The Role Of Articulation Mechanisms In Speech Perception

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THE ROLE OF ARTICULATION MECHANISMS
IN SPEECH PERCEPTION

by
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ABSTRACT

Experimental evidence from a variety of studies in the area of speech and language behaviour has indicated the presence of a relationship between speech perception and speech production. Current "motor" theories of speech perception have proposed that the processing of speech sounds employs, in some capacity, neuromotor mechanisms which are involved in speech production. The present series of studies investigated the relationship between speech perception and speech production in an attempt to determine whether articulation mechanisms are actively involved in the speech perception process, and under what conditions this articulatory motor involvement may be present.

The basic experimental paradigm involved the articulation factor as the independent variable, and accuracy measures on perception tests as the dependent variable. Subjects were presented with a series of speech or non-speech sounds via earphones. During the presentation of each sound, subjects were required to perform one of two types of simple motor tasks. One type of task involved specific movements of the articulatory musculature (e.g. tongue movement). The other type of task - a non-articulatory motor task which served as a motor task control condition - involved movements of the hand and finger. A no-task condition was also used in most of the studies. The scores of the different motor task groups on the speech and non-speech perception tests were examined. Successive experiments varied such factors as the type of motor task, the type of speech and non-speech sounds in the perception tests, the age of subjects, mode of presentation of stimuli, and aspects of the experimental design and procedure, in order to assess the contribution of these factors to the task effects.
The major findings of the present series of studies were:

(1) the performance of articulatory motor tasks during presentation of speech sounds produced consistently (but not always significantly) lower scores on tests of speech sound perception than were produced by the performance of motor tasks which did not involve the articulatory musculature.

(2) the articulatory motor tasks produced a consistent but small interference effect relative to no-task conditions, while the non-articulatory tasks showed a slight tendency to enhance scores relative to a no-task condition, on tests of speech perception.

(3) although motor task group differences for non-speech sounds were not significant in any study, and the magnitude of these differences was greater for speech sounds than for non-speech sounds in three of four studies, the predicted task group x stimulus type interaction did not reach statistical significance in any of the four studies.

(4) under certain conditions, the magnitude of the task group differences appeared to be influenced by the sex of subjects and the specific consonant sounds used in the speech perception test. The findings were generally consistent with, although not strongly supportive of, a motor theory interpretation which hypothesizes that articulatory motor mechanisms play a role in the processing of speech sound information.
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INTRODUCTION

In 1924, Watson advanced the view that "what psychologists have hitherto called thought is, in short, nothing but talking to ourselves". This statement was an attempt to underline the importance of articulation processes in "internal speech" or thought processes. Even before Watson's proposal, however, there had begun an active investigation into the nature and role of articulation mechanisms in a wide variety of experimental contexts. Early research in this area had revealed that various peripheral articulatory-motor responses did in fact occur during thinking, reading, sleeping, and in response to presentation of various types of auditory stimuli. A number of these investigations into what has been referred to as the "motor theory of thinking" have been compiled in a recent book by McGuigan (1966).

Electromyographic Studies

One of the earliest experimental investigations into the relationship between articulation processes and speech perception (Wyczoikowska, 1913) proposed a model of speech perception which anticipated current theory in this area. In this study, it was found that auditory presentation of words and melodies to subjects resulted in minute movements of the tongue. Attempting to account for these findings anatomically, Wyczoikowska noted that two of the nerve pathways which innervated the tongue (the lingual and glossopharyngeal) were also connected indirectly with pathways which innervated the ear. Consequently it was suggested that "Only when the stimulus coming from the voice of person A incites mechanically the same coordinate movements of the organ of speech of person B, is the latter able to understand the word spoken and heard. This means, however, that one does not completely understand the word that is spoken to him until it is repeated by his own organ of
speech" (p.454).

These early investigations into the relationship between articulation and speech perception have been pursued and elaborated upon in recent years. Various studies which have measured electromyographic responses of the speech musculature to presentation of auditory stimuli have reported marked changes in the amplitude of the response upon presentation of prose material to subjects. Bartoshuk (1956), recording from electrode placements on the arm, chin, and forehead during auditory presentation of a short story observed consistent, positive increases in EMG amplitude from the chin placements, with only small random fluctuations from the other placements. Similar increased EMG activity from chin placements on Ss listening to a story was reported by Smith, Malmo and Shagass (1954). These findings have been confirmed in a recent study by McGuigan and Rodier (1968). They observed increases in EMG amplitude (relative to resting levels) from both tongue and chin electrodes upon presentation of prose, backward prose and white noise. No similar increase was recorded from arm electrodes. However, the only significant increase in muscle potential occurred from the chin placement, as has been previously found, and only in response to presentation of prose material. In addition, auditory presentation of prose and backward prose to subjects who were reading produced significant increases in subvocalization, while presentation of white noise alone did not produce this effect. The authors have suggested that the occurrence of this articulatory activity during subvocalization may in some way facilitate the perception of processing of verbal stimuli.

A viewpoint very similar to the above interpretation has been presented by Luria (1966) who notes:
"The development of the ability to perceive spoken sounds and to hear speech requires the closest participation of the articulatory apparatus and assumes its final character only in the process of active articulatory experience. The first years of the development of speech are taken up with this acquisition of the ability to hear speech with the participation of articulation. This process of auditory-articulatory analysis is at first manifest and overt in character. As electromyographic studies have shown... it recedes into the background only gradually so that when, or shortly before the child begins to attend school, the hearing of speech ceases to require the actual participation of articulation. However, if the child is told a word with a complicated sound, or still more asked to write it, the articulatory apparatus will again be brought into visible use to aid in the perception and recognition of the precise sound structure of the word." (p.102)

Luria's position appears to parallel that of several other investigators concerned with the developmental aspects of language and speech (e.g., Fry, 1966; Chase, 1967) particularly in regard to the interdependence of speech production and speech perception. Chase (1967) has pointed out that a somewhat analogous situation exists in the research on visually guided limb movement (e.g., Held & Hein, 1963) which has stressed the importance of the parallel organization and development of the visual and motor processes.

One line of evidence suggesting that speech production mechanisms may be involved in speech analysis has come from studies which have investigated the perception of extralinguistic aspects of speech such as loudness, stress and intonation. In a study by Ladefoged, Draper and Whitteridge (1958), a speaker produced a given sentence while EMG recordings were taken from his internal intercostal muscles, which function to increase the pressure in the lungs. It was found that when listeners were required to estimate the positions of stress in the spoken sentence, their estimates corresponded very closely to the positions in
the sentence where the speaker had shown increased muscle activity. These authors have suggested that in judgments of stress in speech, listeners likely employ some information about how much muscular activity they would have to use to produce similar sounds. In other words, a listener might attempt to supplement the acoustic information from the speaker with motor information from his own musculature. Similar observations have been made by Fonagy (1966), who employed a series of acoustic, pneumographic, electrophysiological, and perceptual measurements. He noted that stress and stress perception were closely related to increased activity of particularly the internal intercostal muscles, and that the activity of certain muscles in stressed sounds was often not reflected in corresponding changes in the acoustic signal. He did point out, however, that listeners at times do base judgments on simplified acoustic cues which may mask articulatory cues.

Using a similar technique in examining factors involved in the perception of loudness in speech, Draper, Ladefoged, and Whitteridge (1958) instructed subjects to count up to 20 while trying to keep the loudness constant. During this procedure, recordings were made of the speakers' sound pressure and lung air pressure levels. They found that the sound pressure level (which is the physical correlate of loudness) varied quite widely, while the lung pressure level (a physiological correlate of loudness) varied much less. Their interpretation, as in the earlier study, was that the speakers appeared to be relying on their articulatory musculature cues at least in part, and not merely on their acoustic output in assessing the loudness of the sounds. Perception of speech loudness was also examined by Lehiste and Peterson (1959), who found that when pairs of vowel sounds, the members of which were produced with different degrees of effort, were presented to subjects
with both vowels at the same sound pressure level, the listeners would almost always judge the sound that was produced with the greater effort as the louder of the pair. On the basis of these findings, they also have suggested that information about the sound production mechanisms is employed in the interpretation of the loudness of speech sounds.

In a recent book, Lieberman (1967) has presented a detailed series of studies in support of his proposed model of production and perception of intonation in speech. According to Lieberman, the use of intonation is an integral part of speech production and perception, and the articulatory-motor gestures which are correlated with intonation are utilized by the listener, not in isolation, but together with other relevant information such as the social and linguistic context. He proposes that the inferences one makes from the basic acoustic signal about the articulatory gestures involved in producing the signal provides an additional "motor meaning" to the signal. Lieberman states his position as follows:

"The listeners 'decode' the input speech signal by using their knowledge of the constraints that are imposed by the human 'output' apparatus. In a sense we have proposed a 'motor' theory of speech perception since we have suggested that there is a close relationship between the inherent properties of the speech output mechanism and the perceptual recognition routine" (p.162).

This last point, i.e., the apparent close relationship between speech perception and production, is one which has been made in the previous discussion and will be stressed again later by others, in support of the view that speech perception is not functionally independent of the articulation mechanisms.

Research on Second Language Learning

Relevant to the question of what role the speech production
mechanisms might play in the perception of speech sounds are the findings of two unpublished studies in language learning which have been cited by Ladefoged (1967). These studies have indicated that articulation processes may be directly involved in at least the development of the ability to discriminate speech sounds, insofar as they suggest that the ability to accurately perceive differences in certain speech sounds develops subsequent to the ability to produce these differences. In one study (Romaquin & Anderson, cited in Ladefoged, 1967) on the learning of English in the Phillipines, the ability of Filipino students to pronounce a list of English words containing contrasting vowel sounds was tested. The students' scores on the correctness of pronunciation were compared with their scores on tests of the ability to discriminate the same sounds spoken by a native English speaker. They found that the students always scored higher in the pronunciation test than in the listening test. Subjects at all levels of proficiency in English were able to produce differences between pairs of similar vowel sounds which they were unable to hear consistently. The other study, by Brière (cited in Ladefoged, 1967) found that when a group of American students were required to learn a number of speech sounds which were not present in their own language, there was nearly always a stage at which a subject could produce the new sounds perfectly but could not hear the differences between pairs of the same sounds when pronounced by the speaker. They noted that this stage did not last very long - very shortly after learning to pronounce the sounds adeptly, the subject began to make correct identifications. Ladefoged notes that these findings conform to his own experience in teaching phonetics, and suggests that in general, if people can hear a difference between a pair of similar speech sounds, they can produce that difference although they do not necessarily do so in ordinary speech, either because they do not
remember to do so, or because it may take additional effort which
is not really required in order to be understood.

Speech Pathology and Speech Perception

The relationship between speech sound discrimination ability and
articulation processes has also been examined in the context of research
in speech and hearing disorders. The ability to distinguish between
closely related speech sounds has been of major interest to speech
pathologists insofar as deficiencies in this ability have been
hypothesized to be an important etiological factor in non-organic
articulation disorders. Such an hypothesis would appear to logically
follow from well-established observations that children who are born
deaf fail to develop normal articulation. However, results of studies
examining the relationship between articulation abilities and speech
sound discrimination (Cohen & Diehl, 1963; Aungst & Frick, 1964;
Sherman & Geith, 1967) have not consistently reported a positive relation-
ship between these two variables. Reviews of the literature in this
area (Powers, 1957; Weiner, 1967) have attempted to isolate those
variables which appear to be important in influencing this relationship.
Powers (1957) has reported that a positive relationship has generally
been found in studies which relate deficiencies in the articulation of
specific speech sounds to deficiencies in the perception of those same
sounds. Weiner (1967) has found the factor of age to be important,
with a positive relationship being reported in almost every study
reviewed which tested children below the age of nine, but no such
evidence in studies using only children above that age. In addition,
a positive relationship was consistently found in studies which used an
error score of four or more sounds as the criterion for articulation
difficulty. Thus, there is reasonable evidence to indicate that speech
sound perception, under certain conditions, is related to articulation ability. However, the research evidence has not yet clearly determined the nature or direction of this relationship. Sherman and Geith (1967), for example, on the basis of their findings that children with low scores on a speech sound discrimination test also performed poorly on articulation tests, have suggested that low speech sound discrimination ability is in general a causal factor in the development of poor articulation. A similar conclusion has been drawn by Menyuk & Anderson (1969) who observed that children's identification of certain synthetically-produced speech sounds was more accurate (i.e. conformed more to adult patterns) than their reproduction of the same sounds. In the light of this, they suggested that the developmental sequence in the acquisition of these sounds is first, the ability to differentiate differences between the sounds and secondly, the ability to reproduce these differences. This viewpoint appears to prevail in much of the literature in this area. However, the studies on language learning by Brière and by Romaquin & Anderson which were cited earlier, suggest that this order of events may not apply, at least not in adults. Menyuk and Anderson themselves observed that adults were more consistent in their reproduction of the sounds than in their identification, and speculate that "while children may be referring to some perceptual mechanism that is, at this stage of development, not closely linked to productive mechanisms, adults may refer to some productive mechanisms for perception of speech sound differences" (p.51). Whether this order of development necessarily occurs even in children is brought into question by a recent study (Butt, 1966), which tested the assumption (based on the hypothesis that perception precedes production of speech sounds) that pretraining in the auditory discrimination of a sound would provide direct positive
transfer to articulation of that sound. Using second-grade children who were taught to discriminate a novel speech sound from similar sounds, it was found that despite the fact that the children learned the discrimination task very well, this training did not facilitate performance on the subsequent articulation task. In fact, the group receiving pre-training was inferior to controls. These results are not congruent with the assumption that discrimination must precede production, or that articulation ability is necessarily a result of speech discrimination ability. Examining the evidence, it appears equally likely, as at least one investigator has noted (Prins, 1963), that speech sound discrimination ability may be to some extent a consequence of articulation ability.

**Articulation and Short-Term Memory**

The function of articulation processes has received considerable attention in research on memory, particularly short-term memory. The relevance of this research to the present discussion of speech perception is perhaps more obvious when one notes that many so-called "perception" studies might well be considered within the realm of short-term memory processes. The problem of distinguishing between these two phenomena has been clearly outlined by Paivio (1971), who notes that in practice, many "perceptual" tasks involve a memory component in the delay between stimulus and response. This of course raises the question of whether the relevant experimental manipulation is operating upon the sensory input or upon the "traces" of that input - i.e., short-term memory. As Paivio has pointed out, one solution would be to restrict "perceptual" tasks to those cases in which delay is negligible or absent, although this results in the elimination of a great many potentially useful tasks. As a viable alternative to making an attempt to completely eliminate memory factors, he suggests that it might be of value to think
of a continuum of information processing which involves perceptual, memory and response factors to different degrees. One could then attempt to maximize or minimize these factors depending on the requirements of the study. A further point that might be added is that a determination of the nature of the elements stored in memory could provide valuable information about what operations or transformations might occur in the initial stages of perceptual processing. In such a context, then, the data from the short-term memory research bears more directly upon the problem under investigation.

The question of whether articulation processes are involved in the encoding of verbal stimuli has been approached from a number of directions. Conrad (1964) observed that the errors made in recalling lists of visually-presented letters in a short-term memory task were highly correlated with the identification errors that subjects made when the same letters were presented auditorially in a white-noise background. The letters most likely to be confused and substituted for one another were those that sounded most alike. For example, letters such as B, C, P, T, all of whose pronunciation ends with an "ee" sound, tend to be confused with one another in recall. The same thing happens with letters such as F, M, N, X, which begin with the same "e" (as in bet) sound. Studies by Wickelgren (1965a, 1965c; 1966b) have similarly found that substitution errors in short term recall of verbal material such as letters, digits and consonant-vowel syllables, tended to have a sound in common with the correct item. Such evidence appears to strongly implicate the auditory aspect of verbal material as the important feature which is being stored in short-term memory. As has been pointed out by Cole, Haber & Sales (1968), while these findings suggest the importance of acoustic factors in short-term memory, they do
not clearly specify the mechanism of encoding since the stimuli used generally have both acoustic and articulatory features in common. That is, the features that make up a sound can be defined by the acoustic parameters that make up a sound wave, or by specifying the articulatory positions of the vocal tract that are required to produce the sound. Consequently, there could be either an acoustic representation of the stimuli, or a motor-kinesthetic representation of the articulatory movements or some combination of both, in the nervous system. Experimental studies have therefore attempted to assess the relative importance of acoustic and articulatory mechanisms in the encoding process. Wickelgren (1965b, 1966a) has found that substitution or intrusion errors in short-term recall of single vowel or consonant sounds are also systematic, and tend to have specific articulatory features in common with the correct sound. He has found that the errors made are accurately predicted by an articulatory description system which considers voicing, nasality, openness of the vocal tract and the place of the tongue. Thus a sound which differed from the correct sound on only one of these dimensions would be substituted more often than a sound which differed on two or more articulatory features. From this he has concluded that the basic speech sounds, or phonemes, are coded in short-term memory, at least in part, as a set of such articulatory distinctive features, each of which may be forgotten semi-independently of each other.

Two recent studies by Hintzman (1965, 1967) attempted to determine whether the short-term memory trace was acoustic or articulatory. In the earlier study, intense white noise was presented during visual presentation and recall of a list of digits and letters. It was reasoned that if the short-term memory trace were auditory in nature, presentation
of the noise might disrupt it and result in a non-auditory pattern of substitution errors, since the subject would presumably have to rely on some other form of coding. He found that the noise had no effect upon the frequency or nature of the intrusion errors. He also noticed that subjects appeared to be rehearsing more audibly in the noise condition. He concluded that confusions in short-term memory are likely kinesthetic in nature, arising from similar muscular feedback patterns produced by subvocal rehearsal of the stimuli. In a subsequent study Hintzman (1967) found that two articulatory features - voicing and place of articulation - influenced confusion errors in a short-term memory task for visually-presented nonsense syllables. Hintzman again interpreted these findings as consistent with his hypothesis of mediation by kinesthetic cues from sub-vocal rehearsal. Wickelgren (1969) has taken issue with Hintzman's rationale and conclusions, and has argued that the existing short-term memory data can be equally well interpreted in terms of either auditory or articulatory encoding, or perhaps in terms of an abstract verbal system that is neither purely auditory nor purely articulatory.

