To provide a framework for our discussion, I will set down in outline form the questions that arise in my mind when I wonder how we might get language into the hearing-impaired child. Some of these questions were raised by Ira Hirsh in his keynote speech the other evening, which reinforces my belief that they will help to organize our discussion this morning.

I should confess at the outset that I know very little about deaf children, even less, indeed, than I know about language processing. It is the more appropriate, therefore, that I should try to make the outline neutral. But I do have views (even biases) that may, in one way or another, influence what I say, so, before proceeding with the outline, I should get them on the record. The most relevant of these concern the function or purpose of grammar. My colleagues and I have written about those views in other places, and at length (Liberman, Mattingly, and Turvey, 1972; Mattingly, 1972a; Liberman, 1973) if only for that reason, I should be as brief as possible.

I believe that grammar—or, more exactly, grammatical recoding—serves to reshape information to enable the speaker-listener to move it efficiently between a nonlinguistic intellect, which has facilities for the processing and long-term storage of ideas, and a transmission system, where sounds are produced and perceived. Without the grammatical reshaping that comes so naturally to all normal human beings, we should have to communicate our ideas by means of sounds that were uniquely and holistically different from each other—one sound pattern, however simple or complex, for each idea. In that case, the number of ideas we could transmit would be limited to the number of sounds we can produce and identify. (Precisely that limitation applies to the normal communication of nonhuman animals if, indeed, it is true that those creatures lack the capacity for grammatical coding.) We do not know exactly how many messages could be transmitted by that kind of "language." But, given the richness of the intellect and the comparative poverty of the transmission system, the scope of such a nongrammatical "language" is orders of magnitude less than that which is afforded by the


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grammars that are so readily available to human beings and that, in my view, set language apart from other perceptual and cognitive processes (Liberman et al., 1972; Liberman, 1973). All this is to imply what some of my colleagues and I believe about the biology of grammar—that the capacity for grammatical processing evolved as a kind of interface, matching the output of the intellect to the vocal tract and the ear. If that is so, the biological development of those grammatical processes should have been influenced by the possibilities and limitations of the mismatched structures they connect. Natural grammatical processes should, then, reflect those influences. Unfortunately, we do not know how far "up" and "down" the grammatical interface the effects of intellect and transmission system go. I have some guesses, based on the formal resemblances between speech and the rest of grammar (Mattingly and Liberman, 1969), but I see no point in inflicting them on you. I will, however, suggest that the point of view I have expressed here is relevant to our concerns. When congenital deafness prevents the use of the normal transmission system, what are the consequences for grammar? If the deaf child bypasses speech entirely, as in the case of natural sign, must he then use a grammar different from the grammar of spoken languages? If so, what are the differences and, more to the point, how far "up" the system do they extend? If the grammar of spoken languages is not appropriate for the transmission system used in sign, how adequately can the signer adapt it? Or must he contrive a more suitable grammar? If so, how well does this more suitable grammar work, and at what cost in effort?

My views about grammatical recoding take a more specific form the more closely we approach to speech at the transmission end of the system. They also become more directly relevant to our concern, since we must surely try to understand speech if we want to know how the deaf child might cope with it. Thus, I think we should want to understand the function of the phonetic representation so that we can better appreciate the consequences, if any, of the failure to develop it in a proper way. We should also want to understand the relation between the phonetic representation and the sound, for we cannot otherwise see how the deaf child might use prosthetic devices that drastically alter the acoustic signal or, in the extreme case, transform it for delivery to the eye or the skin. (See: Liberman, Cooper, and Studdert-Kennedy, 1968.)

