SPEECH PRODUCTION AND PERCEPTION IN A PATIENT WITH SEVERE IMPAIRMENT OF SOMESTHETIC PERCEPTION AND MOTOR CONTROL

PETER F. MacNEILAGE *and* THOMAS P. ROOTES

Haskins Laboratories, New York, New York

RICHARD ALLEN CHASE

Neurocommunications Laboratory, Johns Hopkins University School of Medicine, Baltimore, Maryland

Studies were made of speech and other motor behavior of a 17-year-old female with severe chronic difficulties in swallowing, chewing, and speaking. Studies included: (a) physical and neurological examination; (b) phonological analysis; (c) electromyography; (d) cinefluorography; (e) non-speech motor tests; (f) tests of phoneme perception, and (g) dichotic auditory perception tests. Neurological examination revealed severe defects in complex somesthetic sensation (e.g. stereognosis). Other sensory functions, including hearing, were normal. Although motor abnormalities of extrapyramidal, cerebellar or peripheral origin were not indicated, the patient was unable to activate the several muscles required for any given speech gesture while at the same time independently controlling their various patterns of activity in normal fashion. It was concluded that this difficulty was not primarily of motor origin but resulted from congenital inability to obtain somesthetic information necessary for learning of the patterns of spatial distribution and temporal modulation of muscle contraction accompanying normal speech. Despite the severe speech production deficits, speech perception approached normality, even in some characteristics which, according to the motor theory of speech perception, are dependent on the listener's referring to the neural correlates of normal speech motor control. Reference to normal motor information does not therefore appear necessary for these types of perceptual performance.

This paper reports part of an extensive study of a 17-year old, right-handed female who first came to medical attention because of severe difficulties in swallowing, chewing, and speaking, which had persisted since early childhood (Bosma, 1967). One aim of the present study was to characterize in detail the patient's speech production, and to relate the results to other information in an attempt to specify the nature of the patient's deficit. A second aim arose from the motor theory of speech perception according to which speech perception

is dependent on stored information about how one's own motor system produces speech (Liberman et al., 1962). This theory prompted the administration of perceptual tests to see whether the patient's severe speech production deficits were reflected in her perceptual capabilities. Six main investigative techniques were used in the study in addition to a general clinical examination of the patient:

1. Phonological analysis of recordings of the patient's speech.
2. Surface electromyographic techniques suitable for simultaneous recording from a number of fast moving articulators (Cooper, 1965).
3. High speed cinefluorographic recordings of the patient's speech (made available to us by Bosma).
4. A number of tests of perception of individual phonemes, e.g., /b/, /d/, /g/, and of individual phonetic characteristics of speech, e.g., the voice-voiceless distinction (Liberman, 1957).
5. Auditory perception tests involving simultaneous presentation of different verbal material to each ear (Katz, Basil, and Smith, 1963; Berlin et al., 1965).
6. A finger movement tracking system for evaluation of manual motor control (Chase et al., 1965).

GENERAL CLINICAL EXAMINATION[1]

The patient had been a full-term infant, delivered by forceps with some difficulty, following a prolonged labor. Pregnancy had been complicated by intermittent bleeding through the second and third trimesters. There was no evidence of neurological impairment in the neonatal period however.

Difficulty sucking and swallowing were noted during the first months of life, and there has been a life-long history of difficulty chewing and swallowing. Marked drooling was noted at one year of age, and has persisted to the present time.

The patient did not develop normal speech motor activity, and has been restricted primarily to the production of vowel sounds most of her life. With the aid of speech therapy during the past few years, minimally-intelligible speech has been developed. There is a life-long history of minor traumatic injuries, primarily contusions and burns.

The patient walked at 11 months, and her general motor development was within normal limits. However some clumsiness of fine movements of the hands has been observed from early childhood. The patient is right handed.

There has never been evidence of intellectual impairment, and despite her marked communication handicap, the patient has done reasonable work in a regular public school.

---

[1] A motion picture film of aspects of the clinical examination of the patient is obtainable from Chase.

The patient is one of three siblings. Neither of the other siblings, nor any other members of the patient's family have similar symptoms.

On physical examination, the vital signs were found to be within normal limits, and the patient was comfortable, cooperative, and well-oriented. The general physical examination revealed findings within normal limits. However, the neurological examination revealed many abnormalities.