A slightly different approach has been taken by Murray (1965a, b, c, 1966b, 1967, 1968) who reported that mouthing consonants as they were visually presented gave consistently, but not necessarily significantly, better recall than did silent reading of the consonants. (Murray 1965b, 1966b). He concluded that the addition of articulatory-motor cues at presentation provided a small degree of facilitation. On the basis of pilot studies which had indicated that holding an object in the mouth during a verbal learning task reduced recall, Murray (1967) devised a series of studies to examine the effects upon recall of preventing subvocalization. Subjects were visually presented with a list of
consonants and were required to repeat an irrelevant "neutral" sound as each consonant was presented. It was found that this "suppression of articulation" procedure significantly reduced recall, compared to conditions where subjects mouthed, whispered or voiced the consonants at presentation. Since no advantage of articulation was observed for lists of letters which all had a sound in common, he concluded that for lists of sounds which vary acoustically, articulation is highly beneficial to recall. An extension of the study confirmed this finding and revealed that articulation of stimuli using a normal tone of voice resulted in better over-all recall than did articulation performed in a monotone fashion. This has led Murray to suggest that one of the advantages of articulation is that by use of appropriate intonation, extra motor discriminative cues may be supplied by the subject at-presentation which facilitate retrieval of the items.

A number of studies have varied the pronounceability of verbal items and examined the effect upon short-term recall. Presumably, if articulation processes are involved in encoding, stimuli which are readily transposed into articulatory components should be more easily "packaged" and stored in memory. There appears to be general agreement that recall is facilitated for more pronounceable items (Blanton & Odom, 1968; Pinkus & Laughery, 1967; Lappin & Lowe, 1969), and that processing time is significantly less for highly pronounceable items than for items difficult to pronounce. (Gibson, Bishop, Schiff & Smith, 1964; Stanners & Meunier, 1969). These observations add support to the idea that articulation factors are of some consequence in the encoding of language stimuli.

An interesting approach to the question of the nature of the components involved in recall has been adopted by Brooks (1968). His
experiments were designed to determine whether verbal and spatial information are processed in separate systems, each of which are responsible for internal processing as well as the execution of overt responses. Brooks reasoned that conflict should occur if concurrent activities within the same system are different in form. If verbal material is recalled using articulatory mechanisms, then having a subject recall this material by signalling his responses using articulatory mechanisms should be more difficult than by signalling in another fashion. To induce articulatory conflict, subjects were presented with a sentence and asked to categorize each word in the sentence from memory as a noun or a non-noun in one of three ways: (1) saying "yes" for a noun, and "no" for a non-noun, or (2) tapping with the left or the right hand for the appropriate response, or (3) by pointing to the words "yes" or "no". The hypothesis proposed was that if some portion of the articulatory system was involved in recalling the sentence, procedure (1) should produce a conflict and require the longest time to categorize the words, since the articulatory system would be used both to say "yes" and "no" and also to aid in the recall of the specific words. This hypothesis was supported. All of his subjects showed a longer average time for vocal output than for the other two forms of output. Subjects also reported that they had more difficulty recalling the sentence in condition (1) than in the other conditions. Brooks notes that the same effect occurred when the subjects were required to mouth the responses, indicating that this conflict effect was not critically dependent upon auditory feedback. This apparent conflict has suggested to Brooks that there is an overlap between the mechanisms which control recall and those which control certain types of overt responding. That is, when a person retrieves a sentence from
memory, he is utilizing some of the same mechanisms necessary for overt vocal responding.

Taken together, the evidence available from these diverse approaches to the study of short-term memory would suggest that while clearly not the only factor, articulation processes play a considerable role in the encoding, storage and retrieval of verbal stimuli.

**Evidence From Haskins Laboratories: A Motor Theory Model of Speech Perception**

Reference has already been made to studies which have used motor theory interpretations of their data. The motor theory of speech perception has been most explicitly formulated and extensively investigated in recent years by researchers at Haskins Laboratories (Liberman, 1957; Liberman, Cooper, Harris & MacNeilage, 1963; Liberman, Cooper, Studdert-Kennedy, Harris & Shankweiler, 1966, Liberman, Cooper, Shankweiler & Studdert-Kennedy, 1967; Studdert-Kennedy, Liberman, Harris & Cooper, 1970). Their research program has attempted to identify the acoustic variables in speech sounds that are important cues in the perception of these sounds. These studies have generally employed synthetically produced speech sounds whereby any of a number of acoustic variables, such as frequency, intensity, duration and time of onset, can be systematically varied and the effect on perception studied.

One of the basic findings of their studies is that for many elemental speech sounds, or phonemes, there appear to be no consistent or invariant acoustic cues which always result in the same sound being perceived. An early indication that there was no simple correspondence between basic units of speech and the acoustic signal came from the observation of speech spectrograms, which are pictures of speech signals
portraying the intensities of the basic frequencies of the sounds as they change over time. Prior to such spectrographic analysis, the stream of speech signals had been considered to be composed of successive, variously sized sound units (corresponding to phonemes, syllables, words, etc.) Analysis of the spectrograms, however, did not reveal discrete segments of the pattern which corresponded directly to discrete linguistic units, but rather they indicated an overlapping or continuity of many of the sounds. In addition, the acoustic pattern for a given sound was found to vary quite considerably for different speakers and for the same speaker on different occasions. Another observation suggested that there was no simple acoustic cues corresponding to each phoneme. Liberman et al (1967) noted that in the production of synthetic speech sounds, it was not possible to produce a single consonant phoneme in isolation - either a consonant plus vowel sound would be heard, or else a non-speech sound. There appeared to be no way to cut the acoustic signal for a syllable such as "da" along the time dimension so as to produce a sound that would be perceived as /d/ alone.

Thus for many sounds there appeared to be no direct correspondence between the acoustic cues and what is perceived. Liberman and his coworkers have suggested that in cases where this lack of correspondence exists, perception appears to be more closely correlated with the patterns of articulation that produce the speech signals than with the acoustic signals themselves. Several types of evidence have been adduced in support of this position. For example, in their early (1954) studies Liberman, Delattre, Cooper & Gerstman found that the major acoustic parameter for a /d/ sound did not remain constant but would vary depending on which vowel sound it preceded. Thus the cue for /å/
when it preceded /i/ sounded like a high-pitched rapidly rising whistle when presented alone. The cue for /d/ when it preceded /u/ sounded like a low-pitched rapidly falling whistle. The reason a person hears the same /d/ sound in all vowel contexts, according to these investigators, is because the primary articulatory movements or the neural correlates of these movements which are involved in producing a /d/ sound, vary negligibly from one context to another. It is to these relatively invariant articulatory-motor correlates that incoming speech sounds are presumably referred.

A closely related finding was that the same acoustic cue was identified as different consonant sounds, depending on its context. In one study (Liberman, Delattre & Cooper, 1952), a specific signal was identified as /p/ when it preceded the vowel sound /i/, but was identified as /k/ when it preceded /a/. The hypothesis advanced to account for this finding was that in speaking, very different articulatory gestures would be necessary to produce the same acoustic effect. The authors suggest the following interpretation:

We assume, then, that the sound patterns ... set off the appropriate movements in the listener (that is, the articulatory movements which the listener would make in attempting to produce these acoustic patterns) or perhaps only the short-circuited neural equivalent of these movements, with the result that the initial schematic phonemes p and k, which can be entirely identical as acoustic stimuli, become clearly differentiated in proprioceptive terms and are therefore finally perceived as distinctly different sounds. (p.514)

Once again, perception would appear to follow the diversity of the articulation patterns rather than the similarity of the acoustic signal.

A number of studies by Liberman and his colleagues (see Liberman et al, 1967) have shown that when a synthetically produced acoustic cue is varied in relatively small, acoustically equal steps through a range
which produces several different consonant sounds (e.g., b-d-g),
listeners do not appear to hear these gradual inter-phonemic changes
corresponding to the gradual changes in the stimulus. Rather they
hear the first few stimuli as, say, /b/, then an abrupt change to
hearing /d/'s for the next few stimuli, and again an abrupt shift to
hearing /g/. Measurements of discrimination along the acoustic
continuum on which these sounds lie revealed that subjects were able to
discriminate between adjacent stimuli that were perceived as different
consonants, but could not discriminate between stimuli that were
originally identified as the same consonant sound. In other words, for
equal physical differences on the acoustic continuum, acuity was
considerably greater across consonant "boundaries" (the point at which
perception shifted abruptly to a different sound) than within the same
consonant class. Liberman et al (1963, 1967,) suggest that such
"categorical" or discontinuous perception of these sounds, despite the
continuous variation in acoustic signal, results from the correspondence
of speech perception with the discrete, discontinuous articulatory
gestures that would be required to produce these sounds.

This evidence for "categorical" perception of speech sounds has
been questioned recently by Lane (1965), who argued that such perception
is not unique to speech sound continua and therefore it is not necessary
to postulate a special speech perception mechanism. A recent reply to
Lane's critique (Studdert-Kennedy, Liberman, Harris & Cooper, 1970) has
answered many of Lane's criticisms and has made what appears to be a valid
point in noting that, "Were every objection raised by Lane accepted, this
other evidence would still remain, and a special theory of speech
perception ... would still be called for". (p.234)
The above-noted experimental findings have led the Haskins workers to the conclusion that speech perception in certain cases appears to mirror the patterns of articulation more closely than the patterns of acoustic signals. This conclusion has received some further support from evidence that for certain phonemes, the pattern of EMG potentials recorded from specific articulatory muscles are relatively uninfluenced by their phoneme context (MacNeilage, 1963; Harris, Lysaught & Schvey, 1965). This finding has been viewed as supportive of the hypothesis that the listener may refer the highly variable acoustic signal of a speech sound to the more nearly invariant neuro-motor correlates of that sound.

On the basis of their own findings as well as related research, Liberman and his associates have summarized their conclusions and formulated a model of the speech perception process in the following statement:

... speech is, for the most part, a special code that must often make use of a special perceptual mechanism to serve as its decoder. On the evidence presented here, we should conclude, at the least, that most phonemes can not be perceived by a straight-forward comparison of the incoming signal with a set of stored phonemic patterns or templates... Though we cannot exclude the possibility that a purely auditory decoder exists, we find it more plausible to assume that speech is perceived by processes that are also involved in its production. The most general and obvious motivation for such a view is that the perceiver is also a speaker and must be supposed, therefore, to possess all the mechanisms for putting language through the successive coding operations that result eventually in the acoustic signal. It seems unparsimonious to assume that the speaker-listener employs two entirely separate processes of equal status, one for encoding language, and the other for decoding it. A simpler assumption is that there is only one process, with appropriate linkages between sensory and motor components ... The assumption is that at some level or levels of the production process there must exist neural signals standing in one-to-one correspondence with the various segments of the language - phoneme, word, phrase, etc. Perception consists in somehow running the process backward, the neural signals corresponding to the various segments being found at their respective levels. (Liberman et al, 1967, pp. 451-454).
This model is detailed in an earlier paper (Liberman, Cooper, Studdert-Kennedy, Harris & Shankweiler, 1966), where the authors note that the reference to motor activity does not necessarily involve reference to peripheral muscle activity and its proprioceptive feedback, although this possibility is not excluded. They further point out that reference to production provides a pathway for perception but this does not preclude direct auditory processing of speech signals by the same mechanisms that are employed for non-speech signals. Reference to production would presumably be used whenever it would facilitate perception, such as in the case of linguistic units that lack invariant acoustic cues.

In several respects, this model is similar to the model of speech perception, referred to as analysis-by-synthesis, proposed by Stevens (1960). This model is based upon the assumption that any device which produces language must store a hierarchy of articulatory rules for getting from an intended message to an articulated signal. These same rules should then allow the device to also get from an hypothesized message to a hypothetical signal. Given a basis for generating hypotheses (such as a preliminary acoustic analysis of the input, or information from the context of the input), and a mechanism for comparing the hypothesized signal with the real signal, the device would then be capable of perceiving speech as well as producing it. Simply put, a listener makes an hypothesis about an incoming message on the basis of certain information, applies a set of articulatory rules to determine what the input would be like if the hypothesis were true, and checks to determine if the input does, in fact, match the hypothetical output.

Rationale for the Present Research

An overview of the evidence presented thus far reveals that the
relationship between articulation processes and speech perception has been studied from diverse theoretical orientations, using a variety of experimental techniques. The possibility that such a relationship exists can hardly be overlooked in the light of the reported findings. What is not obvious is the nature and direction of this relationship. The EMG studies reviewed indicated that articulation processes were active during the presentation of speech sounds, but these studies did not indicate whether articulatory activity was directly involved in the perception process, although this suggestion was made. The evidence indicating a relationship between articulation problems and speech sound discrimination ability similarly left open the question of the direction of causality of the relationship - is speech sound discrimination ability a function of articulation ability, or vice-versa? Both interpretations have been offered. While there is some evidence from language learning studies that speech production ability may precede speech perception ability, there is also evidence that the lack of normal speech-motor abilities from birth does not preclude adequate processing of many types of speech sounds (Lenneberg, 1967; MacNeilage, Rootes & Chase, 1967). The short-term memory data can and have been interpreted, as Wickelgren (1969) has noted, in terms of both articulatory and auditory encoding processes. And lastly, the work of the Waskins researchers, although specifically implicating articulatory mechanisms directly in the process of speech perception, has also been of a correlational nature insofar as it points to a more direct relationship between perception and articulation factors than exists between perception and acoustic factors.

The series of studies reported in this dissertation represent an attempt to determine somewhat more directly whether certain articulation
processes are actively involved in the processing of speech sounds, by experimentally manipulating the articulation variable and measuring its effects upon the perception of specific speech sounds. According to the motor theory interpretation, the processing of speech sounds employ, in some capacity, the same neuro-motor mechanisms that are involved in the production of speech sounds. If this were in fact the case, one would expect that if the articulation mechanisms of a listener were being engaged in their motor capacity at the same time that a speech signal was being presented, these mechanisms should be less capable of performing their role in speech perception. Reducing the availability of certain articulation processes by engaging them in non-relevant motor activity should, therefore, reduce the overall efficiency of their processing capacity.

To test this hypothesis the following experimental paradigm was employed. Subjects were presented with speech sounds via earphones. During the presentation of each sound, subjects were required to perform one of two types of simple motor tasks. One type of task involved movements of the articulatory musculature, generally the tongue. The other type of task, the non-articulatory motor task, involved movements of the hand or finger. It was predicted from assumptions of the motor theory that performance of the articulatory motor task, insofar as it activated speech production mechanisms, would result in less efficient processing of speech sounds than that produced by the performance of a comparable non-articulatory motor task. The non-articulatory motor task served as a control for any effects of general motor activity upon auditory perception. That is, since any obtained differences in perception accuracy between an articulatory task and a no-task condition could be attributed to non-specific effects of simple motor task
performance, it was necessary to compare the effects of articulatory motor activation to the effects of other non-articulatory motor activation.

In most of the studies to be reported, a no-task condition was also included in the design to assess the specific effects of the two types of motor tasks employed in each study. It was possible, for example, that the performance of any simple motor task would generally interfere with perception accuracy since it could demand the division of attention between listening and task performance. In this case, both motor task groups would score lower than the no-task group. However, it would be predicted that the performance of the articulatory motor task, because of its specific interference effects due to involvement of articulation processes, would result in a greater decrement than the non-articulatory motor task. It was also possible that such motor task performance could induce greater concentration upon the stimulus sounds and consequently enhance perception accuracy for both motor task groups relative to the no-task group. In this case, the motor theory prediction would be that this general enhancement effect would be opposed by the interference effects of articulatory activation, and that the articulatory motor task condition would show less of an enhancement effect than that of the non-articulatory motor task condition. It should be noted, however, that regardless of the general effects of motor task performance relative to a no-task condition, (i.e. enhancement or decrement) the motor theory would predict lower scores for the articulatory motor task condition than for the non-articulatory task condition on tests of speech sound perception.

All of the studies to be reported employed the same basic experimental paradigm. Variations in the type of motor tasks and auditory
stimuli in the individual studies attempted to determine if, and under what conditions, the predictions derived from the motor theory would be supported. The initial three experiments examine the effects of articulatory and non-articulatory motor task performance upon the perception of speech sounds only. Each of the remaining four experiments compares the effects of the two types of motor tasks on speech sound perception to their effects upon the perception of non-speech sounds. The latter studies examined the hypothesis that the differential task effects predicted for speech sounds would not occur for non-speech sounds.
EXPERIMENT I

The present experiment was designed to determine the effects of performing (a) a simple motor task involving the speech musculature and (b) a simple motor task which did not involve the speech musculature, upon the accuracy of identification of a series of speech sounds.

The original experimental design had called for three independent task groups - articulatory motor, non-articulatory motor, and no-task conditions. Pre-testing of the stimulus sounds, however, had indicated considerable between-subject variability in accuracy of identification of the sounds. It was therefore decided to have the subjects in each motor task group serve as their own controls. According to motor theory predictions, performance of the articulatory motor task should result in a greater interference effect, or a lesser enhancement effect (as noted earlier) in the identification of speech sounds than that produced by the performance of a comparable non-articulatory motor task. It was predicted, therefore, that the task-minus no-task scores would differ for the articulatory and non-articulatory motor task groups and be reflected in a relevant interaction in the statistical analysis.