Let us consider first the function of the phonetic representation in the conversion between ideas and sounds. We do not know the shape of ideas in the intellect, but we should doubt that they are strung out in time as they are after they have been transformed into sound. If that doubt is well founded, we should suppose that the meaning of the longer segments of language (for example, sentences) must transcend the meaning of the shorter segments (for example, words) that they comprise. There is, then, a need for a buffer in which the shorter segments can be held until the meaning of the longer segments has been extracted. I suspect that the universal phonetic features became specialized in the evolution of language as appropriate physiological units for storage and processing in that short-term buffer. (See: Liberman et al., 1972.) Since the substitution of sign for speech does not remove the need to spread ideas in time, we must wonder how or how well the need for short-term storage is met. We should also wonder what happens when, instead of bypassing the normal transmission system entirely, as in natural sign, one rather enters directly (if only approximately) at the level of the phonetic representation by finger spelling or by writing (and reading) the letters of the alphabet. For if those substitute signals do not engage the phonetic features, then the deaf child may have to make do with
other representations—for example, visual or kinesthetic images. How efficient are these nonphonetic representations for the storage and processing in short-term memory that the perception of language may be presumed to require? (See, for example, Conrad, 1972.)

But suppose that instead of avoiding the sound by representing the phonetic message directly, (as in finger spelling or alphabetic writing) we try, as many have, to present the acoustic signal to the deaf child in a form (for example, spectrographic) suitable for presentation to an organ other than the ear. One of the problems we will then encounter arises from the nature of the relation between the sound and the phonetic message. A great deal of evidence supports the conclusion that speech is not an alphabet or simple substitution cipher on the phonetic representation, but rather a complex and grammatical code (Liberman, Cooper, Shankweiler, and Studdert-Kennedy, 1967; Liberman et al., 1968). Indeed, if speech were not a complex code it could not work efficiently, for just as the transmission system is not well matched, most broadly, to the intellect, so also is it unable, more narrowly, to deal directly with the phonetic representation. Thus, the rate at which the phonetic message is (or can be) communicated—up to 20 or 30 phonetic segments per second—would far exceed the temporal resolving power of the ear if, as in a simple cipher, each phonetic segment were represented by a unit sound. But there is another, equally important problem we should expect to have if the phonetic representation were transmitted alphabetically: the listener would have great difficulty identifying the order of the segments. Though little is known about the ability of the ear to identify the order of discrete (nonspeech) sound segments, recent work suggests that it fails to meet the normal requirements of speech by a factor of five or more (Warren, Obusek, Farmer, and Warren, 1969). That is, when segments of distinctive non-speech sounds are arranged in strings of three or four, their order can be correctly identified only when the duration of each segment is five or more times longer than speech sounds normally are.

The complex speech code is a grammatical conversion that nicely evades both those limitations of auditory perception: several segments of the phonetic message are commonly folded into a single segment of sound, which takes care of the problem posed by the temporal resolving power of the ear; and there are context-conditioned variations in the shape of the acoustic cues that provide non-temporal information about the order of segments in the phonetic message, thus getting around the ear's relatively poor ability to deal with order on a temporal basis. (See: Liberman et al., 1967; Liberman et al., 1972.) But for our purposes the important point is that these gains are achieved at the cost of a very complex relation between phonetic message and acoustic signal. We are not normally aware of how complex this relation is because the decoding is ordinarily done by an appropriately complex decoder that speech has easy access to. Unfortunately for the needs of the deaf child, however, that decoder is connected to the auditory system. What happens, then, when we try to present the raw (that is, undecoded) speech signal to some other sense organ, such as the eye? On the basis of what we know about speech we can, I think, understand some of the difficulties that are encountered; we can also, perhaps, see opportunities that might be exploited.

I should like to turn now from a more specific concern with grammatical processes near the transmission end of the system to consider some hypotheses about language that deal with grammatical processes more generally. In speaking of the
function of these processes, I have suggested that by appropriately interfacing mismatched structures of intellect and transmission, grammar makes possible the efficient communication of ideas from one person to another. But I believe that an equally important function of a grammar is to enlarge the possibilities for communicating ideas to oneself. By getting ideas out of the inarticulate intellect and down at least part way into the language system, we conceivably achieve a kind of control that we could not otherwise have managed. If so, having a grammar confers on us much the same kind of advantage that a mathematics does. A significant part of normal human cognitive work may then depend in one way or another on grammatical processes. In that case we have reason to be concerned about the consequences that may follow when these processes are tampered with.