Examination of the cranial nerves showed several abnormalities. The corneal reflexes were absent bilaterally. A pin prick was not perceived as being sharp anywhere on the face, or in the oral cavity. There was no sensation of pain in the oral cavity either on probing with a sharp instrument, or on deep pressure with a blunt instrument. There was marked inability to organize movements of the lips and tongue. Protrusion of the tongue anterior to the teeth was impossible, as was deviation of the tongue to right or left. The gag reflex was absent. Smell and taste sensation were normal.

Gait and station were normal, but it was impossible for the patient to perform heel-to-toe walking without visual guidance. Muscle strength and tone were normal, and no atrophy or fasciculations were noted. There was marked impairment of coordinated movements of the fingers of both hands, greater on the left than on the right. When visual guidance was not allowed, tasks such as apposition of the thumb to the tip of each of the other fingers in sequence were almost impossible to perform. Marked improvement followed the allowance of visual guidance. There was considerable impairment of articulation, more marked for consonant sounds that for vowel sounds, undoubtedly related to the observable difficulties in organizing tongue and lip movements.

The ability to check movement was normal, and no rebound, past-pointing, or ataxia were noted. No tremor was observed either at rest or on voluntary movement. Moderate choreiform movement of the fingers of both hands was noted in association with abduction of the fingers, and hyperextension at the metacarpophalangeal joints of all fingers when the arms were held in full extension.

The deep tendon reflexes were all within normal limits, but more active on the left side. No pathological reflexes were noted.

Sensory examination showed that a pin prick was usually perceived as a dull sensation, and never experienced as painful, even when considerable pressure was applied. This was the case over the entire body surface, and in the oral cavity. However, a pin prick was experienced as being less dull than pressure with a blunt object, and was readily distinguished from a light touch with a wisp of cotton. Light touch, position, vibratory, and temperature sensation were grossly normal. The patient was able to identify numbers written on the palms of her hands with a blunt instrument while her eyes were closed. Bilateral simultaneous stimulation of symmetrical portions of the trunk, extremities, and face revealed no evidence of extinction. Localization of point stimulation was performed accurately for the trunk and extremities, but errors of one to three inches in the localization of point stimulation were common for the face. Two-point discrimination was normal for the trunk and extremities. However,

two-point discrimination was impaired for the lips. Marked impairment of stereognosis was noted for both upper extremities. When a coin was placed in the patient's hand, she failed to position it between the finger tips, but rather permitted the coin to fall into the palm of her hand from which position she manipulated the coin very awkwardly. Coins were inaccurately identified most of the time, sometimes being identified as rubber bands. Simply stroking the palm of the hand during such testing was noted to initiate exploratory movements which were continued until the examiner requested that they be discontinued.

The electroencephalogram showed a borderline normal record, with some asymmetry of alpha activity in the occipital regions. Skull x ray demonstrated increased vascular markings in the parietal region, considered probably to be a normal variant. Biopsies of oral mucosa and skin from the fingers all showed normal neural elements. Use of the Wechsler Bellevue Form I yielded a verbal IQ of 83, a performance IQ of 99, and a full scale IQ of 90 (dull normal). Audiological evaluation demonstrated normal pure-tone and speech-reception thresholds for both ears.

EXPERIMENTAL STUDIES OF NONVOCAL MOTOR ACTIVITY

Of the motor abnormalities revealed by clinical examination, those affecting the oral area were investigated more thoroughly with tests of speech production described later in the paper. The abnormalities of coordinated movements of the extremities were also investigated further, by analysis of finger movement patterns generated during a tracking task (Chase, 1965; Chase et al., 1965). In a typical test, the patient's arm and hand were placed in a positioning device and the extended index finger was fixed in a cup attached to a pulley system. A 2 cm horizontal bar on an oscilloscope represented the reference or null position at which the patient was required to maintain her finger. A second 2 cm bar was controlled by the patient's vertical finger movement about this position, and represented the error signal which the patient was required to eliminate.

The results showed a number of abnormalities of finger movement patterns. The most notable finding was a marked decrease in the amplitude of higher frequency components of movements. Normal subjects invariably show moderate amplitude movements at about 10 Hz, but these movements are not grossly observable in the patient's record. It is of interest that experiments with normal subjects in which 1 cc of 1% xylocaine was infiltrated on each side of the base of the proximal phalanx, resulting in complete elimination of light touch sensation in the finger, showed an attenuation of the higher frequency components of finger movement quite similar to the pattern demonstrated by the patient without local anesthesia. The patient also showed intermittent, high-amplitude departures of the finger from the target position, and definite impairment of her ability to follow a moving target.