Method

Subjects. Ss were 24 male and 24 female students enrolled in an introductory psychology course. All Ss were right-handed and had no known hearing impairments.

Auditory stimuli. The stimuli used in the speech sound identification test consisted of 6 synthetically-produced consonant-vowel syllables
which differed from one another only in the initial consonant sound. The syllables used were Ba, Da, Ga, Pa, Ta, Ka. The sounds were taken from a tape produced at the Haskins Laboratory. The 6 syllables were used to generate a randomly ordered list of 36 syllables, with each syllable occurring 6 times in the list. The 6 basic syllables, followed by the list of 36 syllables, were then re-recorded on a master tape. Each syllable sound on the tape was preceded by a click occurring 2 seconds prior to syllable onset, and was followed by a click occurring 1 second after syllable offset. The 2 click sounds served as "start" and "stop" cues respectively. The stimuli were presented via a Tandberg model 64X tape recorder over Sharpe Ha-10 stereophonic earphones. The syllable sounds were presented one at a time in binaural fashion, with the volume set at the middle range of the recorder volume control.

Motor Tasks. In the articulatory motor task condition, the S was required to extend his tongue and move it at a steady rate from one side of the mouth to the other. In the non-articulatory motor task condition, the S was required to hold a pencil in the right hand and tap it at a steady rate on a sound-deadened surface in front of him. The movement involved only the wrist and hand, with the forearm resting on the table.

Procedure. Ss were randomly assigned to one of the two motor task groups, and tested individually. Each subject was seated inside an IAC model 401-A acoustical room and wore a set of earphones over which the instructions and stimulus sounds were presented. In both of the experimental groups, each S heard the syllable identification test twice - once during a control condition where the subject listened to each of the sounds without performing any motor task, and once during the task
condition where he was required to perform either the articulatory or non-articulatory motor task while listening to each of the sounds. The order of presentation of control and task conditions was counter-balanced for Ss in both experimental groups.

The S was instructed that he would hear a list of syllable sounds, presented one at a time, and that he would be asked to identify each one by writing down the appropriate syllable shortly after each sound was presented. The 6 basic syllables used were typed on the top of the answer sheet. The S was told that in order to familiarize him with the types of sounds involved, he would first hear each of the basic syllables in the order indicated on his answer sheet. Following this, the list of 36 syllable sounds were presented. For the motor task conditions, the experimenter demonstrated the appropriate task to be performed. The S was instructed to begin performing the motor task at the onset of the "start" cue, and to continue the task until the "stop" cue was presented, at which time he would record his response. Performance of the task continuously from "start" to "stop" cue was required to ensure that the motor movements would be performed throughout the entire duration of each of the sounds. Observation of each S through the window of the testing chamber, and simultaneous monitoring of the sounds ensured that the subject was following the correct procedure. In the control conditions, the "start" cue merely served as a warning signal, and S was again required to wait until the "stop" cue before recording his response. Subjects were reminded that the correct sound would always be one of the 6 basic syllables, and they were told not to leave any trials blank, but to guess if they were not sure.

**Analysis.** For each S, two scores were recorded and analyzed. One was the total number of correct identifications out of a maximum of 36. The
other measure was the number of errors (out of 6) made on each of the 6 syllables. This was of interest insofar as any differential effects of the two motor tasks might only occur for specific consonant sounds and not for all of them.

The total number of correct responses was tabulated for Task Groups (tongue-movement/tapping), Task Conditions (task/no-task), Sex of Subject, and Orders (task condition first/task condition second). These scores were analyzed by a 2 x 2 x 2 x 2 analysis of variance, with repeated measures on the Task Condition factor. For the consonant error analysis, the factors of interest were Task Group, Task Condition, Sex, and Consonants (B/D/G/P/T/K). A 2 x 2 x 2 x 6 analysis of variance, with repeated measures on the Task Condition and Consonant factors was performed on this measure.

Results

The mean number of correct identifications for Task vs. No-Task conditions within each motor task group are presented in Figure 1. The analysis revealed a poorer overall performance of the Task condition relative to the No-Task condition, as indicated by a significant main effect for Task Condition (F=6.21, df=1/40, p<.02). From Figure 1 it is clear that this effect is present only in the Tongue-Movement group and not in the Finger-Movement group, and this was reflected in a significant Task Group x Task Condition interaction (F=6.21, df=1/40, p<.02). Comparisons of the mean scores by the Newman-Keuls procedure (Winer, 1962, p.80) indicated that the Task condition mean was significantly lower than the No-Task mean for the Tongue-Movement group, (p<.01), while there was no difference between these means for the Tapping group. No other main effects, interactions, or comparisons
Figure 1: Mean identification scores for Task and No-Task conditions within each motor task group in Experiment 1.
between means were significant.

In the consonant error analysis, a significant main effect for Task Condition was found (F=7.29, df=1/44, p<.01), as well as a significant Task Condition x Task Group interaction (F=4.67, df=1/44, p<.05). Both of these results reflect the same findings observed in the above analysis, interpreted in terms of error scores rather than in terms of the number correct.

The magnitude and direction of the differential motor task effects did, however, appear to be affected by the sex of the subject and the specific consonant sound, as indicated by a significant Task Group x Task Condition x Sex x Consonant interaction (F=4.67, df=5/220, p<.05). Figure 2 shows the mean error scores for each of the subgroups. A comparison of the means revealed only two significant differences between Task and No-Task conditions. The Tapping task produced significantly fewer errors than its No-Task condition (p<.01) on the /t/ sound, but only for males. The Tongue-Movement task produced significantly more errors than its No-Task condition (p<.01) on the /p/ sound, but only for females. Further inspection of Figure 2 indicates that for males, the Tongue-Movement condition made more errors (relative to its No-Task condition) than did the Tapping condition (relative to its No-Task condition) on four of the six consonant sounds (all except /p/ and /k/). For females, the same effect is also seen on four of six sounds (all except /t/ and /k/). It would appear that the sounds /p/, /t/ and /k/ provided the main source of variability in the obtained four-way interaction.

Discussion

On the basis of the motor theory view that processing of speech
Figure 2: Mean error scores for Task and No-Task conditions for males and females on each consonant sound in Experiment 1.
sounds involves articulatory-motor processes, it was hypothesized that the performance of an articulatory motor task (tongue movement) would produce a greater degree of interference than the performance of a comparable non-articulatory motor task (tapping), in the processing of speech sounds. The results of the present study found that the performance of the articulatory motor task produced a significant decrement, relative to a no-task condition, in the accuracy of identification of a series of consonant-vowel syllable sounds. The non-articulatory motor task was found to have virtually no effect upon the accuracy of identification of the sounds, relative to its no-task condition. These findings were reflected in a significant Task Group x Task Condition interaction, and are consistent with motor theory predictions.

The differential effects produced by the performance of the two motor tasks appears to apply for a majority of the consonant sounds for both males and females, although the presence of a significant four-way interaction suggests that the magnitude of this effect may depend to some extent upon the sex of the subject and the specific consonant sound being presented. It is of interest to note that those consonant sounds which did not show the expected differential task effects (/p/, /t/, /k/), were all of the phonetic class of unvoiced stop consonants. If these findings were found to be reliable, it could indicate differing degrees of involvement of articulation mechanisms in the processing of voiced and unvoiced consonant sounds.
EXPERIMENT II

Experiment II was designed essentially as a replication of Experiment I. A second purpose of the study was to assess the generality of the findings in the first experiment; i.e. to determine whether the results of the previous experiment were specific to the two types of motor tasks employed, or whether it is possible to make a more general statement about the effects of articulatory versus non-articulatory motor tasks. To answer this question, the present study employed a different non-articulatory motor task, and compared it to tongue movement with respect to its effects upon accuracy of identification of speech sounds. In the selection of this new task, consideration was given to the possibility that the differential effects of the two motor tasks in the first study might be attributable, at least in part, to differences in the level of difficulty or attentional requirements of the two tasks. It might be argued, for example, that although both tasks appeared to be of equal complexity in that they both required simple, repetitive, and rhythmic movements, the tapping task was a more highly practised movement than was moving of the tongue from side to side, and might, therefore, require less concentration and attention than the tongue movement task. The present study, therefore, employed a non-articulatory task which closely matched the tongue movement task in terms of overt motor pattern, as well as in the fact that it was not a highly practised motor pattern. These requirements being met, there would appear to be little a priori basis for assuming that moving the tongue should be more difficult, or require more attention than a comparable non-articulatory motor task.
Method

Subjects. Twenty male and 20 female students enrolled in an introductory psychology course served as Ss. All were right-handed and had no known hearing impairments. Ten male and 10 female Ss served in each experimental condition.

Auditory stimuli. The stimuli comprising the speech sound identification test were identical to those used in Experiment I. There was, however, one modification of the test. As the mean identification score for the control conditions in the first experiment was relatively high (approximately 29/36), the difficulty level of the test was increased by the addition of a white noise background to each of the syllable sounds in the test. A wide-band (0-20,000 cps) white noise signal produced by a Grason-Stadler noise generator was recorded on magnetic tape and then re-recorded on the second track of the identification test tape. Both tracks were then "mixed" internally by the tape recorder and the subject was presented with a combined speech sound and white noise signal. As the speech sounds and white noise were recorded on separate tracks, the volume of each could be independently controlled. A speech signal/noise ratio of suitable "difficulty level" was established by varying the volume of the white noise during pre-testing to determine the effect on identification test scores. The onset of the white noise occurred 2 seconds prior to the presentation of each syllable sound and continued until 1 second after the offset of the syllable sound. Thus the onset and offset of the white noise served in place of the click sounds as the "start" and "stop" cues respectively.

Motor tasks. The articulatory motor task was the tongue movement task described in the previous experiment. The non-articulatory motor task
required the subject to place his right forearm on the table in front of him, extend his right forefinger (in pointing fashion) and move it from side to side at a steady rate between two fixed posts which were two inches apart. This was designed to approximate as nearly as possible the motor pattern of the tongue movement task.

Procedure and analysis. Both the procedure and analysis were identical to those of Experiment I.

Results

The mean number of correct identification for Task vs No-Task conditions within both of the motor task groups is presented in Figure 3. The analysis revealed that the mean score for the Tongue-Movement group was significantly lower than that of the Finger-Movement group (F=5.0, df=1/32, p<.05). None of the comparisons between individual means plotted in Figure 3 were statistically significant. The expected Task Group x Task Condition observed in Experiment I interaction was not obtained. The analysis also revealed a significant Task Condition x Order of Conditions interaction (F=11.44, df=1/32, p<.01). This interaction was not observed in Experiment I and indicated the presence of an order or practice effect, discussed below.

Discussion

Although the analysis indicated that the mean score for the Tongue-Movement group was significantly below that of the Finger-Movement group, the expected Task Group x Task Condition interaction observed in Experiment I was not significant in the present results. Inspection of Figure 3 indicates that for some reason, the No-Task condition mean
Figure 3: Mean identification scores for task and no-task conditions within each motor task group in Experiment II.
score was considerably lower for the Tongue-Movement group than for the Finger-Movement group. Had the scores for the two No-Task conditions been equivalent (as would be expected on the basis of random assignment of subjects to groups), the pattern of scores would have been virtually the same as in the first experiment. In this experiment, as in Experiment I, there was virtually no difference between the Task and No-Task condition scores for the Finger-Movement group.

Examination of the significant Task Condition x Order of Conditions interaction revealed that the order in which the Task and No-Task conditions were performed played a major role in determining the scores. In both orders of presentation (task first/task second) the score for the condition which was performed second was found to be significantly higher (p<.05) than the score for the condition performed first. This was not observed in Experiment I. It was also found that the magnitude of this order effect differed considerably for the two groups. For the Finger-Movement group, there was little difference (.5 points) in mean score whether the task was performed first or second. For the Tongue-Movement group, however, when the task condition was performed second it resulted in a mean score approximately 4 points higher than when it was performed first. This differential order effect would tend to elevate the Tongue-Movement task scores in Figure 3 to a greater extent than was the case for the Finger-Movement group. Similarly, there appeared to be a difference in the size of the order effect for the No-Task conditions of the two groups. For the Finger-Movement group, the increase in score when the No-Task condition was performed second (relative to when it was performed first) was approximately 2.5 times the comparable increase observed for the Tongue-Movement group. This tended to elevate the No-Task condition score for the Finger-Movement group relative to the
Tongue-Movement group.

Although it is possible to speculate why such differences in the effects of order for both groups were found it is of interest to note that such differential effects would militate against a simple interpretation of the effects of task performance upon the accuracy of identification of speech sounds. For this reason, it was decided to re-analyze the data using only the scores for the conditions which occurred first, and in this way eliminate problems of interpretation relating to order effects.

The re-analysis of the data therefore used only half of each subject's data - i.e. the score for the condition performed first. This resulted in three independent groups of scores, with 10 scores in each of the Finger and Tongue-Movement groups, and 20 in the No-Task group. In this design, the motor theory would predict lower scores for the articulatory motor task relative to the non-articulatory motor task. The results of Experiment I also suggested that the tongue movement task would show a decremental effect relative to the No-Task condition.

A one-way analysis of variance was performed on these three independent samples. Since the number of subjects in each group was not equal, and since it has been shown that the F statistic is most sensitive to heterogeneity of variances when the number of observations for each treatment is unequal (Box, 1953), the Hartley $F_{\text{max}}$ statistic was computed to test for homogeneity of variance. This revealed an $F_{\text{max}}$ of 1.69, which provided no grounds for rejection of the assumption of homogeneity. The analysis of variance revealed that the mean scores of the three groups differed significantly ($F=3.25$, $df=2/37$, $p<.05$). Post-hoc comparisons of the means indicated that the score for the Tongue-Movement group was significantly lower ($p<.05$) than that of the Finger-Movement group. No other comparisons were significant. The means for each of
the groups are indicated in Figure 4. Thus, when order was controlled, the predicted difference between motor task group scores was obtained. The difference between the Tongue-Movement and No-Task scores, although not significant, was in the same direction as observed in Experiment I.

A 3 x 6 analysis of variance was performed on the consonant error measure. There were 3 levels of Task Group and 6 levels of Consonant, with repeated measures on the Consonant factor. The results showed only a main effect for Consonants (F=29.73, df=5/185, p<.01).

The findings illustrated in Figure 4 show a small enhancement effect for the Finger-Movement group and a small decremental effect for the Tongue-Movement group, relative to the No-Task condition. These data are consistent with the motor theory predictions that the performance of an articulatory motor task would result in less efficient speech processing than that produced by the performance of a non-articulatory motor task. The results also suggest that the nature of the non-articulatory motor task was not a crucial factor in producing the effect, since the present study employed a different non-articulatory task than was used in Experiment I.

The results of the analysis of consonant errors are in general agreement with that of the first experiment. The absence of a significant Task Group x Consonants interaction suggests that the differential effects of the tasks was a general one and did not differ significantly for the different consonants. The only significant F ratio in the analysis was the main effect for Consonants, which indicates that in general, more errors were made on some consonants than on others. This question was of little theoretical interest and was therefore not examined further.
Figure 4: Mean identification scores for each motor task group based upon re-analyzed data of Experiment II.
EXPERIMENT III

Primarily two questions were examined in Experiment III. First, it was of interest to determine whether the obtained differential effects of articulatory and non-articulatory motor tasks on speech perception would also be found in young subjects. Since overt articulation is a prominent feature in the early development of language capacities in children, it would seem reasonable to expect that articulation mechanisms could play a role in speech perception in children. That the age of subjects might be a significant factor was also suggested by the evidence reviewed earlier indicating that a consistent positive relationship between articulation abilities and speech sound discrimination exists only in young children (Weiner, 1967). Other researchers, however, (Manyuk & Anderson, 1969) have hypothesized that the perceptual mechanisms of children, unlike those of adults, may not be closely linked to productive mechanisms. According to these investigators, the use of articulation processes in speech perception would be more likely to occur in adulthood. If speech production mechanisms are used in speech processing by children, then the differential task effects predicted by the motor theory would be expected to occur. In order to test hypothesis, the present study used young children as subjects.

A second question of interest in the present study related to the nature and mode of presentation of the speech sounds. Both Experiments I and II had employed synthetically-produced consonant-vowel syllable sounds in the speech sound identification test. The somewhat unusual quality of the sounds had provided a useful test which was neither excessively easy nor difficult to perform. However, a point that might reasonably be raised is whether similar results would have been obtained using speech sound stimuli produced by a normal voice. It could be
argued that the synthetically-produced stimuli might not be processed as human speech, and that the observed effects could not be unambiguously interpreted in terms of speech processing mechanisms. In order to clarify this point, the same syllable sounds were used in the present study, but were produced by a male voice rather than by machine.

The use of normal-voice speech sounds required a method of presentation that would permit the sounds to be presented "purely" (i.e. not degraded in any way), while still providing a useful speech perception test that would produce a suitable range of scores. The procedure adopted was that of "dichotic" presentation of pairs of consonant-vowel syllable sounds. This involved the simultaneous presentation of two different sounds over earphones, with one sound presented to the left ear and the other to the right ear. The subject was required to identify both sounds that were presented. This procedure provided an added advantage of permitting an analysis of the effects of the motor tasks at two levels. That is, the effects of the motor tasks could, as before, be reflected in differences in overall accuracy; or alternatively, the different task groups might show different patterns of left vs. right ear scores. The pattern of ear scores was of interest since research by a number of people (e.g. Kimura, 1961b, 1967; Broadbent & Gregory, 1964; Bryden, 1967) has established the existence of a right-ear superiority in the accuracy of report of dichotically presented verbal stimuli, and a left-ear superiority for certain non-verbal stimuli. The right-ear superiority has been interpreted by Kimura and others as reflecting more efficient neural connections from the right ear than from the left ear to the left cerebral hemisphere, which is known to be the dominant hemisphere for speech processes in most cases. If the articulatory motor task interfered with these processes, it could
conceivably interfere with the pattern of right-ear superiority normally seen in perception of dichotic verbal stimuli. Such an interference effect would be expected to be greater than that produced by the non-articulatory motor task, and would be reflected in a Task Group x Ear interaction.