I have also spoken of the human intellect as though it were in no sense linguistic—that is, as if all the accommodating to the transmission system had been done by the development of the grammatical interface. That leaves out of account the possibility that in the evolution of language the intellect and the transmission system themselves underwent alterations that tended to reduce the mismatch. In the case of the vocal tract, indeed, there is evidence that such an accommodation did occur. The vocal tract of human beings is different from that of other primates (Lieberman, 1968; Lieberman, Klatt, and Wilson, 1969; Lieberman, Crelin, and Klatt, 1972), and the difference appears to have produced for us a greater ability to transmit the phonetic message, thus easing somewhat the job that the speech grammar has to do. But what of the other end of the system? Was the originally nonlinguistic intellect also altered in the direction of a better fit to the other structures in the linguistic system? We do not know, of course, but if it was, then we should have to suppose that the human intellect is to some extent specifically adapted to normal grammatical processes. Given that possibility, we have another reason for wondering whether alteration of normal grammatical processes might have consequences for intellectual ability.

Throughout this introduction I have spoken of "natural" grammatical recordings, which implies a bias I particularly want to get on the record—namely, that such recordings are not arbitrary inventions or cultural artifacts, but rather the reflections of deeply biological processes. I believe, as do many other people who concern themselves with language, that human beings come equipped with the capacity to develop grammars, including, as I have already emphasized, the grammar of speech that connects the phonetic message to the acoustic signal. To the extent that we force these processes into unnatural channels, we can expect to encounter difficulties. Unnatural grammars will very likely be hard to learn, especially if they are as complex as they may need to be. Indeed, the fact that people do not learn to read spectrograms suggests that we cannot, by learning, acquire a grammar of speech or make the natural grammar work with an organ other than the ear (Liberman et al., 1968).

Now let us turn to the outline I spoke of at the beginning, the one that might help us to organize our discussion. Though the shape of the outline conforms rather well to the views I have just talked about, the outline itself does not prejudge any of the issues it raises, or so I hope. The larger division in the outline is between those methods that would aim at delivering to the hearing-impaired child as close an approximation to the spoken language as possible, and those that would use a different transmission system, such as, for example, the gestures of sign. The first method is further divided between those presenting speech in unencoded form (that is, as a signal from which the phonetic message
has not been extracted) and those presenting it in decoded form (that is, for example, as a phonemic or phonetic transcription). With undecoded speech there is, of course, an additional, subordinate choice among modalities: do we present the signal to the ear, the eye, or the skin?

I. COMMUNICATION OF A STANDARD, SPOKEN LANGUAGE

It seems reasonably obvious that we should want, if possible, to develop in the deaf child a reasonable approximation to standard, spoken language. Because the greatest number of natural grammatical processes is then used, the fullest possible development of language becomes a relatively easy matter, and there is the least risk of crippling the kinds of cognitive processes that normal grammatical processes ordinarily serve. Those advantages are, of course, in addition to giving the child access to standard literature of all kinds and the ability to communicate more readily with normal-hearing people. I do not mean to propose that we eschew all other possibilities, since the advantages of trying to give the child an approximation to a standard language can be outweighed by many considerations. Indeed, I do not mean to propose anything here, but only to frame the possibilities.

A. Transmission of the Undecoded Speech Signal

I said in my introductory remarks that there is a complexly encoded relation between the phonetic message and the acoustic signal. The salient characteristic of the speech code is that information about successive segments of the phonetic message is often transmitted simultaneously on the same parameter of the sound. As a consequence, there is, in general, no acoustic criterion by which one can identify segments of sound that correspond in size or number to the segments of the phonetic message, and the acoustic shape of the cues for a phonetic segment will often vary greatly as a function of context. The perception of speech requires, then, a complex decoding operation. In this section we will consider those ways of presenting speech, including even rather elaborately processed speech, in which, no matter how well the speech signal penetrates the person's deafness, the decoding job has yet to be done. But first, by way of introduction, I should say more about the speech code and the speech signal. Thus, I should emphasize that the relation between phonetic message and sound is not always that of a complex grammatical code; there are, intermittently, quite transparent or unencoded stretches. In those parts of the speech signal that carry the phonetic message in encoded form, there is, as I have pointed out, the complication that information about more than one phonetic segment is carried simultaneously on the same acoustic parameter. In the transparent or unencoded stretches, however, there is no such complication: a segment of sound carries information about only one phonetic segment. In slow articulation the vowels and fricatives, for example, are reasonably transparent, as are some aspects of the distinctions among phonetic manner classes. The fact that the phonetic message is sometimes encoded in the speech signal and sometimes not becomes important later in this section of the outline when we consider how to present the speech signal to an organ other than the ear.