Tests of Speech Production

Phonological Examination. The verbal material used for analysis consisted of the patient's readings of a number of lists of monosyllables and disyllables, and some polysyllables. Recordings were also made of some speech exercises, such as rapid syllable repetition, and of periods of casual conversation with either the examiner or the patient's mother. Lists were usually read from flash cards bearing the required words. Some recordings were also made of the patient's attempts to mimic words pronounced by the examiner. The main lists of syllables were as follows:

1. A list of 94 common monosyllables, largely of the consonant-vowel-consonant form, but with a few syllables containing consonant clusters. All standard consonants of American English were used, and three vowels, /i/, /u/, and /æ/. Each syllable was produced twice by the patient. In this list, single consonants to be reported on here occurred from 14 to 40 times in non-cluster context.

2. A number of disyllables in which the initial, unstressed syllable, was always /ə/, and the second, stressed syllable, consisted of one of 16 consonants followed by one of the four vowels /i/, /ɛ/, /a/, or /u/. The set of 64 utterances was repeated 8 times.

3. A number of disyllables in which the initial, unstressed syllable was /ə/, and the second, stressed syllable was composed of /h/ followed by one of 10 vowels. Each utterance was repeated 7 times.

Analysis of the data largely took the form of broad phonetic transcriptions of the patient's utterances either by a listener who did not know what the stimulus word was, or by the examiner himself. No gross or systematic differences in the results of these two types of transcription were observed.

Electromyography. A comparison was made between the motor function of the patient and that of a normal subject during speech, by means of recording electromyograms from some of the muscles of speech. The myograms were recorded with surface suction electrodes. The apparatus and the recording methods have been described elsewhere (Harris et al., 1964; MacNeilage and Sholes, 1964). Electrodes were placed at 3 locations:

1. Upper lip at the midline.
2. Tongue tip—dorsal surface.
3. Tongue blade (approximately 6 cm posterior to the tip, on the dorsal surface).

During speech, a vibration pickup placed against the thyroid cartilage recorded the periods of voicing. The inventory spoken by both subjects included consonant-vowel-consonant syllables with /p/, /t/, or /k/ in initial position, /i/, /u/, or /a/ in medical position, and /p/ in final position. A number of disyllables were also spoken.

Cinefluorography. High speech cinefluorograms of the patient producing 7 consonant-vowel-consonant syllables involving stop consonants and either the vowel /i/ or /æ/ were recorded (see Bosma, 1967).

Tests of Speech Perception.

Dichotic Perception Tests. These are tests in which pairs of speech stimuli are presented simultaneously, one to each ear. Normal subjects tend to be more efficient in recall from the right ear and this is thought to be due to the predominant role of the left temporal lobe in language behavior (Kimura, 1961).

1. Staggered spondee word test. (Katz, Basil, and Smith, 1963). This involves presentation of pairs of spondee words to the two ears in a temporal arrangement shown in the following example:

> right ear: up   town
> left ear: down   stairs

In this example, the word *up* is presented to the right ear alone, the words *town* and *down* are presented simultaneously to both ears, and finally the word *stairs* is presented to the left ear alone. The two words that do not overlap in time also form a spondee word, in this case *up stairs*. The patient received 40 sets of words. The test was scored on the ability to correctly identify the words.

2. Rhyming test. (Berlin et al., 1965). This is a test of a subject's ability to identify rhyming monosyllables that are identical except for one consonant, and which overlap in time. Words like *back* and *bat* are presented to both ears simultaneously. The patient is asked to write down the words heard, and identify the ear to which they are presented. Twenty-five pairs of words were presented to the patient, and the percentage recalled correctly was noted.

Phoneme Perception Tests. Each test is composed of a series of stimuli consisting of systematic variations in an acoustic cue shown by previous work at Haskins Laboratories to be important in normal phoneme perception. This work has been summarized in a number of papers, e.g., Liberman, 1957; Liberman et al., 1964; Fry, 1964. In these tests, the subject is either asked to identify each stimulus as a particular phoneme (Identification test) or to discriminate between stimuli by saying which two, of three successively presented stimuli

are the same (Discrimination test). The patient made between 10 and 72 individual judgments per stimulus item, depending on the test. The modal number of judgments was approximately 35. Her results were compared with those cited for groups of normal subjects in the original studies, unless otherwise stated.

1. Voiced stop consonant identification and discrimination.
   The stimuli were 13 synthetic vowels ranging perceptually from /ba/ through /da/ to /ga/ as a result of systematic variations in second and third formant transitions (Studdert-Kennedy, Liberman, and Stevens, 1963).