A final modification employed in the present study was to require subjects in the non-articulatory motor task group to perform the task using the non-preferred (left) hand. The rationale for this modification was the same as that applied in Experiment II - i.e., to determine the generality of task effects to particular types of motor movement.

Method

Subjects. The Ss were 18 male and 24 female elementary school children ranging in age from 7 to 9 years. All Ss were right-handed and had no known hearing impairments. Six males and 8 females served in each of the three experimental groups. The Ss in each group were equated by means of matched triads for age, grade and class.

Auditory stimuli. The speech sound stimuli in the identification test consisted of the same six consonant-vowel syllable sounds used in the previous experiments. The sounds were produced by a male speaker rather than being synthetically produced. A list of 18 syllable-pairs were selected from a set of all possible syllable-pairs with the restrictions that (a) no syllable was paired with itself, (b) each syllable occurred 6 times in the list, (c) each syllable occurred 3 times as the left-sided member of a pair and 3 times as the right-sided member of a syllable pair. In the preparation of the test tape, one member of each pair was recorded on one of the tracks, and the other member recorded on the second track. To produce simultaneous onset of the sounds, both sounds
in a pair were recorded at the same point on the tape, which was marked with a felt-tipped pen. To ensure consistency of the sounds in each pair, the originally recorded 6 syllables were used to make up all 18 pairs. The final test tape consisted of the 6 individual syllable sounds presented one at a time at 2 second intervals, followed by 3 practice pairs of syllable sounds, followed by the test list of 18 pairs.

**Motor tasks.** The articulatory motor task was the same as in the previous studies. The only difference in the non-articulatory motor task from that of Experiment II was that the task was performed with the left rather than the right hand. A small wooden base, on which two vertical posts were mounted 2 in. apart, was placed on the subject's lap. When S was not performing the task, he rested his hand on the wooden base, and kept his left forefinger extended between the two posts. As in experiment II, he was required to move his forefinger from side to side between the posts when doing the task.

**Procedure.** The basic procedure outlined in Experiment II was followed with certain changes made primarily to accommodate the age of the subjects. Subjects were randomly assigned to the Finger-Movement, Tongue-Movement, and No-Task groups, and were tested individually. Testing was done at the children's school in a quiet room, and each child wore a set of earphones over which the instructions and speech sounds were presented. The child was told that he would hear a voice saying some sounds, and that he should repeat each sound after hearing it. The experimenter then repeated the six basic syllable sounds. The child was then asked to repeat each syllable after it was presented on the tape. This served the dual purpose of familiarizing the S with the sounds and ensuring that there was no articulation or hearing difficulties. The series of six syllables was presented 3 times for each S with this portion of the tape being re-played
twice after the initial presentation. If a child made more than two errors on any series, or was unable to correctly repeat the syllables by the third time, he was not tested further. In the next part of the procedure the child was told that he would be hearing the same sounds that he had been listening to, but that now they would be presented two at a time, with a different sound coming to each ear. He was also instructed that the sounds would always be from the group of 6 sounds, and that there would always be two different sounds. He was told to guess at the sounds if he was not sure. Three practice pairs of syllables were then presented. For Ss in the task groups, the experimenter then demonstrated the task to be performed. In this study, the click sounds were not used on the tape to cue the onset and offset of the task, as this was found to be quite difficult for the children to remember. Instead, the subject was instructed to begin performing the task when the experimenter said "start" and to continue until the experimenter stopped the tape. The tape recorder was therefore manually started and stopped before and after each syllable was presented. The "stop" cue was not given verbally in order not to distract the subject's attention from reporting the sounds. The "start" cue was given approximately 2 seconds before the onset of each syllable-pair and the "stop" occurred immediately after each pair was presented. Ss' verbal responses were recorded on answer sheets which indicated the correct responses and the ear to which each syllable was presented.

**Analysis.** The number of correct identifications for the left and right ears of each subject was tabulated and analyzed by a $2 \times 2 \times 3$ (Sex $\times$ Ear $\times$ Task Group) analysis of variance, with repeated measures on the Ear factor. A subsequent one-way analysis of variance was performed on these scores, collapsed over the Sex and Ear levels, for the 3 task
groups. The number of errors made on each consonant sound were again tabulated and analyzed, using a 2 x 6 x 3 (Sex x Consonant x Task Group) analysis of variance, with repeated measures on the Consonant factor.

Results

The analysis of the ear scores revealed a significant main effect for the Ear factor indicating higher scores for the sounds which were presented to the right ear than for those presented to the left ear ($F=4.49$, $df=1/36$, $p<.05$). Figure 5 shows this effect, and it can be seen that each of the three groups contributed to the right-ear superiority. It is also clear from this figure, as well as from the absence of a significant Ear x Task Group interaction, that the pattern of ear scores did not differ for the different task groups. It was found that the scores for the three motor task groups differed significantly ($F=3.80$, $df=2/36$, $p<.05$). Inspection of Figure 5 indicates that for both the left ear and right ear scores, the Tongue-Movement group again had lower scores than the Finger-Movement group, with the No-Task group falling between the two task groups. Post-hoc comparisons revealed that these differences, when examined for the left and right ears separately, did not reach statistical significance.

Comparison of the combined-ear scores by a subsequent one-way analysis of task group scores, collapsed over the Sex and Ear factors revealed a significant $F$-Ratio ($F=3.80$, $df=2/39$, $p<.05$) for the task groups. The mean task group scores are shown in Figure 6 for purposes of comparison with Figure 4. Comparisons between means showed that the Tongue-Movement groups scored significantly lower ($p<.05$) than the Finger-Movement group. No other comparisons were significant.

In the analysis of the consonant errors, a significant main effect
**Figure 5:** Mean identification scores for left and right ears within each motor task group in Experiment III.
for Consonants was found ($F=21.15$, df=5/180, $p<.001$) as well as a
significant Consonant x Task Group interaction ($F=1.99$, df=10/180,
$p<.05$). This interaction is plotted in Figure 7. Comparisons of
the means showed that for the consonant B, the Tongue-Movement groups
made significantly more errors ($p<.01$) than both the Finger-Movement
and No-Task groups. For D, the Tongue-Movement group again made more
errors than the other two groups, although only the difference between
the Tongue-Movement and No-Task groups was significant. For G, the
No-Task group made significantly more errors than the Finger-Movement
group ($p<.01$) and the Tongue-Movement group ($p<.05$). No other
comparisons were significant.

Discussion

One of the questions asked in the present study was whether the motor
task group difference predicted from the motor theory of speech perception
would be found in young children. When the scores for the left and
right ears were combined and the total scores analyzed, the resultant
pattern of scores shown in Figure 6 was very similar to that observed
in Figure 4 of Experiment II, which also involved three independent groups
of subjects in the experimental design. As in Experiment II, the present
study showed that the mean scores for the Tongue-Movement group was
significantly lower than that of the Finger-Movement group, with the
No-Task group score falling between the two task group scores. It would
appear that similar processes are operating for both the adults and
children. Applying the motor theory interpretation to these results,
it would seem that the processing of speech sounds is to some extent
dependent upon speech production mechanisms at a relatively early age.
Such a conclusion would fit relatively well with the observations of
Figure 6: Mean combined - ear identification scores for each motor task group in Experiment III.
Figure 7: Mean error scores for each motor task group on each consonant sound in Experiment III.
various researchers in the area of language development (e.g. Fry, 1966; Luria, 1966) who have stressed the close relationship between articulation and speech perception processes in the early developmental stages of language abilities.

The agreement of the present results with the findings of Experiment II indicates that the synthetically-produced speech sounds employed earlier were in fact being processed similarly to the normal voice speech sounds used in this experiment. Support for this conclusion also comes from the fact that these same synthetic stimuli, when used in auditory perception experiments involving dichotic presentation, have shown the same pattern of right-ear superiority which has been found for other types of normal voice speech sounds (Shankweiler & Studdert-Kennedy, 1967).

It is clear from Figure 5 that the performance of the two motor tasks did not differentially affect the pattern of right-ear superiority which is typically observed for verbal stimuli. In each group, identification of sounds presented to the right ear was more accurate than for the sounds presented to the left ear. Nor did the pattern of task group scores for the left ear differ significantly from the pattern seen for the right ear. The differential task effects of the two motor tasks does not, at least in children, appear to involve the mechanisms which operate to produce a right-ear superiority. The task effects would appear to modify the overall efficiency, as opposed to the relative ear efficiency, of processing of speech sounds.

In the consonant error analysis, the significant Task Group x Consonant interaction indicated that the task effects were not uniform for all consonant sounds. It may be noted in Figure 7 that the Tongue-Movement group made more errors than the Finger-Movement group on 4 of
the 6 consonants (B, D, G, K), which would account for the significant differences in mean scores which have been found between these two task groups. The direction of the difference between these two groups is reversed for the consonant sounds P and T, where the Finger-Movement group made more errors than the Tongue-Movement group. This reversal would seem to provide the basis for the interaction. Despite the presence of the interaction, present results support the interpretations of previous consonant error analysis insofar as they again show that the differential effect of the two motor tasks (i.e. the greater error scores for the Tongue-Movement group) is present for the majority of the sounds. A further observation is that, as in Experiment I, the two consonants for which the pattern of error scores was reversed were both unvoiced consonants.

In summary, the results of the present study closely parallel those of Experiment II and are consistent with motor theory predictions. The findings suggest that the mechanisms underlying the task effects observed earlier in adults are also operative in children. The differential task effects observed in the present study appear to reflect a modification at the level of overall efficiency, rather than relative ear efficiency, of speech sound analysis. The recurrence of similar effects to those observed in the last experiment, despite changes in the speech-sound quality, the mode of presentation of the stimuli, and the hand used in the non-articulatory motor task, implies a minimal role for these factors in the production of the Task Group differences.
One of the questions raised by the results of the preceding studies is whether the mechanisms producing differences in scores for the two motor task groups are specific to certain types of sounds. Several of the proponents of the motor theory position have pointed out that their theory does not preclude the possibility of direct auditory processing of speech signals by the same mechanisms that are employed for non-speech signals (Liberman et al, 1966). Articulation mechanisms presumably would be used whenever such usage would facilitate perception. This would imply that certain types of speech sounds may be minimally or negligibly dependent upon articulation processes for their analysis. Such sounds would not be expected to show the same differential interference effects of motor tasks as have thus far been observed with the consonant-vowel syllable sounds. An obvious question then presents itself. What kinds of sounds involve the use of such articulation mechanisms? The determination of the characteristics of such sounds might provide information about the types of operations that articulation mechanisms are performing. One of the main interests of the present (and subsequent) study, therefore, was to examine the effects of the articulatory and non-articulatory motor tasks upon a different and more complex type of speech sound than has been used heretofore. The speech sounds used in this study were tri-syllabic nonsense words.

An additional aspect of the present and the following studies was the inclusion of non-speech sounds in the experimental design. Although Liberman et al (1966) speculate that speech sounds may be processed entirely or in part by mechanisms used in the analysis of non-speech
sounds, it is not specified whether articulation mechanisms might theoretically be employed in the processing of non-speech sounds. Conceivably, sounds such as humming, laughing or crying which are produced by articulation mechanisms but which are essentially non-speech sounds, may involve the use of articulatory elements in their processing. Instrumental melodies may evoke verbal components during the perceptual process. Possibly "reference to production" might facilitate the processing of such sounds and thus involve the use of articulation mechanisms in the perception of these sounds. However, for most non-speech sounds, use of articulation mechanisms would likely be minimal, and if this were the case one would not expect differential task effects to occur with these sounds. The addition of a non-speech sound perception test was designed to test this inference. Assuming that the speech sounds were of the type which involved the use of articulation mechanisms, and the non-speech sounds were of the type that did not, it would be expected on the basis of motor theory assumptions that differential motor task effects would be found for the speech perception test but not for the non-speech sound test, i.e. a task x stimulus interaction. In the present study melodic segments were used as non-speech sounds.

The present study employed dichotic presentation of the speech and non-speech sounds. It was of interest to determine whether the two types of motor tasks would differentially affect the pattern of left-right ear scores in adults.

Method

Subjects. The subjects were 20 male and 26 female students enrolled in an introductory psychology course. All Ss were right handed and had no known
hearing impairments. Ten males and 13 females served in each motor
task group.

Auditory Stimuli. The stimuli for both the speech and non-speech
perception tests were obtained from tapes used in other auditory
perception studies (Kimura, 1961, 1964). The speech sound perception
test consisted of a series of pairs of tri-syllabic nonsense words
recorded by a female speaker. Corresponding syllables in each pair
contained the same vowel but different consonant sounds. An example
of such a pair might be Baf-nud-rol ...... Dat-muv-gom. Each of the
pairs was recorded on magnetic tape for dichotic presentation as
described in Experiment III and was preceded and followed by click
sounds which served as "start" and "stop" cues for the performance of
the motor tasks, as in Experiments I and II. A group of four tri-
syllabic nonsense words followed 3 seconds after the "stop" cue for each
stimulus pair. The four test "words" were spaced 2 seconds apart.
Two of the four nonsense words were identical to the two words included
in the previous dichotic pair, and the other two were similar types of
words in which one or both of the consonant sounds in each syllable were
altered. The subject was required to select which two of the four
nonsense words had been presented in the dichotic pair. Each trial,
therefore, consisted of a dichotically-presented pair of nonsense words
followed by four normally-presented (i.e. binaurally presented) nonsense
words. The test tape consisted of two practice trials and 12 test trials.

The non-speech sound test was similar to the speech sound test, with
the exception that the individual stimuli corresponding to nonsense words
consisted of 4-second segments of classical music. As in the speech
sound test, each dichotic pair of melodies was followed by a group of
four melodies, two of which were identical to the melodies included in the
dichotic pair. There were two practice trials and 10 test trials on the test tape.

Motor tasks. The articulatory motor task once again involved movement of the tongue from side to side. The non-articulatory motor task again consisted of movement of the left forefinger from side to side between two fixed posts, while resting the left forearm on the table in front of the subject.

Procedure. The testing procedure was essentially the same as that followed in the first two experiments. Subjects were assigned to either a Finger-Movement or a Tongue-Movement motor task group. In both of the task groups, Ss heard both the speech sound and non-speech sound tests. The order of presentation of the tests was counterbalanced. In each of the tests, S was familiarized with the dichotic presentation procedure and instructed that he would be required to identify which two sounds had been presented dichotically from the group of four sounds which followed each pair. The S was not required to report the sounds themselves, but to identify them by their place in the group of four sounds. For example, he might report "first and third" if he thought these were the correct sounds. Following initial instructions, the S was given a practice trial with the stimulus sounds. Following this trial, he was acquainted with the motor task he was required to perform and instructed that the click sounds were to cue the onset and offset of the task. He was then given a second practice trial using the test procedure. The series of test trials was then presented. The tape was stopped after each trial while S reported his responses. Upon completion of the first test, the S was told that he would be doing a second test, and that the only change in the procedure would be in the type of sounds he would be hearing. The second test tape was then
presented.

Analysis. The percent correct scores for the left and right ears were calculated for each subject and the data were analyzed by a 2 x 2 x 2 x 2 (Sex x Ear x Task Group x Stimulus Type) analysis of variance, with repeated measures on the Ear and Stimulus Type factors. In order to facilitate interpretation of the statistical results, the simple main effects and interactions (Winer, 1962, p.174) were subsequently examined by separate 2 x 2 x 2 (Sex x Ear x Task Group) analysis for the speech sound and non-speech sound scores.

Results

Since there were unequal cell Ns, tests for heterogeneity of variance (Winer, 1962, p.94) were carried out and revealed Cochran's C values of .1607, .2581, and .1673 respectively for the overall and component analysis. These values provided no basis for the rejection of the assumption of homogeneity of variance.

The results of the four-way analysis of variance revealed several statistically significant findings. The sounds coming to the right ear were generally reported more accurately than those presented to the left ear, as indicated by the significant Ear effect (F=8.62, df=1/42, p<.01). Subjects performed better on the non-speech sound test than on the speech sound test (F=65.60, df=1/42, p<.001). As neither of these differences were directly relevant to the hypothesis under investigation, they were not further examined. Examination of the overall accuracy scores (i.e. the combined left and right ear scores) indicated that the mean score for the Tongue-Movement group was again slightly lower than that of the Finger-Movement group - 53.4% compared to 54.7%. The absence of a significant Task Group main effect indicates that this
difference was not significant. The nonsignificant Task Group x Stimulus Type interaction indicates that the pattern of Task Group scores for the speech sounds did not differ significantly from the pattern for non-speech sounds. For the latter sounds, the Tongue-Movement group obtained a score of 68.9% correct compared to the score of 70.7% correct for the Finger-Movement group. In addition to the significant main effects for Ear and Stimulus Type described above, two significant interactions were found. The Sex x Ear x Task Group interaction ($F=5.26, df=1/42, p<.05$) indicated that the pattern of left and right ear scores was to some extent dependent upon sex of the Ss and the particular task group that they were in. This interaction was further qualified by a significant Sex x Ear x Task Group x Stimulus Type interaction. The subsequent analysis of the speech sound data alone again indicated a significant right-ear superiority ($F=10.19, df=1/42, p<.01$) as well as a significant Sex x Ear x Task Group interaction ($F=13.77, df=1/42, p<.001$). Both of these effects were observed in the original analysis. For the non-speech sound data, however, no significant main effects or interactions were found. This would indicate that the Ear effect and Sex x Ear x Task Group interaction observed originally were primarily accounted for by the speech sound scores. The absence of similar significant effects for the non-speech sound test scores would likely account for the involvement of the Stimulus Type factor in the significant four-way interaction observed in the original analysis.