I should also emphasize here that there is an aspect of the speech signal that has, in principle, nothing to do with encodedness, but that nevertheless can make speech hard to deal with, especially for the deaf. I refer to the well-known fact that speech is, from an engineering standpoint, a very poor signal.
The acoustic energy is not highly concentrated in the first two or three formants, which carry most of the important linguistic information, but is rather smeared broadly through the spectrum. Moreover, some of the most important acoustic cues are rapid frequency changes of the formants, the so-called formant transitions; such rapid frequency swings are, by their nature, physically indeterminate. In the processing we normally do in speech perception, therefore, we must not only decode the signal so as to recover the phonetic segments which are so complexly encoded in it, but also, apparently, clean up the signal—track the formants, as it were—and deliver to the decoder a clearer parametric description of a still undecoded signal. I know of no evidence that human beings have devices (shall we call them property filters?) to do that job. It is nonetheless relevant to our concerns, however, to know that the linguistically important acoustic cues are poorly represented, and to wonder, then, whether we might help the deaf by altering speech to make it a better signal.

1. Getting the undecoded speech signal in by ear. If we are to deal with the undecoded speech signal, then we should want, if possible, to get it in by ear in order to take advantage of all the physiological equipment, including especially the speech decoder, that is naturally connected to the auditory system. But we must then alter the speech signal in some way that is calculated to evade the condition of deafness. The simplest and most common alteration is amplification. I will not discuss that remedy further, except to say the obvious, that it does not always solve the problem.

I would rather consider other, more complicated alterations in the speech signal. Here I have in mind that, as I said in the introduction to this section, the speech signal may be hard to deal with, not only because of its peculiarly complex relation to the phonetic message, but also because the important cues are not among the most prominent features of the acoustic landscape. By using what we now know about those cues, and by taking advantage of the techniques that enable us to manipulate them in convenient and flexible ways, I should think we might be able to make speech significantly more intelligible to the deaf. We should want first, for this and for other more general purposes, to extend our knowledge about the acoustic cues by discovering exactly which ones deaf people can and cannot hear. Then we should explore the possibility of producing a more effective signal by putting the acoustic energy where it counts, and by specifically reinforcing certain cues. Of course, many of the alterations that might, on a common-sense basis, be expected to help could only be managed with totally synthetic speech, since it is beyond our present technological capabilities to process "real" speech as to produce those patterns that are likely to prove most effective. But it is nonetheless worthwhile, I think, to see how much better we can do with even the most extreme, synthetic departures from normal speech. We all know that what is technologically not feasible today is child's play tomorrow, so if we find that certain kinds of synthetic speech can be got through to the deaf better than natural speech, we can look forward realistically to the possibility of someday being able to produce such signals from "real" speech. But there might also be an immediate application. I have in mind the problems of the congenitally deaf child and the possibility that the development of his linguistic system might be promoted—or, more exactly, not held up—if speech could more effectively be got through to him. Of course, if we could provide him only with exposure to appropriately tailored synthetic speech, he could not interact with it in the normal way. Still, he might, like the chaffinch, gain something important if his normal language mechanisms had proper data to work on.
There are other possibilities for alterations in the speech signal that might also increase intelligibility for the deaf. In that connection I should like to take particular note of some work done recently by Timothy Rand (1973). That work is the more relevant because a member of our conference, Dr. Pickett, has results that are related to those of Rand, and Dr. Pickett will, I believe, describe those results for us at this session. Rand has found that when the formants are split between the ears the two higher formants are, to a significant extent, released from the masking effects of the lowest one. More specifically, the procedure and the findings are as follows. Using synthetic speech to have the stimulus control he needs, Rand presents binaurally the syllables [ba], [da], and [ga], which are distinguished only by the transitions of the second and third formants. He then determines by what amount he must reduce the intensities of the second and third formants to bring the subjects' accuracy of identification down from nearly 100 percent, where it is before the intensity reduction, to a level just slightly above chance. In another condition, he carries out exactly the same procedure, but this time with dichotic rather than binaural presentation. In the dichotic condition the first formant is presented to one ear, the second and third formants to the other. The first thing to be said about the results is that, as had been known before, the listener fuses the two inputs quite readily and hears an intelligible utterance. But, for our purposes, the more important result is that, in order to produce a reduction in intelligibility equal to that of the binaural condition, Rand must, in the dichotic condition, reduce the intensities of the second and third formants by an additional 15 db. That is, in the dichotic condition the transition cues for the stop consonants can, other things equal, be heard (and used) by the subjects at a level 15 db lower than that required in the normal binaural condition. Thus, it is as if the dichotic presentation produced a 15 db release from masking. I should emphasize that Rand's work has been done with normal-hearing subjects, and the degradation in the speech has so far been only in the form of intensity reduction. Still, we might want to consider the implications that Rand's work could have for improving speech intelligibility with the deaf. Perhaps Dr. Pickett will do that.

