the other alternatives in each of the eight sets of each condition, the reversal of earphones permitted the overall difficulty of the multiple-choice problem to be equalized for the two ears.

Each subject was tested in both the S and SS conditions. Starting ear and presented order of conditions were all counterbalanced. For each condition, the score for each ear was the number of correct identifications for that ear. Thus, for each ear in each condition, the maximum possible score was eight.

Subjects

The subjects in this study were 48 male English-speaking students from introductory and second-year psychology courses. All subjects were right-handed, and no subject had any auditory deficit of which he was aware.

RESULTS

The number of correct responses for each ear in each of the two conditions was computed for all subjects, and an analysis of variance was applied to these data. This analysis shows one significant main effect, an overall right-ear superiority [$F(1,47) = 8.54$, $p < .01$], and a significant Ear by Condition interaction [$F(1,47) = 7.79$, $p < .01$]. Correlated t tests, performed to compare the left- and right-ear scores within each condition separately, clarify the basis for this interaction. As indicated in Table 2, a significant right-ear advantage occurs in the S condition. In contrast, there is no asymmetry effect at all in the SS condition.

DISCUSSION

Quite clearly, the presence of the cues to phrase structure provided by the overt rhythms of speech in conjunction with bound morphemes and function words led to a greater right-ear advantage in the processing of dichotically presented nonsense sequences than did cues to structure provided by bound morphemes and function words alone.

To interpret these differences in perceptual asymmetry, however, first requires an analysis of the mechanisms that may be supposed to underlie the laterality effect. In this respect, the two contributing factors appear to be hemispheric specialization for language and the greater efficiency of the contralateral pathways over the ipsilateral connections. Each ear has

connections to both hemispheres, but in the dichotic listening situation, the stronger contralateral message from the right ear to the left hemisphere seems to suppress the ipsilateral message from the left ear (Milner, Taylor, & Sperry, 1968). In fact, the left-ear signal appears to reach the left hemisphere only by traveling first to the right hemisphere and then crossing over via the corpus callosum. Thus, Studdert-Kennedy and Shankweiler (1970) suggest that the right-ear advantage arises because of an information loss to the left-ear signal during its relatively extended and indirect transmission route.

Studdert-Kennedy and Shankweiler (1970), in the elaboration of their transmission-loss model, further propose that the absence of a significant right-ear superiority does not necessarily indicate an absence of cerebral dominance. That is, even though the perceptual function may reside exclusively in the language-dominant hemisphere, a lack of asymmetry may still result when the signals are not susceptible to transmission loss, so that both messages are equally operated upon by the left-hemispheric speech mechanisms.

Within the context of this form of reasoning, then, the lack of asymmetry found in the SS dichotic situation should not lead to the conclusion that these sequences do not engage the language mechanisms of the left hemisphere. It should be emphasized that this conclusion would be contrary to all the available evidence showing that left-hemispheric dominance in speech perception exists at the level of phonetic structure (Kimura, 1967; Kimura & Folb, 1968; Shankweiler & Studdert-Kennedy, 1967; Studdert-Kennedy & Shankweiler, 1970). Rather, it seems more reasonable to assume left-hemispheric specialization for the perception of the sequences in both the S and SS dichotic conditions and to ask why there are differences in their susceptibility to information loss during transmission.

One answer may lie with the notion of similarity. In a recent study, Schwartz (1970) has shown that the more distinguishable competing speech signals are from each other in a dichotic listening situation, the less the right-ear superiority. Specifically, he found that when two random number sequences were dichotically paired, a significant right-ear superiority emerged, but when a random number sequence was pitted against either a sequence consisting of the number "two" repeated several times or speech noise, there was no right-ear advantage.

Table 2
Mean Percent Correct

	Left Ear	Right Ear	t Applied to Laterality Differences
Structured Condition	71	82	3.96*
Semistructured Condition	78	78	0.18

Note—Although ear scores are listed in percentages, the *t* tests were applied to the number of correct recognitions.

**p* < .001 (two-tailed test)

How does this particular notion of similarity apply to the results of the present study? If Chomsky and Halle (1968) are correct in supposing that a form of syntactic appreciation precedes and determines detailed phonetic shape, then when the competing sequences vie for the unilateral speech processors of the left hemisphere, it is their cues to phrase structure which are processed first. In the S condition, the cues are the function words, the bound morphemes, and the overt rhythms of speech. The acoustic correlates of these short sequences, however, are not too dissimilar. Further, in relation to the information contained in a meaningful utterance, it cannot be claimed that the bound morphemes and function words really provide very much structure. In this sense, then, there is very little to distinguish between the syntactic structures of any of the paired sequences in the S condition. Because of this similarity, transmission-loss occurs to the left-ear signal and a right-ear superiority emerges.

The sequences of the SS condition are characterized by even less structure. In fact, the results of the present study are consistent with a previously reported finding (O'Connell, Turner, & Onuska, 1968) that bound morphemes and function words, in themselves, do not provide cues to structure. In other words, the influence of these cues is generally limited to intonated strings. The bound morphemes and function words notwithstanding, then, it would appear that the perceptual system treats each SS sequence as a series of discrete elements to be processed individually without any preliminary structural analysis. This increases the dissimilarity of the dichotically paired sequences, and since the task is one of recognition, a correct choice may be based on the processing of only a few of the separated elements. Thus, it seems reasonable to suggest that the lack of asymmetry in the SS condition is a result of the left-ear messages not being susceptible to information loss. In other words, the task is not necessarily made easier; it is just that the left- and right-ear SS messages appear to engage the left-hemispheric

speech mechanisms equally.

Presumably, as the literature on aphasia suggests (e.g., Luria, 1964), at least some aspects of syntactic structure are processed in the language-dominant hemisphere. However, the present findings do not necessarily lead one to the conclusion that the mechanisms which specifically operate upon the overt rhythms of speech are also lateralized. The right hemisphere is known to play a major role in the processing of auditory patterns (e.g., Milner, 1962), and quite possibly a preliminary and partial analysis of prosodic contours can be carried out in both hemispheres. That is, although the details of processing phonetic structure (with an attendant generation of phonological rules) may be relegated to the left hemisphere, the convergence of the two stimuli in the dominant hemisphere may occur before or after an initial analysis of intonation. In either case, transmission loss should accrue to the left-ear signal.

The findings of the present study do suggest, however, that the overt rhythms of speech can play an important role in the initial determination of structure (cf. Neisser, 1967) and that, even when the stimulus is a sequence of nonsense syllables, attention is directed towards structure as well as to the individual elements comprising the sequence. Thus, it has been argued that the speech sounds contained in the sequences of both dichotic listening conditions are processed by the language-dominant hemisphere and, applying Studdert-Kennedy and Shankweiler's reasoning (1970), that the null laterality effect in the SS condition is due to reduced transmission loss. Further, it has been suggested that, in general, the more dissimilar dichotically competing signals are, the less the transmission loss. When intonated strings are presented dichotically, the language mechanisms of the left hemisphere attempt to process structure as well as operating on the individual phonemes. Since the structures of the S sequences are not easily differentiated, transmission loss occurs to the left-ear stimulus and a right-ear superiority emerges. If, as in the Ss condition,

however, there are insufficient cues to structure, then the dissimilar elements are processed individually with very little transmission loss accruing to the left-ear signal.

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