The significant Sex x Ear x Task Group interaction for the speech sound test scores is illustrated in Figure 8. Post-hoc comparisons between the means revealed a significant ($p<.01$) right-ear superiority for the females in the Finger-Movement group, and for the males in the
Figure 8: Mean left and right ear identification scores for males and females within each motor task group on the speech sound test in Experiment IV.
Tongue-Movement group. No other comparisons were statistically significant. Inspection of Figure 8 indicates that the pattern of left-right ear scores depends both on sex and task group. In the Finger-Movement group, males show a small, non-significant right-ear superiority, while females show a large and significant right-ear superiority. A different pattern is seen in the Tongue-Movement group. Here the males show a large, significant right-ear superiority, while females demonstrate a small left-ear superiority.

Discussion

One of the questions posed in the present study was whether the performance of the articulatory motor task would produce poorer performance than a non-articulatory motor task in the perception of speech sounds which were different from, and more complex, than those employed in the previous experiments. The difference in mean scores between the Finger-Movement and Tongue-Movement groups on the speech sound test was not statistically significant, although the difference was in the direction predicted by the motor theory hypothesis.

A further question asked was whether the effects of task performance would differ for the speech and non-speech sounds. The absence of a significant Task Group x Stimulus Type interaction indicates that the pattern of task group mean scores for speech sounds did not differ significantly from that of non-speech sounds. The absence of significant task group differences on the non-speech sound test, it will be recalled, was expected according to predictions derived from the motor theory hypothesis.
A pertinent question which arises is: what aspects of the speech stimuli used in the present study may have acted to produce smaller task group differences than have been observed with the consonant-vowel syllables used earlier? It is possible that increasing the complexity of the speech sounds may have brought into play other perceptual mechanisms which involved the use of articulation processes to a lesser degree. If this were the case it would suggest that articulatory-motor involvement in processing speech sounds may be greatest in the analysis of the simpler linguistic units such the phoneme or the syllable, and least in the analysis of higher order units. Conceivably, the use of a more complex sound could have substantially increased the number of acoustic cues which do not require the use of articulation mechanisms in their analysis, allowing a more direct auditory processing by mechanisms normally involved in non-speech sound processing. Liberman et al (1966) have suggested such a possibility for some types of speech sounds.

Although the overall accuracy on the perception tests did not differ significantly for the two motor task groups, the pattern of ear scores resulting from the dichotic presentation of the sounds was affected by both the type of motor task performed and the sex of the subject. The significant Sex x Ear x Task Group interaction for speech sounds is presented in Figure 8. It is clear that the pattern of left-right ear scores differs for males and females, and that the nature of this sex difference depends upon the specific task group. Exactly why these differences in ear pattern between males and females should occur within each task group is not readily apparent. Research on dichotic presentation of speech stimuli has not generally reported significant sex differences in magnitude or direction of ear superiority. There is, however, some evidence that the right-ear superiority tends to develop
earlier for females than for males (Kimura, 1967). Possibly the performance of a task during presentation of the sounds led to different listening strategies for males than for females. If this were the case, however, one might question why the strategy would result in an enhanced right-ear superiority for females relative to males in the Finger-Movement group, but a reversed left-ear superiority for females relative to males in the Tongue-Movement group. It appears that the nature of the motor task performed was a determinant in these differential patterns of ear scores. Of particular interest and relevance to the hypotheses under investigation is the fact that the only case in which the normally occurring right-ear superiority did not occur was in females of the Tongue-Movement group. It appears that movement of the tongue did act to modify a process normally seen to operate in the perception of speech sounds (i.e. right-ear superiority), although this was so only for females. The fact that the males in the Tongue-Movement group showed no similar interference effects may suggest that females employ articulation mechanisms in this particular aspect of speech sound analysis to a greater extent than do males, and for this reason show a greater degree of modification of their relative ear scores. This interpretation, however, is highly speculative at this time.

It should be noted that the results of Experiment III suggested that the differential effects of the two motor tasks did not involve the mechanisms which operate to produce a right-ear superiority. Experiment III, however, employed children as subjects while the present study involved college students. These facts point to the possibility of an increasing participation with increasing age of articulation components in this particular speech perception mechanism. Older
subjects might therefore demonstrate greater sensitivity than children
to effects of an articulatory motor task upon the ear score measure.
Such a conclusion, on the basis of a different line of evidence, has
been drawn by Menyuk & Anderson (1969) who have proposed that the use
of articulation processes in speech perception would be more likely to
occur, or would occur to a greater extent, in adults than in children.
It is possible that this proposal may be a valid one, at least for
certain levels of speech sound analysis.

The observation of no significant differences in overall accuracy
or in ear pattern scores between the two motor task groups on the non-
speech sound test is consistent with the hypothesis that differential
effects of the two tasks would not be expected to occur with most types
of non-speech sounds, which presumably do not employ articulation
mechanisms in their analysis. The observation of no significant
differences for these sounds is also of interest insofar as it suggests
that the motor tasks used in this study (and the previous two studies)
were in fact comparable in terms of difficulty level and attentional
requirements. Were this not so, inequalities in task difficulty would
be expected to be reflected in differences between the task groups in
the accuracy of perception of these sounds.

In summary, the present study did not find significant differences
between the two motor task groups in the overall accuracy of perception
of the speech sounds, as has been observed in Experiments II and III,
although differences were in the direction found in the earlier studies.
Since a more complex type of speech sound was used in the present study,
the absence of such differences could indicate that the complexity of
the speech sounds is a determinant of the degree to which articulation
mechanisms are involved in the processing of speech sounds. The
expected Task Type x Stimulus Type interaction was not significant. The two tasks did, however, appear to differentially affect the pattern of ear superiority, particularly for females. The analysis of the scores for the non-speech sounds revealed no such differences, in agreement with motor theory predictions.
EXPERIMENT V

Experiment V was designed to investigate two main questions. The first question, which stems from the results of Experiment IV, was whether the complexity of speech sounds is a major factor in the determination of differential effects of the articulatory and non-articulatory motor tasks. Experiment IV, which did not find statistically significant motor task differences, was the first study to use 3-syllable sounds as opposed to the single syllable sounds used in previous studies. In addition to this aspect of the sounds, there were other features that may have acted to minimize differences between the two task groups, such as the multiple-choice procedure for identifying the presented sounds. That is, the fact that the subject did not have to identify each of the consonant sounds in the nonsense word and could have used only part of the acoustic information to identify the entire "word", may have resulted in the speech perception test being less sensitive to task effects. In order to determine if complexity (i.e. number of syllables) was a factor, the present study employed consonant-vowel syllables of the type used in the first three studies, but presented in tri-syllabic units, e.g. Ba-Ga-Da. As in the earlier studies, subjects were again required to identify each of the consonant sounds presented. If these sounds, which have previously been found to show differential task effects when presented singly, did not show similar effects when presented in tri-syllabic units, it would suggest that complexity of the speech sounds was an important variable.
As in Experiment IV, the present study included a non-speech sound perception test in order to test the hypothesis that the task effects predicted for the speech sounds would not be expected for non-speech sounds. To determine whether this prediction would be confirmed with another type of non-speech sound, a new non-speech sound test was devised in which the S was presented with a series of tone trigrams, with each of the tones differing from each other in frequency. Subjects were required to label the tones low, medium, or high, relative to one another. This test was designed to be as similar as possible in structure to the speech sound test, as was the case in Experiment IV. This was intended to minimize the likelihood that any differential task effects for the two types of sounds could be attributed to differences in the test procedures.

The second question of interest was whether the predicted task effects would be obtained for a new measure of discriminability of the speech and non-speech sounds. The previous studies, as have most studies of speech sound discrimination, employed error scores (or the number of correct identifications) as a measure of perception. Recently, McInish and Tikofsky (1968) have used response latency measures in tests of speech sound discrimination and have found that response latencies were correlated with error scores, and are particularly useful in distinguishing discriminability of errorless responses. That is, although treatment groups might show the same number of correct identifications, the response latencies could indicate differences between the groups which presumably reflect differences in difficulty of discrimination. The present study, therefore, employed a response latency measure in addition to an accuracy measure. Presumably, the greater the degree of
interference produced by task performance, the longer the response time should be. On the basis of this assumption and the findings of McInish & Tikofsky, the motor theory hypothesis would predict that response latencies for the articulatory motor task group should be greater than those observed for the non-articulatory motor task group.

The present study, then, sought to further clarify the stimulus conditions under which differential task effects would be observed, by examining the effects of articulatory and non-articulatory task performance upon two measures of speech and non-speech sound perception.

Method

Subjects. Thirty male and 30 female students enrolled in an introductory psychology course served as Ss. All were right-handed and had no known hearing impairments. Ten males and 10 females were randomly assigned to each of the 3 experimental groups used in the study.

Auditory stimuli. As in the first three studies, consonant-vowel syllables were used as speech sounds. The present study extended the number of consonant sounds used from 6 to 16, which included all of the English consonants except C, H, J and Z. Once again, each consonant was followed by the vowel ‘a’. A list of 40 syllable-trigrams was constructed, with each trigram consisting of three different consonant sounds. A table of random numbers was used to generate the list, and each consonant occurred either 7 or 8 times in the list. Each of the 16 consonant-vowel syllable sounds were recorded at the same intensity level (as indicated on the tape recorder V-U meter) in an audiometric room by a male speaker. These sounds were then used to make up the test tape. The sounds were recorded on a single track of the tape for binaural presentation. Since subjects were to report all of the consonant
sounds in each trigram, dichotic presentation of the sounds was not employed as this would have required Ss to report six sounds per trial, and the probability of memory errors would have been considerably increased. The three syllables in each trigram were spaced approximately \( \frac{1}{2} \) second apart from one another on the tape. As in the previous studies, each trial was preceded and followed by "start" and "stop" cue sounds, which signalled the onset and offset of task performance. The tape recorder was stopped between trials to permit S to record his responses and to allow E to record response latencies, as described below. The test tape consisted of 3 practice trials and 40 test trials.

The stimuli used for the non-speech sound test were 16 brief (1-second) tones, which differed in frequency from one another. The tones were produced by a signal generator and ranged in frequency from 300 to 450 cps, in 10 cps steps. These tones were used to make up a series of 40 tone trigrams, with each trigram consisting of three tones of different frequency, and spaced approximately \( \frac{1}{2} \) second apart. The maximum difference in frequency between the high and the low tones was 40 cps. Pre-testing had indicated that differences larger than 40 cps resulted in relatively high levels of discrimination by most subjects and that the selected set of tones produced an intermediate level of difficulty. As a result of the construction of the tone trigrams by a random numbers table, each of the six possible sequential arrangements of the tones into trigrams (i.e. low, middle, high; low, high, middle etc...) occurred between 5 and 8 times in the test. For example, the arrangement "middle, high, low" occurred 7 times, while another arrangement (high, middle, low) occurred 5 times. As in the speech sound test, each trigram was preceded and followed by "start" and "stop" cues, and the recorder was stopped between trials. The test tape consisted of 3 practice
trials and 40 test trials.

**Motor tasks.** The articulatory and non-articulatory motor tasks were identical to those employed in the preceding three studies. The finger-movement task required S to move the left forefinger from side to side, and the tongue-movement task required S to move the tongue from side to side. The no-task control condition required Ss merely to listen to the sounds without performing any task.

**Procedure.** Ss were randomly assigned to one of the three experimental groups, i.e. Finger-Movement, Tongue-Movement or No-Task groups. Ss were tested individually in a quiet testing room, and each S received both speech and non-speech sound perception tests, with the order of presentation being counterbalanced. In previous studies, the difficulty level of the speech sound tests had been established by use of synthetically produced sounds, white-noise masking, or dichotic presentation. In the present study, an intermediate level of difficulty was established for the speech and non-speech sound test in pre-testing by presenting the speech sound tape at various volume levels on the tape recorder and determining the level which resulted in a suitable range of scores.

Subjects receiving the speech sound test were told that they would hear a series of 3-syllable speech sounds with each syllable consisting of one of the consonants of the alphabet followed by the vowel sound /a/. They were informed that each trigram would be preceded and followed by the cue sounds. A practice trial was then presented to familiarize the subjects with the types of sounds that they would be hearing. A second practice trial was then presented, and Ss were instructed to write down on the answer sheet, in the order that they occurred, the 3 consonant sounds that were presented (e.g. 3 - G - D). They were told to record their responses after hearing the "stop" cue which followed the trigram.
In a third practice trial, S again listened to the trigram, recorded his response after hearing the "stop" cue, and was instructed to then press a button located at the top right hand corner of his answer sheet, as soon as he completed his response. Pressing the button stopped a Hunter Model 100A clock-counter which had been started by the "stop" cue following each sound via a sound-activated relay connected to the external speaker output of the tape recorder. This permitted the experimenter to record a response latency measure for each trial. The clock-counter was re-set manually after each trial, when the tape recorder was stopped. The distance from the answer sheet to the timer button was kept constant for all Ss by keeping both the button and the answer sheet in a fixed position on the table. The S was instructed to keep his pen in a fixed position on each trial to ensure that all subjects were starting their responses from the same physical position. These latter conditions were aimed at minimizing variations in response latencies due to individual differences in response style.

Ss were asked to respond and to press the button as quickly as possible. Since they were required both to press the button and write their responses with the same (right) hand, it was not possible for them to press the button before their response was completed. The last part of the instructions familiarized subjects with the motor task that they were to perform. The three practice trials were then repeated with Ss instructed to begin the motor task at the onset of the "start" cue and continue until they heard the "stop" cue, at which time they would record their responses and then press the button to stop the timer. In the case of the No-Task Control group, the three practice trials were simply repeated without further task instructions. The test trials were then presented.
For the non-speech sound test, the procedure was essentially the same, with the exception that Ss were required to identify the 3 tones as low, medium, or high relative to one another, and write down the order in which they were presented by indicating, for example, M H L, etc., for each trigram.

**Analysis.** For the speech sound test, an item (syllable sound) was scored as correct only if it was recorded in the correct position in the trigram. It was therefore possible to get a score of 0, 1, 2, or 3 correct for each trial. Had the same system of scoring been adopted for the non-speech sounds, it would not have been possible to get a score of 2 correct for each trial, since an error in one of the positions of the trigram would have automatically resulted in an error in another position. This results from the fact that the tones were judged relative to one another. Consequently, a different system of scoring was adopted in which a response on a given trial was considered as a series of judgments of each tone relative to the other two tones, in terms of being higher or lower in frequency. For example, on a trial where the correct sequence of tones was L M H, the first tone is lower in pitch than the second and third tones, and the second tone is lower than the third. If the subject's response was L H M, he would have correctly judged the 1st tone as lower in pitch than the second and third, but would have erred in judging the second tone as higher than the third. Thus two of the three judgments would have been correct. This system therefore permitted scores of 0, 1, 2 or 3 on each trial.

The number of correct responses on both the speech and non-speech sound tests were converted to percent correct scores (i.e. total correct/120 x 100) and subjected to a 2 x 2 x 3 (Sex x Stimulus Type x Task Group) analysis of variance, with repeated measures on the Stimulus Type
factor. An-identical analysis of variance was performed upon the response latency measures. In addition, the consonant errors for the speech-sound test were analyzed by a 2 x 16 x 3 (Sex x Consonants x Task Group) analysis of variance.

Results

The overall main effect for Task Group was significant (F=4.36, df=2/54, p<.02). The simple main effects for Task Group were then examined. Figures 9a and 9b show the task group mean scores for the speech and non-speech sound tests respectively. Comparisons of the means in Figure 9a (the speech sound test) showed that the difference between the Finger-Movement and the No-Task groups and between the Finger-Movement and Tongue-Movement groups, were statistically significant (p<.05). Comparisons of the means for the non-speech sounds (Figure 9b) indicated that none of the differences reached statistical significance.

The main effect for the Stimulus Type factor was also found to be statistically significant (F=304.59, df=1/54, p<.001). Inspection of Figures 9a and 9b illustrates that this effect was due to the superior performance of all groups on the non-speech sound test. The expected Task Group x Stimulus Type interaction was not significant.

The analysis of the response latency measures revealed the same two main effects to be statistically significant. The Task Group main effect was significant (F=3.43, df=2/54, p<.05), and the simple main effects for Task Group were again examined. Figures 10a and 10b show the simple main effects of Task Group for the speech and non-speech sound tests respectively. Although post-hoc comparisons of the means in Figures 10a and 10b did not reveal any significant differences, the means
Figure 9: Mean percent correct for each motor task group on (a) the speech sound test and (b) the non-speech sound test in Experiment V.
Figure 10: Mean response latencies for each motor task group on (a) the speech sound test and (b) the non-speech sound test in Experiment V.
are graphically illustrated for purposes of later comparison with
the mean scores obtained for the percent correct measure. As in the
percent correct measure, the F ratio for the Stimulus Type factor was
again significant for the response latency measure (F=6.21, df=1/54,
p<.05), and inspection of Figures 10a and 10b shows that this was due
to the fact that for each task group, response latency was longer on the
non-speech sound test than on the speech sound test. This effect was
qualified by a Stimulus Type x Sex interaction (F=4.33, df=1/54, p<.05),
which revealed that the differences in response latencies for the two
tests were almost entirely accounted for by the males. Females showed
almost identical mean response latencies for speech and non-speech tests.