2. Getting the undecoded signal in through a nonauditory modality. Over the years, and especially in the recent past, attempts have been made to help the deaf by presenting the speech signal to the eye or the skin. Those attempts were very adequately reviewed by Dr. Pickett at the 1970 meeting in Easton, Maryland. As our contribution to an earlier meeting at Gallaudet, Franklin Cooper, Michael Studdert-Kennedy, and I undertook to describe the difficulties facing anyone who tries to decode the acoustic stream of speech without the aid of the physiological decoder that normally does it for him (Liberman et al., 1968). Indeed, the source of those difficulties should be apparent on the basis of what I have said here today about the complexly encoded nature of the relation between the acoustic signal and the phonetic message. If the sounds of speech were an alphabet on the phones—that is, if there were a discrete acoustic segment for each phonetic segment, or if the segments were merely linked as in cursive writing—then it should be no more difficult to read spectrograms than to read print. (Of course we should still have to contend with the fact that signal-to-noise ratio of speech would be poorer by far than that of print; that would, however, pose no very serious problem.) But, as I have said already, the relation of the speech signal to the message it carries is not that simple. Though the speech code matches the requirements of the phonetic representation to the particular limitations of the transmission system, thus permitting these two structures to work well together, it does so at a price; to extract the
phonic message from the acoustic signal requires a special and complex decoder. Such a decoding mechanism is apparently quite readily available to all human beings, but, unfortunately for our present purposes, it is connected to the auditory system, and experience in trying to learn to read spectrograms suggests that it cannot be transferred to the eye (or the skin).

Given what we know about the speech code and the way it is normally perceived, we have reason to be pessimistic, I think, about the possibility that the eye or the skin can ever be a wholly adequate substitute for the ear as a pathway for speech sounds or even as an alternative entry to the speech decoder. It does not follow, however, that no useful information about the speech signal can be transmitted through nonauditory channels. There are, as I have pointed out, relatively transparent or unencoded stretches of speech in which the relation between acoustic signal and phonetic message is quite straightforward. Since these stretches are not in need of complex decoding, they might be more readily "understood" when transmitted through the eye or the skin.

At all events, I would suggest that in the design of prosthetic aids for the deaf we take into account what we now know (or could, by further research, learn) about the speech code. We should then more clearly see both the difficult problems and the promising possibilities.

B. Transmission of the Decoded Speech Signal

In an alphabetically written language there is a fairly straightforward relation—a rather simple substitution cipher, indeed—between the segmented optical shapes and the phonetic or phonemic segments they represent. We might suppose, therefore, that in presenting language to the eye of the deaf child it would be the better part of wisdom not to offer the raw speech signal, which requires decoding, but rather an alphabetic representation, which does not. Indeed, this seems the more reasonable because we know that while normal-hearing people have not learned to read spectrograms, some have learned to read language in an alphabetically written form.

But the matter is not that simple. There is abundant evidence that reading is a secondary linguistic activity in the sense that it is grafted onto a spoken-language base (Mattingly, 1972b). Thus, reading came late in the history of our race. Moreover, an alphabet, which represents the decoded phonetic segments, is the most recently invented orthography, and it is significant that it has been invented only once. Most relevant of all, of course, is the fact that among normal-hearing children many who speak and perceive speech perfectly well nevertheless cannot learn to read.