The analysis of consonant errors revealed a significant main effect
for Task Type (F=3.26, df=2/54, p<.05) which reflects the main effect for
Task Type found in the analysis of the percent correct scores. A
significant main effect for Consonants was also found (F=64.88, df=15/310,
p<.001), indicating that subjects in general tended to make more errors
on certain consonants than on others. This was of no direct relevance to
the questions under examination, and was not further examined.

Discussion

Examination of the results of the speech sound-test, shown in Figure
9a, indicated that the pattern of task group means observed in Experiments
II and III were again found in the present study. Once again the Tongue-
Movement group scored significantly lower than did the Finger-Movement
group, with the No-Task group score falling between these two groups.
It would thus appear that the use of more complex (i.e., polysyllabic)
speech sounds did not in itself modify the differential task effects.
Thus complexity, as defined previously, does not appear to be a major
determinant of such effects, as had been suggested in Experiment IV. Another conclusion which may be drawn from these results is that the effects of the articulatory and non-articulatory motor tasks were not specific to the group of six consonants which had comprised the speech sounds in the first three studies. The present study involved most of the consonant sounds of the English language.

Once again, no significant task effects were found for the non-speech sounds, as expected. Despite the fact that significant differences were present for the speech sounds and not for the non-speech sounds, the pattern of task scores was similar to that seen for the speech sound test, as reflected in the absence of the predicted Stimulus Type x Task Group interaction.

A second aim of the present study was to determine whether a response latency measure would also be sensitive to differential task effects and could be meaningfully related to the scores obtained on the percent correct measure. It was anticipated that the more difficulty a S had in processing sounds, the more errors he was likely to make and the more time he would take in responding. This expectation was confirmed only in part. If Figures 9a and 10a are compared, it can be seen that the Tongue-Movement group which had a significantly lower accuracy score than the Finger-Movement group, took longer to respond (although not significantly so) than did the Finger-Movement group. For the No-Task and Finger-Movement groups, however, the mean accuracy scores and response latencies did not correspond in the same fashion. While the Finger-Movement group tended to be more accurate than the No-Task group (on both perception tests) it nevertheless showed longer response times than the No-Task group. A similar lack of correspondence between latency and accuracy is evident in the fact that while mean response
latencies on the non-speech sound test were greater than on the speech sound test, the accuracy on non-speech sounds was also greater than on speech sounds. This was seen for all three task groups.

The main effect for Stimulus Type was qualified by a significant Sex x Stimulus Type interaction, which indicated that the main effect for Stimulus Type was primarily due to the male Ss. The females, on the other hand, showed nearly identical mean response latencies for both speech and non-speech sound tests. No such interaction was observed for the accuracy measures, where performance was superior on the non-speech sound test for both sexes. These findings appear to reinforce the conclusion that the relationship between accuracy measures and response latency measures on tests of auditory perception is not a simple one. A greater degree of difficulty on a test may be reflected in longer processing times and a greater number of errors. However, a greater degree of difficulty on a test could also result in more careful attention and deliberation (and therefore longer response times) which may in turn decrease the number of errors on the test. The operation of both of these factors could account for the lack of a direct correspondence between the two measures.

As noted above, the pattern of task group accuracy scores for the speech sound test was similar to that seen for the non-speech sound test, although none of the differences found on this latter test were statistically significant. Since the predicted Task Group x Stimulus Type interaction was not obtained on either the accuracy or the response latency measure, it appears that the two types of stimuli were being processed similarly in some respects. In the present study the non-speech test was designed to match the speech test in as many aspects as possible, and this could have contributed to the similar pattern of task
group scores on the two perception tests. Both tests required similar types of labelling responses - i.e. three different consonant labels (e.g. LMK; BDG) were recorded on each trial in both tests. In addition, the ordering of these consonants was important in both tests. The tendency to respond in similar fashion on both tests may have been further enhanced by the subject's establishment of a response 'set' after the performance of the first of the two tests. Any or all of these factors could have contributed to similarities in the patterns of accuracy and response latency measures on the two types of tests. However, if these factors were not the basis for the similar patterns of mean scores on speech and non-speech sounds, the results would not provide support for one of the predictions derived from the motor theory, namely that the motor task group differences predicted for speech sounds would not occur for non-speech sounds.

The analysis of the consonant errors once again provided no evidence that the motor task effects differed significantly for the different consonant sounds, as no significant Consonant x Task Group interaction was found. This finding is in general agreement with the results of the earlier studies.

In summary, the differential effects of the performance of articulatory and non-articulatory motor tasks upon the accuracy of perception of speech sounds, which has been observed in previous studies, was again found in the present study which involved a wider range of consonant sounds. The complexity of the speech sounds did not detract from this effect. No significant differences in accuracy between the motor task groups were present for the non-speech sound test. The analysis of response latency measures also revealed significant effects of the different tasks, and the direction of these effects were similar for both
speech and non-speech sounds. The lack of a consistent correspondence between accuracy and response latency measures suggests that while a latency measure may yield certain information about subjects' performance, this measure alone is not likely to provide a reliable index of discriminability of speech and non-speech sounds.
EXPERIMENT VI

The preceding experiments have attempted to delineate the major factors contributing to the differential effects of articulatory and non-articulatory motor tasks upon the perception of speech sounds. The major parameters under investigation have been the type of auditory stimulus and the nature of the motor tasks performed. In all of the studies reported thus far, the type of articulatory motor task has been kept constant. The present study was designed to investigate whether the differential task effects which have been found are specific to the particular type of articulatory motor task which has been employed. Specifically, it was of interest to ascertain whether variations in articulatory gestures would produce concomitant variations in magnitude and/or direction of motor task effects. Such information would be of value in determining the types of neuromotor processes that may be involved in speech sound analysis. The present study, therefore, required subjects to perform a different articulatory motor task than used previously. This necessitated a modification of the non-articulatory motor task as well in order to match the two types of motor tasks in terms of overt motor pattern, as has been done in the previous studies. The consonant-vowel syllable sounds used in all but one of the previous studies also served as speech sound stimuli in the present study. As was the case in Experiments IV and V, a non-speech sound perception test was again employed.

It will be recalled that the results of Experiment IV suggested
that at least for female subjects, performance of an articulatory
motor task may influence the pattern of ear superiority which is
normally found for verbal stimuli. In order to further investigate
this possibility, dichotic presentation of the speech sounds was used
in this study.

Method

Subjects. Ten male and 10 female students enrolled in an introductory
psychology course served as subjects in each of the Finger-Movement and
Tongue-Movement groups. All Ss were right-handed and had no known
hearing impairments.

Auditory Stimuli. The stimuli used in the speech sound test were the
same six synthetic consonant-vowel sounds used in Experiments I and II.
These syllables were used to generate a list of 24 pairs of syllables,
which was then recorded on tape for dichotic presentation. No syllable
was paired with itself. As the pairs were generated from a random
numbers table, the frequency of each syllable in the list varied from 7
to 10 occurrences. Each dichotic pair of syllable sounds was preceded
and followed by "start" and "stop" cue sounds. The test tape consisted
of 3 practice pairs and 24 test pairs of consonant-vowel syllables.

The non-speech sound stimuli consisted of 25 trials of the Timbre
subtest of the Seashore Measures of Musical Talents. Every other
trial of the 50-trial test was used. In this test, each trial consists
of two 1-second tones of equal intensity and duration presented in rapid
succession, (approximately .5 second intertone interval), with the
subject being required to report whether the two tones were the same or
different in timbre or tonal quality. Each trial was preceded and
followed by the usual "start" and "stop" cue sounds. The test tape
consisted of one practice trial and 25 test trials.

Motor tasks. The articulatory motor task required S to move his tongue in the forward-backward direction rather than from side to side as had been required in the previous studies. S was asked to extend and retract his tongue in and out of the mouth at a steady rate, while keeping his mouth slightly opened. The non-articulatory motor task required him to extend and retract his left forefinger at a steady rate, while resting his left forearm on the table in front of him with the palm resting on the table and the hand forming a fist. This task as noted above, was designed to approximate as closely as possible the overt pattern of motor gestures required by the tongue-movement task.

Procedure. The procedure was very similar to that followed in the previous studies. Ss were randomly assigned to either the Finger-Movement or the Tongue-Movement group, and were tested individually. Ss were seated in the acoustical chamber and given the appropriate instructions over headphones. Each S performed both the speech and non-speech tests, the order of presentation being counterbalanced.

For the speech sound test, S was told he would be listening to a number of consonant-vowel syllable sounds which he would be asked to identify. He was informed that the sounds would consist of the six basic syllable sounds which were written down on a sheet of paper in front of him. S was then presented with each of the sounds as practice. He was then familiarized with the dichotic presentation procedure and instructed that he would be presented with dichotic pairs of syllables which had been selected from the group of six syllables he had just listened to, and that he would be required to report which two of the six possible syllables were presented. A practice dichotic pair was then presented. The motor task to be performed was then described to the subject and he was instructed
that the sounds preceding and following each dichotic pair were to cue
the starting and stopping of the motor task. Two further practice
trials were given with the subject following the entire procedure, and
the test trials were then presented. The tape was stopped after each
trial while the S reported his response and the latter was recorded by
the experimenter. As was the usual practice, Ss were encouraged to
guess if they were not sure of the correct response. Upon completion
of the first test, the S was told that he would be doing a second test
in which the procedure would be similar but the sounds would be different.

For the non-speech sound test the S was informed that he would be
hearing pairs of brief tones, played in quick succession, in normal
binaural (as opposed to dichotic) fashion. (Binaural presentation was
employed since dichotic presentation of two identical tones would be
perceived as a single tone). For each pair of tones the S was to judge
whether the two tones were the same or different in tonal quality or
timbre, and report "same" or "different" for each trial. A practice
trial was then presented. The S was familiarized with the motor task
procedure, and two more practice trials were given using the entire
procedure. The test trials were then presented, with the tape being
stopped after each trial to record the Ss' responses.

Analysis. Since it was not feasible to employ dichotic presentation with
the non-speech stimuli the pattern of ear scores could not be examined
for these stimuli, as had been done in Experiment IV. The analysis,
therefore, was performed in two parts. First, an overall analysis of
variance which did not involve the Ear factor was performed on the data
for both speech and non-speech sound tests. For the speech sound test,
the left and right ear scores were combined into a single score for each
S. These scores and the scores on the non-speech sound test were converted
to percent correct scores (i.e. \( \frac{\text{no. correct}}{48} \times 100 \) and \( \frac{\text{no. correct}}{25} \times 100 \) for the speech and non-speech sound tests respectively), and subjected to a \( 2 \times 2 \times 2 \) (Sex x Stimulus Type x Task Group) analysis of variance, with repeated measures on the Stimulus Type factor. In order to examine the effects of task performance on the pattern of ear scores on the speech sound test, the left and right ear scores on this test were analyzed by a \( 2 \times 2 \times 2 \) (Sex x Ear x Task Group) analysis of variance, with repeated measures on the Ear factor. To determine whether task effects interacted with specific consonant sounds, an analysis of consonant errors was performed, as in the previous studies, using a \( 2 \times 6 \times 2 \times 2 \) (Sex x Consonants x Task Group x Ear) analysis of variance with repeated measures on the Consonants and Ear factors.

Results

The overall analysis of the percent correct scores showed a significant main effect for Stimulus Type (\( F=53.79, \text{df}=1/40, p<.001 \)). This finding was of little theoretical interest, indicating that in general, Ss did better on the non-speech sound test than on the speech sound test. No other main effects or interactions were significant. Examination of the mean scores for the speech sound test indicated that the Tongue-Movement group score was again lower than the Finger-Movement group score - 58.2% compared to 59.4% - although this difference was small and non-significant. This slight difference was present for both males and females. For the non-speech sound test, a similar small difference was found between the two groups, and in the same direction as for the speech sounds. The Tongue-Movement group had a mean score of 76.2% correct compared to a mean score of 79.3% correct for the Finger-
Movement group. The direction of this difference was accounted for by the female Ss only, with the males scoring higher in the Tongue-Movement group than in the Finger-Movement group.

The analysis of the speech sound scores alone revealed no significant main effects or interactions. The scores for the right ear were generally higher (although not significantly so) than for the left ear, as has generally been found with speech sound stimuli. The mean ear scores for the two motor task groups for both males and females are shown in Figure 11, for purposes of comparison with comparable data (see Figure 8) found in Experiment IV. The similarity of the patterns of scores in these two studies appears worthy of note and is discussed below.

In the analysis of the consonant errors, only the main effect for Consonants was statistically significant (F=39.79, df=5/200 p<.001), indicating that more errors were made on some consonant sounds than on others. No other main effects or interactions were significant.

Discussion

One of the aims of the present study was to determine whether the type of articulatory motor movements used in the experimental paradigm was a significant factor in the differential task effects observed in the earlier studies. Although it was once again observed that the Tongue-Movement group mean scores for both males and females were lower than those of the Finger-Movement group, on the speech sound's test, these differences were small and not statistically significant. While this might suggest that the magnitude of the difference between articulatory and non-articulatory motor task group scores is at least in part dependent upon the type of articulatory motor movements involved,
Figure 11: Mean left and right ear identification scores for males and females within each motor task group on the speech sound test in Experiment VI.
certain other factors should be considered. It may be recalled that a similar small (and non-significant) difference in the same direction was found in Experiment IV, which employed dichotic presentation of tri-syllabic nonsense words in the speech sound test. That study also showed a significant Sex x Ear x Task Group interaction for the speech sounds, which suggested that the tongue movements modified the left-right pattern of ear scores normally found for verbal stimuli, although this was so only for the females. While this Sex x Ear x Task Group interaction was not statistically significant in the present study, the pattern of ear scores for males and females for both motor task groups was similar to that found in Experiment IV, as can be seen when Figures 11 and 8 are compared. The most notable similarity is the fact that in both studies the only case in which a right-ear superiority did not occur was for the females in the Tongue-Movement group. A further comparison which may be noted is the absence of significant task effects for the non-speech sound tests in both studies.

The parallel results in both studies are of interest in view of the fact that both the auditory stimuli and the motor tasks in the present study were different from those in Experiment IV. Were the results of the present study considered alone, it could be argued that the lack of statistically significant task effects was at least partly due to the fact that a new articulatory motor task was used. It could be reasoned that the new task did not involve the speech production mechanisms to a sufficient degree to interfere with speech perception mechanisms. However, Experiment IV, which showed similar results to those of the present study, used the same articulatory motor task which has produced significant task effects in other studies. This would suggest that the nature of the articulatory motor task was not a critical
factor accounting for the absence of the task effects. In Experiment IV it was suggested that the lack of significant differences in overall accuracy between the two motor task groups could have been partially due to the nature of the speech sound stimuli, which may have been insensitive to differential interference effects. This explanation, however, could not account for the similar findings of the present study, since the speech sounds used in the present study have been found to be sensitive to task effects in earlier studies. A common factor in both of these studies was the use of dichotic presentation procedure. Both studies indicated that for females at least, the articulatory motor task modifies the typical pattern of right-ear superiority seen for verbal stimuli, while no similar effect was seen for the non-speech sounds. It may be, therefore, that while the dichotic presentation procedure does show differential task effects at the level of ear score patterns, it is for some reason not as sensitive to differences in overall accuracy scores. A possible reason for this lack of sensitivity may be that Tongue-Movement effects which primarily affect one ear are compensated for by an increased dependency upon the other ear, leaving the combined ear score relatively unchanged. If the ear scores for females in Figures 8 and 11 are examined, it can be seen that in both studies, the Tongue-Movement group had a lower right-ear score than the Finger-Movement group, but this was offset by a higher left-ear score than the Finger-Movement group. Thus differences between the two motor task group mean scores may have been minimized in this way. Nevertheless, the results of the present study are consistent with the suggestion made in Experiment IV that articulation processes may be involved in the mechanisms in adults that operate to produce a right-ear superiority in the perception of dichotically presented speech sounds, and that females appear to employ
these processes to a greater extent than do males.

The analysis of consonant errors once again showed no indication that differential task effects are more likely to be present on some consonant sounds than on others, in agreement with the results of several of the previous studies.

In summary, neither the predicted Task Group differences nor the Task Group x Stimulus Type interaction attained statistical significance. Certain of the results, however, were observed to parallel those of earlier studies (particularly Experiment IV). The Tongue-Movement group mean score on the speech sound test was again lower than that of the Finger-Movement group. The absence of significant task group differences for non-speech sounds was observed with a new type of sound. The left-ear superiority for females in the Tongue-Movement group, which was observed in Experiment IV, was also seen in the present study. While these observations cannot be interpreted as significant support for the motor theory hypothesis, they are in a direction consistent with motor theory predictions. The similar pattern of scores seen in Experiment IV and the present study led to the suggestion that the use of the dichotic presentation procedure in both studies may have minimized task group differences on the speech sound test, and that the introduction of new motor tasks was not a major reason for the small task group differences. The question of comparative effects of different types of articulatory and non-articulatory motor tasks upon the perception of speech and non-speech sounds was pursued in the following study.
EXPERIMENT VII

The last study of the series was designed to employ a set of experimental conditions which, on the basis of previous findings, would permit the assessment of the motor theory hypothesis in the absence of certain complicating factors. A second purpose of the study was to pursue the question raised in Experiment VI as to whether specific patterns of motor gestures are more effective than others in producing articulatory/non-articulatory task group differences on tests of speech perception.

The purpose of optimizing the experimental conditions was approached in several ways. To avoid possible order effects arising from use of a repeated-measures design, an independent groups design was used. Since the differential task effects had been observed most clearly and consistently with binaural (i.e. non-dichotic) presentation of consonant-vowel syllable sounds, the binaural presentation procedure was used with consonant-vowel stimuli in the present study. The syllable sounds were again presented in groups of three, in order to extend the stimulus duration period and consequently increase the amount of motor activation during stimulus presentation. Several of the studies had indicated that the sex of the subjects interacted with task effects. As the number of males and females in each condition had been relatively small in these studies, the present study attempted to assess the involvement of the sex factor once again, using a larger sample size. Since the present study was concerned with determining whether any
differences which were present for the speech sounds would also be present for non-speech sounds, a non-speech sound task similar to the Timbre sub-test used in Experiment 6 was employed, namely, the Pitch sub-test of the Seashore Measures of Musical Talents.