We should not be surprised, then, to discover that congenitally deaf children, having had little or no chance to master the primary spoken language, find it exceptionally difficult to acquire a secondary, written form of it. Indeed, the fact that such children have more than the normal amount of trouble learning to read, and that they do not normally attain so high a final level of achievement, is itself strong evidence for the essentially secondary nature of reading. It seems intuitively reasonable to me that a child (or anyone else) should have difficulty mastering the grammatical (as opposed to the lexical) elements of language if his initial and only exposure is to the written forms, but I don't know how to talk about that in any intelligent way. I will only say, therefore,
that it is surely important to us that reading is significantly harder for those who do not speak—that it is, in effect, difficult to acquire the language by eye.

How much do we know about this and what else should we try to learn? Is the deaf child's success in reading related to his ability to deal, by whatever means, with the spoken language? If so, what is the nature of the relation? Is there some kind of threshold effect—that is, is some certain amount of competence with the spoken language enough to enable the child to break through and acquire the rest of the language by reading? Can we discover whether experience with particular aspects of the spoken language is more important than experience with some others? And what does it mean, precisely, to say that a congenitally deaf child reads poorly? What kinds of errors does he make, for example, and how do those compare with the errors made by normal-hearing children? Are the deaf child's errors spread evenly (or randomly) over all aspects of language, or do the difficulties pattern in ways that make sense in terms of anything we know about language? Is there any factual support for my intuition that the deaf child might have more trouble with the grammatical items than with the lexical ones? Is that what is reflected in the comment I heard from one of the participants at this conference, that teachers sometimes refer to the performance of deaf children in reading as "noun calling?" If, as I suggested earlier, the phonetic representation normally provides an efficient vehicle for storage and processing in short-term memory, what kinds of alternative representations are available to the deaf child, and how well do they work for the same purpose?

Our outline would be incomplete if we omitted another method of communicating decoded speech to the deaf child, though in this case the decoding is not complete and only some aspects of speech are communicated at all. I refer to "lip reading." The gestures of articulation occur at a stage just prior to the one where much of the most severe encoding occurs. Though the gestures do not thereby escape as many complications as my colleagues and I had once supposed, still they are, by contrast with the acoustic signal, more simply related to the phonetic message. To the extent that the deaf child can see at least some of the articulatory gestures, he has access to a reasonably straightforward representation of the phonetic message. Conceivably, we will want to consider today what we now know or ought to try to learn about lip reading. We may also want to wonder whether there are greater possibilities with that method than have yet been realized.

II. COMMUNICATION BY AN OTHER-THAN-SPOKEN LANGUAGE

Given the problems that the deaf child has with speech, we must consider alternative means of communication. Surely the most obvious and important of these is sign language. Unfortunately for our purposes, and for me, I know almost nothing about sign, so I will not presume to talk about it. All that I can do is to include it in our outline as a subject that you may want to discuss, and, more presumptuously, raise a few questions that my own biases lead me to ask.

Seeing grammar as a kind of interface, I assumed in my introductory remarks that it might bear the marks of the several structures, intellect and transmission system, that it connects. On that basis I raised questions about the consequences of using a different transmission system. In sign the transmission system is very
different, involving neither the vocal tract nor the ear. I should ask, then, as I did earlier, whether the grammar of sign is different from that of any spoken language, and if so, exactly how different? (Apart from its relevance to our understanding of the deaf, an answer to that question should be of interest to students of language, because it tells us something about how far up the grammatical interface the effects of the transmission system extend.) If the grammar of sign is very different, is there a price to be paid, either in effort or in efficiency, for not being able to use, as the normal-speaking person does, those grammatical processes that presumably evolved with language and are now a part of our physiology? You probably know more than I do about research on sign, including, for example, the work of Stokoe (1960) or that of Bellugi and Fischer (1972). If so, I hope you will include sign in our discussion. In any case, it is time for me to stop talking and, instead, to invite from you the comments that are the principal purpose of this meeting.

REFERENCES