As a further attempt to select conditions of possible importance for the appearance of differential task effects, the duration of the motor tasks was changed in this study. In all of the previous studies, the motor task onset was cued approximately 2 seconds prior to presentation of the sound, and the offset of the task was signalled 1 second following stimulus offset. This period was extended to 5 seconds prior to, and 5 seconds following the presentation of each sound in the present study. The extension of the period preceding the stimulus onset was intended to minimize the possibility that task performance was not begun by the time of onset of the stimulus sound, and to provide sufficient time for the subject to establish a steady and rhythmic pattern of motor movements which would be in progress at the time of onset of each sound. The extension of task performance following the offset of the sound represented the addition of a short-term memory component to the experimental paradigm. All of the previous studies had been designed to minimize the memory component in the perception tests, insofar as it was of interest to test the hypothesis that the experimental manipulations were in fact acting primarily upon direct sensory input rather than the coded or stored "traces" of that input. The difficulty of distinguishing between effects upon "perception" as opposed to effects upon short-term memory has been discussed earlier. The research literature reviewed in the introduction suggested that articulation mechanisms were operative in the storage and retrieval as well as the input stages of verbal information processing. It was conceivable,
therefore, that short-term memory processing would also be susceptible
to interference effects of the articulatory motor tasks, insofar as
these tasks engaged articulatory motor elements that were involved in
short-term storage of verbal material. One might predict, therefore,
that the addition of a short-term memory component to the perception
test would increase the sensitivity of the test to possible task
interference effects.

The second purpose of the present study - the determination of
whether certain patterns of motor movements were more effective than
others in producing differential task effects - was examined by
comparing the effects of three different types of articulatory motor
tasks and two different types of non-articulatory motor tasks, plus a
no-task condition, upon speech and non-speech perception tests.

The present study, therefore, was designed to optimize the
conditions under which differential task effects would be expected to
occur, and to compare various types of motor movements with respect to
their tendency to produce such effects.

Method

Subjects. All Ss were students enrolled in an introductory psychology
course. All were right-handed and had no known hearing impairments.
The original design had called for 20 males and 20 females in each motor
task group. As six task groups were used, and two types of auditory
stimuli (speech and non-speech sounds) were used in the perception tests,
the independent groups design required a total of 480 subjects.
Failure of a considerable number of subjects to appear and/or to follow
the correct procedure resulted in a reduced sample size. Table 1
presents the number of subjects tested in each condition. A total of
Table 1

Number of Subjects Serving in Each Experimental Group in Experiment VII

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
<th>Group 5</th>
<th>Group 6</th>
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<tr>
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<td>15</td>
<td>15</td>
<td>14</td>
<td>14</td>
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<tr>
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Speech Test

<table>
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<th>Group 3</th>
<th>Group 4</th>
<th>Group 5</th>
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</thead>
<tbody>
<tr>
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<td>14</td>
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<td>27</td>
<td>29</td>
<td>29</td>
<td>30</td>
<td>29</td>
</tr>
</tbody>
</table>

Non-Speech Test
368 subjects were tested.

Auditory stimuli. The same six synthetic consonant-vowel syllable sounds used in Experiments I, II and VI were employed in the speech sound test. A list of 30 3-syllable sounds was constructed from the six sounds. The list was generated with the aid of a random numbers table, with the restriction that each syllable sound occurred 15 times in the list. The originally recorded six sounds were used as a master tape from which the syllable sounds were re-recorded into trigrams on a single track of magnetic tape for binaural presentation. The syllables in each trigram were spaced approximately 1 second apart. Each trial was preceded by a "start" cue 5 seconds prior to the onset of the trigram and was followed by a "stop" cue 5 seconds after the offset of the trigram. There was a 5 second interval between the "stop" cue of one trial and the "start" cue of the following trial, during which the subjects recorded their responses. The test tape consisted of 3 practice trials and 30 test trials.

The non-speech sound test consisted of the last 30 trials of the Pitch subtest of the Seashore Measures of Musical Talents. In this test, each trial involves the successive presentation of two brief tones of equal intensity and duration, but which differ in frequency. The inter-tone interval on each trial was approximately .5 seconds. The subject was required to judge whether the second tone was higher or lower in pitch than the first. Once again, each trial was preceded and followed by "start" and "stop" cue sounds. There was a 5 second interval between the "stop" cue of one trial and the "start" cue of the following trial. The test tape consisted of 3 practice trials and 30 test trials.

Motor tasks. The present study employed three articulatory motor task groups, two non-articulatory motor task groups, and a no-task control group. The description of each motor task requirement is presented
below in the form of the instructions given to each group. All motor
task instructions were followed by the general statement "Do this at a
steady and fairly rapid rate from the onset of the 'start' cue to the
onset of the 'stop' cue, making sure that you do not hesitate during
the presentation of the sounds". The specific instructions for each of
the motor tasks were as follows:

Group 1: Chewing movements. "The task you will be doing is making simple
chewing movements. To facilitate performance of this task, you have
been provided with a piece of chewing gum. When you are chewing the
gum, be sure to keep your mouth closed and try to make as little noise
as possible with your teeth".

Group 2: Mouthing a nonsense syllable. "The task you will be doing is
simply repeating the nonsense syllable BLEE to yourself silently, over
and over. Do not whisper or say it aloud, but mouth it".

Group 3: Moving the tongue from side to side. "The task you will be
doing is simply moving your tongue from side to side, keeping your
mouth slightly open and your tongue extended as you move it from side to
side."

Group 4: Moving forefinger from side to side. "The task you will be
doing is simply moving your left forefinger from side to side. Resting
your left hand on the table in front of you, clench your hand into a
fist and extend your forefinger, moving it from side to side."

Group 5: Touching thumb and forefinger. "The task you will be doing is
simply touching the thumb and forefinger of your left hand together,
Holding your left hand on the table in front of you, move your forefinger
up and down, touching your thumb with your forefinger each time you
move your finger down."

Group 6: No-task. "Make sure that you are sitting relatively still from
the "start" to the "stop" cue, without making any unnecessary body movements, such as tapping your foot or hand."

**Procedure.** A group-testing procedure was adopted to accommodate the relatively large number of Ss tested in the present study. For this purpose the facilities of one of the language laboratories at the University of Western Ontario were used, which permitted the testing of up to 40 subjects per test session. The laboratory was designed to visually isolate each S from other Ss on his left and right, but allowed Ss to be observed by the experimenter from the front of the room. Ss were seated in the laboratory and instructed to adjust the volume controls on their consoles to a pre-selected position and to leave the controls in this position for the duration of the testing session. They were then instructed to pick up a set of instructions and answer sheet at the front of the room. Each testing session used either the instructions for the speech sound test or those for the non-speech sound test. The testing sessions employing the speech sound stimuli were alternated with those using the non-speech sounds. For both tests, the instructions consisted of a sheet of general instructions plus an attached sheet describing the motor task to be performed. Depending on the task to be performed, each set of instructions was marked with a number from 1 to 6, which corresponded to the type of task to be performed. For example, a sheet marked 1 would be provided with instructions to perform the chewing movements task, while a sheet with number 6 provided instructions for the no-task control condition. In each testing session, a group of instruction sheets (including an equal number of each set of task instructions) was placed at the front of the room. Prior to each testing session, the sheets were thoroughly shuffled to insure random order. Ss were required to pick up a copy of
the instructions and in this way were randomly assigned to one of the six groups. Ss were then required to put on their earphones, and all further instructions were given over the earphones via the master control unit in the laboratory. They were requested to fill in their name, age, sex, and instruction sheet number in the appropriate place on the answer sheet, and to read their instructions. The general instructions were essentially similar to those used in the previous studies, and described the kinds of sounds that would be presented, the type of motor task to be performed, and the cues which would signal the onset and offset of task performances.

For the testing sessions using speech sounds, S was first presented with each of the six basic syllable sounds which would be used, in the order indicated on the top of the answer sheets. This was followed by three practice trials in which S was required to follow the complete procedure outlined in the instructions, including the recording of responses. Ss were required to record three consonants for each trigram presented. The 30 test trials were then presented. For the non-speech sounds, three practice trials were also given, followed by the 30 test trials. Ss were required to record S (same) or D (different) for each trial.

The test tapes were played over the earphones via the tape playback on the master control unit and were monitored by the experimenter. An assistant aided in observing subjects to ensure that instructions were properly followed.

Analysis. The number of correct responses on the speech and non-speech sound tests were converted to percent correct scores (i.e. \[
\frac{\text{number correct}}{90} \times 100 \quad \text{and} \quad \frac{\text{number correct}}{30} \times 100 \quad \text{for speech and non-speech sound tests, respectively.}
\] Since the number of Ss in each condition was
unequal, a test for homogeneity of variance was performed, using the Cochran test (Miner, 1962, p. 92). The C value obtained was .0953, which did not reach statistical significance, and the hypothesis of homogeneity of variance was not rejected. The scores were analyzed by a 2 x 2 x 6 (Sex x Stimulus Type x Task Group) analysis of variance for independent groups. The error scores for the consonant sounds were also analyzed, using a 2 x 6 x 6 (Sex x Consonants x Task Groups) analysis of variance, with repeated measures on the Consonant factor.

Results

The analysis of the percent correct scores revealed that the females were generally more accurate than males on both speech and non-speech sound tests (F=8.02, df=1/344, p<.01). A significant main effect for Stimulus Type (F=128.90, df=1/344, p<.001) indicated that the performance on the non-speech sound test was significantly better than on the speech sound test. No other main effects or interactions were statistically significant. The only statistically significant effect observed in the analysis of consonant errors was the main effect for Consonants (F=15.60, df=5/920, p<.001) reflecting the fact that more errors were made on some consonant sounds than on others.

Discussion

The absence of a statistically significant Task Group main effect or Task Group x Stimulus interaction indicated that no significant differences were present between the different task group mean scores, and that the pattern of means on the speech sound test did not differ significantly from that observed for the non-speech sounds. Thus neither of the motor theory hypotheses being tested in the present study
were statistically confirmed. However, as was observed in Experiment VI, the results tended to be in a direction consistent with motor theory predictions, and are illustrated in Figures 12 and 13.

Inspection of Figure 12a shows that two of the three articulatory motor task groups scored lower than both of the non-articulatory motor task groups. For the non-speech sound test, shown in Figure 12b, this trend is reversed. Two of the three articulatory motor task groups scored higher than both of the non-articulatory motor task groups. This difference in trend for speech and non-speech sound tests is perhaps more evident in Figure 13, which compares the mean score of all subjects performing articulatory motor tasks with the mean for all of the subjects performing non-articulatory motor tasks and to the mean score of the no-task group. It can be seen in Figure 13a that the speech perception score for the articulatory motor task group is lower than that of the other groups, whose scores are similar to one another. For the non-speech sounds (Figure 13b) however, the score for the non-articulatory motor task group is lower than that of the other groups. The reversal of the direction of the motor task group difference for the different types of auditory stimuli suggests that differences in scores for the two motor task groups were not a function of intrinsic differences in the demands or difficulty of the two types of tasks. It would appear, rather, that an important variable in the determination of the magnitude and direction of the differential task effects was the type of auditory stimuli used in the perception test - i.e., speech or non-speech sounds.

It may also be noted (see Figure 12) that the Tongue-Movement group score was lower than the score of the Finger-Movement group score on the speech sound test, which has been found in the preceding studies. This
Figure 12: Mean percent correct for each task group in Experiment VII on (a) the speech sound test and (b) the non-speech sound test.
Figure 13. Mean percent correct for combined task groups in Experiment VII on (a) the speech sound test and (b) the non-speech sound test.
was not the case for the non-speech sound test, where the direction of the difference was in fact reversed. Although these differences were not manifested in a statistically significant interaction, they are in the direction observed in the earlier studies and predicted by a motor theory hypothesis.

The second purpose in the present study was to determine the relative effects of different types of simple motor movements upon the perception of speech and non-speech sounds. As the main effect for Task Groups was not statistically significant in the present study, individual comparisons of task group mean scores were not performed. Examination of these scores, however, may provide some suggestions as to the variables contributing to differential task effects observed in preceding studies.

It may be noted in Figure 12 that of the three articulatory motor tasks, the chewing movements resulted in the highest score. This observation would oppose the suggestion that differences between articulatory and non-articulatory task group scores were due to noise produced by movements of the articulatory apparatus. If this were the case, the chewing of gum would clearly be the most likely of the motor tasks to involve a noise component. Yet this task provided less interference than all but one of the motor tasks (Finger-Thumb Movement) on the speech sound test, and less than all of the other motor tasks on the non-speech sound test, where its mean score was virtually the same as that of the No-Task group.

The observation of minimal interference effects of the chewing task is also of interest insofar as one might expect greater interference from a task involving movements of the lips, tongue and jaw, as compared to a task requiring only simple movements of the tongue. Although highly
speculative, one possible interpretation of the pattern of scores obtained here is that the chewing movements involved more gross, undifferentiated and less finely controlled motor gestures than did either of the other articulatory motor tasks, and that the degree of precision and integration of the motor movements may play a role in determining the extent of interference that the task produces. The fact that the mouthing of the nonsense syllable, which required the greatest degree of specific, integrated motor activity, did in fact show the lowest scores of the three articulatory tasks would tend to agree with such an interpretation. Conceivably, the degree of perceptual interference could vary as a function of the extent to which the articulatory motor gestures approximate those utilized in speech production.

A question to be considered concerns the attempt of the present study to optimize the possibilities of obtaining differential effects of the articulatory and non-articulatory motor tasks. Although the results were in the direction predicted by the motor theory hypothesis, the differences were not large enough to produce a statistically significant Task Group main effect, or Task Group x Stimulus Type interaction. Several factors may have been of consequence in this regard. One such factor may have been the group-testing procedure which was not employed in any of the other studies. Since it was not possible to closely observe all of the subjects at all times during testing, this might have introduced a greater degree of variability into the task performance than would have occurred in individual testing. Another novel factor in the present study was the introduction of a short-term memory component into the perception tests. The absence of significant task effects despite the addition of this factor suggests
that memory factors do not play a major role in the production of
differential task effects, particularly since all of the previous
studies in which significant task effects were found involved a minimal
delay interval between the auditory stimulus and the subject's response.
In the present study, the addition of a delay period before responding
could in fact have acted to oppose differences in scores between
groups. That is, original perceptual identifications of sounds made
immediately after stimulus presentation may have been partly lost or
their order confused, after the delay interval. This would tend to
apply particularly in the case of speech sounds, where the three
consonant sounds had to be recalled in the correct order. In this way,
the effect of short-term memory errors may have acted to diminish
possible differences between groups which were attributable to the effects
of task performance.

As in the previous studies, the consonant errors were again
analyzed to determine whether task effects might have been present for
certain consonant sounds and not for others. The absence of a Task
Group x Consonant interaction indicated that such was not the case, in
agreement with the findings of most of the earlier studies.

In summary, the results of the present study, while they did not
reach statistical significance, tended to be consistent with a motor
theory interpretation. Tasks involving articulatory motor movements
were found to produce lower scores on a speech sound perception test
than those produced by tasks involving non-articulatory motor movements.
The direction of the difference between the scores for the two types of
motor tasks was reversed for the non-speech sound perception test. It
was suggested that the magnitude of the effects produced by articulatory
motor tasks upon speech sound perception may depend, in part, upon the
extent to which the motor activity in the task approximates that employed in the production of speech sounds. The failure to obtain larger task group differences implied a minimal role of short-term memory factors in the production of the significant task effects which have been found in certain of the previous studies. Although certain factors which may have minimized the magnitude of differential task effects were noted, the absence of larger differences despite attempts to optimize conditions in the present study suggests that the role of articulation mechanisms in the perception of simple speech sounds, at least under certain conditions, must be at best a relatively small one.
SUMMARY AND CONCLUSIONS

The present series of studies have investigated the motor theory view that speech production mechanisms are employed in the processing of speech sounds. Essentially two main hypotheses were derived from the motor theory of speech perception. The first hypothesis was that involvement of the articulation mechanisms of a listener during presentation of a speech signal would result in a decrease in the listener's efficiency of processing that signal. The experimental paradigm used to test this hypothesis was outlined earlier. In terms of this paradigm, the motor theory predicted poorer performance for an articulatory motor task group than for a comparable non-articulatory motor task group on tests of speech sound perception. A second hypothesis was that the pattern of task group scores predicted for speech sounds would not be obtained for non-speech sounds, since these sounds presumably do not involve articulation mechanisms in their processing. To what extent do the obtained results support either or both of the above hypotheses?

Considering the first hypothesis, a survey of the results provides consistent but not strong support for the motor theory prediction. The consistency is evident in that in all of the reported experiments, the overall mean score for the articulatory motor task group was lower than that of the non-articulatory motor task group on the speech perception tests. (This applies to the results of the last study when the means for the separate articulatory motor task groups are combined and
compared to the combined mean of the non-articulatory motor task groups). In statistical terms, the probability of obtaining the same directional result (i.e. articulatory task mean < non-articulatory task mean) by chance was .006, as determined by a "binomial" test (Hays, 1963, p.141). Thus the overall trend of the results is consistent with the initial prediction. However, examination of the individual experiments reveals that the magnitude of the predicted task group differences was generally small and reached statistical significance in only four of the seven studies (Experiments I; II; III, and V).

As noted in the introduction, most of the studies (five out of seven) employed a no-task condition in addition to the motor task conditions in order to assess the specific effects (enhancement or interference) of the motor tasks relative to a no-task condition. It will be recalled that either effect of motor task performance was theoretically possible. A review of the results indicates that in all five of the studies employing a no-task condition, the articulatory motor task group scored lower on the speech sound tests than the no-task group, although this difference was statistically significant in only one (Experiment I) of the studies. The non-articulatory task, on the other hand, scored higher than the no-task condition in three studies (significantly so only in Experiment V), showed no difference in one study (Experiment I), and scored slightly below the no-task condition in one study (Experiment VII). The articulatory motor tasks, therefore, produced a consistent but small interference effect relative to a no-task condition, while the non-articulatory tasks showed a slight tendency to produce a small enhancement effect relative to a no-task condition, on tests of speech perception. It is possible, therefore, that general effects of simple motor task performance tend to slightly
enhance performance (possibly by requiring greater attention) on speech perception tests. This general effect appears to be opposed by more specific interference effects produced by involvement of the articulatory musculature.

The magnitude and/or direction of motor task group differences on speech sound tests was affected in some cases by at least two factors. One factor found to interact with effects of task performance was sex of subjects. In Experiments IV and VI, the pattern of right-ear superiority typically seen in dichotic perception of speech sounds was reversed for females in the articulatory motor task group. Since this reversal was observed in both of these studies despite differences in the types of motor tasks and speech sounds employed, it suggests that the processing of dichotically presented speech sounds in adults may involve the use of articulatory mechanisms, and that such mechanisms play a greater role for females than for males.

A second factor which interacted with task group effects was the type of consonant sound presented (Experiments I and III). Examination of the error scores in these experiments indicated that the only consonant sounds which did not show more errors for the articulatory group than for the non-articulatory group were those sounds belonging to the phonetic class of unvoiced stop consonants (/p/, /t/, /k/). This gave rise to the speculation that unvoiced sounds may involve articulation mechanisms in their processing to a lesser degree than do voiced consonants. However, the interaction with consonants was only observed in two of the six studies which employed consonant-vowel stimuli. In order to assess whether there was, in fact a tendency for certain consonants to be producing the strongest differential task effects in all of the studies, the error scores on each of the six consonant sounds
for articulatory and non-articulatory task groups were compared in each study.

Table 2 presents a summary of the differential task effects for each of six consonants in each of the studies. The magnitude of the effect (mean error score for articulatory group minus mean error score for non-articulatory group) for each consonant is also ranked in size relative to the other consonants in the same study.

Several points are apparent from Table 2. First, the differences between the two motor task groups on all of the consonants are very small in each study. Second, the articulatory group made more errors than the non-articulatory group for the majority of consonants in all but one study (Experiment VI). Examination of those instances where the predicted direction of the difference was reversed (as indicated by minus signs), reveals that this reversal did in fact occur on voiced as well as unvoiced consonant sounds. It might be noted, however, that six of the nine observed reversals occurred on the unvoiced sounds. These observations indicate a slight tendency for unvoiced consonants to show a weaker differential task effect than the voiced consonants. Finally, inspection of the rank orders of the magnitude of the differential task effects provides little evidence of specific consonant sounds consistently producing the strongest effect in all of the studies. The summed rankings indicate very little difference between the consonants, with the one exception of the sound /t/, which tends to produce a generally weaker effect than all of the other consonant sounds.

In consideration of the small but consistent differences between articulatory and non-articulatory motor task group scores on the speech sound tests, it may be asked whether such differences could be attributed to differences in difficulty level or attentional requirements
Table 2

Magnitude and Rank of Motor Task Group Differences in Error Scores for Individual Consonant Sounds

Differences are ranked from smallest (1) to largest (6). Tied ranks are averaged.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Consonant Sounds</th>
<th>B</th>
<th>D</th>
<th>G</th>
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<th>T</th>
<th>K</th>
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<td>I Difference</td>
<td>+0.6</td>
<td>+0.5</td>
<td>+0.8</td>
<td>-0.1</td>
<td>+0.4</td>
<td>-0.2</td>
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<td>5</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>3</td>
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</tr>
<tr>
<td>II Difference</td>
<td>+0.6</td>
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<td>+1.9</td>
<td>-1.9</td>
<td>+0.5</td>
<td>+0.6</td>
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<tr>
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<td>-0.4</td>
<td>-0.6</td>
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<td>+0.8</td>
<td>+0.3</td>
<td>+1.9</td>
<td>+0.1</td>
<td>+1.8</td>
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<td>VI Difference</td>
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of the two types of tasks. Several arguments oppose such an interpretation. First, the two types of motor tasks were designed to involve simple, repetitive motor movements. In all but the first and part of the last study, the two types of tasks were matched as closely as possible in terms of requiring similar, relatively unpracticed patterns of overt motor movement. For example, moving the tongue from side to side was matched with moving the finger from side to side, and extension of the tongue in and out of the mouth was matched with extension and retraction of the forefinger. At this level, at any rate, there appears to be little a priori basis for assuming that one type of task should be more difficult, or require more attention than the other.

A second point is the fact that the articulatory motor task used in all but one study (i.e. movement of the tongue from side to side) was compared with several different non-articulatory motor tasks such as tapping the hand, movement of the forefinger from side to side using both the preferred and non-preferred hands, and touching of the thumb and forefinger of one hand. In addition, four different types of articulatory motor tasks were used in the present series of studies. Performance of articulatory motor tasks consistently produced lower scores on the speech sound tests than did non-articulatory motor tasks.

There seems to be little basis for assuming that articulatory motor tasks would be consistently more difficult than non-articulatory motor tasks, despite the use of varying combinations of articulatory and non-articulatory motor tasks.

Several observations from the data also oppose the likelihood that the articulatory/non-articulatory task group differences were primarily a function of differences in task difficulty. Inspection of
the results of those studies which employed non-speech sound tests indicates that in none of the four studies, each of which used a different type of non-speech sound, were there significant differences between articulatory and non-articulatory group mean scores on the non-speech sound tests. Differences in task difficulty would be expected to produce significant differences between these means. The absence of any significant differences between motor task groups on the non-speech sound tests in the presence of consistent and sometimes significant differences on the speech sound test would suggest that factors other than task difficulty were operative in producing the differences observed on the speech perception tests.

An alternative interpretation of the task group differences, discussed in the last study, was that the interference effect of the articulatory motor task could be attributable in part to possible acoustic interference effects produced by movements of the articulatory musculature. However, as noted in the discussion of the final study the minimal interference produced by the "gum chewing" task, which clearly produces the greatest "noise" component, is opposed to such an interpretation. Furthermore, it may be recalled that in Experiment V, the speech sound stimuli were presented at low intensity levels to increase the difficulty of the perception test. Under such conditions, the presence of extraneous noise would likely have its maximal interference effect. Yet, the mean score for the articulatory motor task group was only very slightly below that of the no-task control group. In all of the other studies the stimuli were presented at levels well above threshold values. The degree of acoustic noise that would have to be generated by articulatory movements in order to substantially mask the stimulus input would be considerable indeed. And if this were in
fact the case, one would still have to account for the greater sensitivity of the speech sounds (compared to the non-speech sounds) to such acoustic interference. All of these points argue against an "acoustic interference" interpretation of the task group differences on the speech sound tests.

The second main hypothesis tested was that the predicted differences between articulatory and non-articulatory task groups on tests of speech perception would not be observed on tests of non-speech perception, since non-speech sound processing presumably involved articulation mechanisms to a minimal or negligible degree. This hypothesis was examined in the last four studies by examining the effects of both types of motor tasks on both speech and non-speech perception. In each of these studies, a Task Group x Stimulus Type interaction would be expected, according to the motor theory hypothesis. Although (a) none of the task group differences for the non-speech sounds were significant in any of the four studies, and (b) the magnitude of the task group difference was greater for the speech sounds than for the non-speech sounds in three of the four studies (both of which are consistent with the above hypothesis), the predicted interaction was not significant in any of the four studies. Thus the results of these studies, although in a direction consistent with the second hypothesis, failed to provide significant support for the prediction of differential task effects for speech and non-speech sounds.

The absence of the predicted Task Group x Stimulus Type interaction clearly indicated that the pattern of task group mean scores did not differ significantly for speech and non-speech sounds. In three of the four studies (Experiments IV, V, and VI), the direction of the task group differences was the same for both speech and non-speech
sounds. Only in the last study was the direction of the difference between the two motor task groups reversed for speech and non-speech sounds, although not sufficiently so to produce a significant interaction. The only other indication of differential motor task effects for speech and non-speech sounds appeared in Experiments IV and VI where there were reversed left-right ear superiorities for females in the articulatory motor task group.

The similarity of the patterns of task group means for both speech and non-speech sounds (most notably in Experiment V) suggests several possibilities. First, it could be argued that the assumption of the second hypothesis, that non-speech sounds do not involve articulation mechanisms, was not valid. Research evidence cited earlier (Ladefoged et al, 1958; Fonagy, 1966; Peterson & Lehiste, 1959; Lieberman, 1967) indicated that speech production mechanisms may be involved in various extra-linguistic aspects such as loudness, stress, and intonation. Certain non-speech sounds might also evoke verbal associations. If this were so, the perception of non-speech sounds might also become vulnerable to the effects of articulatory motor task performance to some extent, and result in similar, although smaller, task effects to those seen for speech sounds. A second point, discussed earlier, was that the similar design of the speech and non-speech tasks may have created a response set which acted to minimize differences in processing of both types of sounds. Although both of these points may have played some role in producing similar patterns of task group scores for speech and non-speech sounds, and therefore a non-significant Task Group x Stimulus interaction, it should be recalled that none of the task group differences on any of the four non-speech sound tests were statistically significant, as expected. However, in three of the four
studies which employed non-speech as well as speech sound tests, the predicted task group differences on the speech sound tests also failed to reach statistical significance, although they were in the predicted direction. It seems clear that the small magnitude of the task differences on the speech sound tests in these studies was the main reason for the failure to obtain the predicted interaction.

A question relating to the consistent but small task group differences obtained on the speech perception tests in the present studies is whether the magnitude of the differences reflects a relatively minor role for articulation processes in speech perception, or whether it is more a reflection of the experimental paradigm used to test the motor theory. Support for the former conclusion comes from a number of related studies which have employed different paradigms and have obtained similar results. Denes (1967) suggested that an important corollary of the motor theory of speech perception was that training in the production of one's own speech was necessary when learning to recognize speech. He tested this hypothesis by having two groups of subjects perform a word recognition task. Prior to this task, one group (called "listeners") heard a pre-recorded speaker repeat a number of words while they viewed a printed list of the words. The other group (called "speakers") listened to the pre-recorded list and repeated the words aloud. He found no statistically significant difference between the number of correctly recognized words on a subsequent recognition test for the two groups.

A recent study by Stassi (1968) attempted to test the motor theory by comparing subjects' ability to discriminate, identify and produce speech and speechlike sounds before and after a learning task which involved either (a) speaking the sounds, (b) listening to them,
or (c) doing neither. The motor theory hypothesis implied that the "speaking" task should produce the greatest post-task improvement. Although Stassi found that neither task had a significant effect upon the discrimination and production scores, he noted that the "speaking" condition produced the fewest errors, and also that this group's production of speech-like sounds was more similar to the actual sounds than the responses occurring under the other two conditions. He concluded that the direction of the results tended to support a motor theory interpretation.

Essentially similar results were found by the present investigator in two preliminary studies. Both studies employed a similar paradigm to that used by Denes and Stassi (described above) in an attempt to determine whether prior articulation of unfamiliar speech sounds (nonsense words and Hungarian words) would facilitate the subsequent discrimination of those same sounds relative to a condition in which the sounds were merely heard but not repeated. In both studies, the "articulation" group showed slightly, but not significantly, more accurate scores on the discrimination task.

Somewhat analogous findings have been reported by Murray (1965b, 1966b) who investigated the effects of adding motor cues during short-term recall of verbal stimuli. As noted earlier, he found that mouthing consonants as they were presented visually gave consistently, but not necessarily significantly, better recall than did silent reading. He concluded that the addition of articulatory motor cues at presentation provided a small degree of facilitation of recall.

Taken together, these latter studies indicate a generally consistent, but relatively small, facilitatory effect of employing articulatory movements (i.e. mouthing or verbalizing) at the time of,
or immediately preceding, stimulus presentation. Moreover, this
effect appears to be similar on tests of speech sound production,
discrimination, and short-term recall. The results of the present
series of studies parallel and extend these findings, insofar as they
demonstrate that when articulatory movements are made during speech
sound presentation (which presumably reduces the availability of
articulatory motor mechanisms for speech processing), there is a
similar consistent but relatively small decremental effect relative to
that produced by (a) the performance of comparable non-articulatory
motor tasks, and (b) a no-task condition. In short, it appears that
the analysis of speech sounds may be slightly facilitated by the
addition of articulatory motor discriminative cues, or slightly
inhibited by the use of speech-motor gestures which reduce the access-
ibility of normally employed articulation mechanisms.

What are the implications of the present findings as they relate
to the events underlying the processing of speech sounds? It may be
recalled that much of the previous research which has explored the
relationship between articulation processes and speech perception has
been of a correlational nature and has left open the question of
whether articulation mechanisms are actively involved in the speech
perception process. The present studies have attempted to answer this
question by experimentally manipulating the articulation variable and
determining the effects of such manipulations upon the perception of
specific types of speech and non-speech sounds. The results of the
present studies, as noted above, have been consistent with, although not
strongly supportive of, a motor theory interpretation which hypothesizes
that articulatory motor neural mechanisms play a direct role in the
processing of speech sound information.
How significant is this role in relation to other factors involved in speech perception? Clearly, the research evidence to date, including the present findings, does not indicate that articulatory motor involvement is of crucial importance in the chain of events underlying the perception of speech sounds. Nor is this particularly surprising. As Miller (1951) observed from a number of studies which attempted to specify the parameters of the acoustic signal which were crucial for speech perception, the speech processing system appears to be capable of utilizing and integrating a wide variety of sources of information, each of which contribute important, but not necessarily essential data. One of these sources of information appears to be provided by the involvement of articulation mechanisms during speech processing. It is evident, as pointed out by Liberman (1967), that such articulatory motor mechanisms must be utilized not in isolation, but in conjunction with other relevant information such as the acoustic, social and linguistic context, and may function to provide an additional "motor meaning" to the acoustic information.

It seems clear that the relative prepotence or significance of different types of information in determining the final speech "percept" must be contingent upon many variables. It has been suggested (Liberman et. al., 1966) that articulation mechanisms would be employed whenever they would facilitate speech perception. Perhaps one of the most profitable research approaches in this area would be to determine under what specific conditions articulatory motor involvement would facilitate speech perception. The present series of studies has been, in part, addressed to this question. The findings suggest a modest degree of articulatory motor involvement in both binaural and dichotic processing of relatively simple consonant-vowel syllable sounds,
becoming operative at a fairly early age. There are, however, many questions as to what level or levels of perceptual analysis employ articulation mechanisms, and to what degree. Illustrative of such questions are (a) is articulatory motor involvement specific to the auditory mode, or would similar effects be seen for visually presented verbal stimuli, as has been suggested in the reported studies on short-term recall? (b) is there a greater degree of involvement of articulation mechanisms in the processing of "difficult" versus "easy" speech stimuli (several EMG studies report a greater degree of sub-vocalization responses to difficult material)? (c) do articulation mechanisms function in the temporal analysis of speech sounds, or in the determination of thresholds to speech stimuli? The use of an articulatory motor task interference technique may provide a useful approach to the investigation of such questions.
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APPENDIX A...

Analysis of Variance Tables
### Experiment I

**Analysis of Correct Identification Scores**

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<th>Source of Variation</th>
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<th>MS</th>
<th>F</th>
<th>P</th>
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### EXPERIMENT I

#### ANALYSIS OF CONSONANT ERRORS

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**TOTAL**                        | 2071.22| 575|      |      |    |
### EXPERIMENT II

#### ANALYSIS OF CORRECT IDENTIFICATION SCORES

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<th>Source of Variation</th>
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#### Within Ss

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**TOTAL** 1635.39 79

#### ANALYSIS OF SCORES FOR CONDITIONS DONE FIRST

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**TOTAL** 756.40 39
## Experiment II

### Analysis of Consonant Errors for Re-Analyzed Data

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### Experiment III

**Analysis of Correct Identification Scores**

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**Analysis of Correct Identification Scores (collapsed over Sex and Ear factors)**

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**Analysis of Consonant Errors**

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**EXPERIMENT IV**

**ANALYSIS OF PERCENT CORRECT IDENTIFICATION SCORES ON SPEECH AND NON-SPEECH SOUND TESTS**

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**TOTAL**          | 61074.92 | 183 |
EXPERIMENT IV

ANALYSIS OF CORRECT IDENTIFICATION SCORES ON SPEECH SOUND TEST

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ANALYSIS OF CORRECT IDENTIFICATION SCORES ON NON-SPEECH SOUND TEST

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### Experiment V

**Analysis of Percent Correct Identification Scores**

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### Analysis of Response Latencies

**Analysis of percent correct identification scores on speech and non-speech sound tests.**

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EXPERIMENT V

ANALYSIS OF CONSONANT ERRORS

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EXPERIMENT VI

ANALYSIS OF PERCENT CORRECT IDENTIFICATION SCORES ON SPEECH AND NON-SPEECH SOUND TESTS

<table>
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ANALYSIS OF CORRECT IDENTIFICATION SCORES ON SPEECH SOUND TEST

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**EXPERIMENT VI**

**ANALYSIS OF CONSONANT ERRORS**

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**TOTAL** | **1030.512** | **527** |
## Experiment VII

### Analysis of Percent Correct Identification Scores

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### Analysis of Consonant Errors

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