2. Front vowel identification and discrimination.
   Stimuli were 13 synthetic vowels made to range from /i/ through /ɪ/ to /ɛ/ by means of systematic variations in the frequencies of the first three formants (Studdert-Kennedy, Liberman, and Stevens, 1963). (The normal control data for the two above discrimination tests are derived from an unpublished study of 10 Haskins Laboratories employees.)

3. Identification of voiced and voiceless stop consonants in initial position.
   The stimuli were 7 synthetic consonant-vowel syllables made to range perceptually from /do/ to /to/ by delaying the onset of the first formant, relative to the other formants, in a series of 10 millisecond steps (Liberman, Delattre, and Cooper, 1958).

4. Identification of a voiceless stop consonant in an initial cluster.
   Eight stimuli were constructed by inserting 8 lengths of silent interval—varying in 10 msec steps from 10 to 80 msec—between the /s/ and the /l/ of a tape recording of the word *slit*. The stimuli ranged perceptually from the word *slit* to the word *split* (Bastian, Eimas, and Liberman, 1961). In the results section, the patient's results are compared with those of only one subject. This was done because different normal subjects made "crossovers"[2] at widely different points on the stimulus continuum making the pooling of data inappropriate. The subject chosen has a crossover point similar to the patient's (see Figure 9) but has a sharpness of crossover typical for normal subjects.

5. Identification of voiced and voiceless stop consonants in intervocalic position.
   Two tests were performed:

   a. Stimuli were 11 synthetic words made to range perceptually from *rabid* to *rapid* by increasing the silent interval between the vowels in a series of 10 msec steps (Liberman et al., 1961).
   b. A similar test to the above in which the silent interval was varied by tape cutting of real speech recordings, producing a series of words ranging from *ruby* to *rupee* (Lisker, 1957).

---

[2] "Crossovers" are regions in the continuum where identifications change from one phonological category to another.

Speech Production

Phonological Examination. As informal observation and the clinical exami-
nation also indicated, vowels were produced much more acceptably than con-
sonants as a general class. Broad phonetic transcriptions of a number of lists
by different transcribers yielded an average of about 80% correct vowel identi-
fications. Long unrounded vowels /i/, /æ/, and /a/ were more often judged
correct than long rounded vowels /u/ and /ɔ/, presumably because of the pa-
tient's inability to produce lip rounding. Long vowels as a class tended to be
more often judged correct than short vowels, with the exception of /ʌ/. When
vowels were judged incorrect they were often transcribed as an adjacent vowel
on the vowel triangle.

The distribution of consonants judged to be correct from the analysis schwa-
consonant-vowel disyllables is shown in Figure 1. Voiced stops were never
judged correct in these utterances, and voiced fricatives were seldom correct.
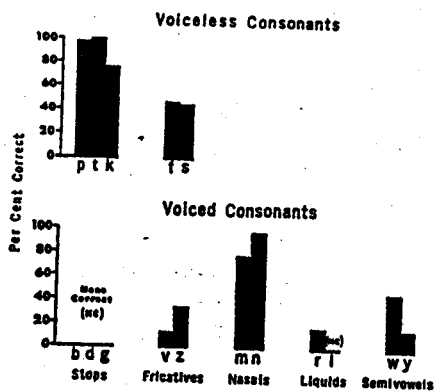
FIGURE 1. Percentages of consonant pro-
ductions judged correct in ə' CV utterances.

On the other hand, voiceless stops as a class were about as often correct as
vowels, and voiceless fricatives were correct on about 50% of occasions. Nasals
were usually judged correct. Liquids as a class were almost never correct, and
of the semivowels, only /w/ was often correct.

Consonant clusters were almost never produced correctly. For the most part,
either a silent interval was inserted between consonants, or only one of the
consonants was produced. The frequencies of correct productions of individual
consonants in clusters were similar to those already noted for noncluster
contexts.

Positional effects on consonant production in CVC monosyllables were most
worthy of note in the case of stop consonants. Figure 2 shows that, in consonant-
vowel-consonant syllables, voiced consonants were never produced correctly
whereas voiceless stops were usually produced correctly. But it can be seen
that all three voiceless stops are more often correctly produced in initial position

than in final position. It is also true of voiceless consonants that, whereas errors in initial position usually take the form of another voiceless consonant, errors in final position usually consist of the absence of any acoustic signal. The voiced consonants usually show a somewhat different pattern of error. For initial /b/ and /d/ the corresponding voiceless consonant is usually the error, although a wide variety of sounds are substituted for /g/. In final position, for
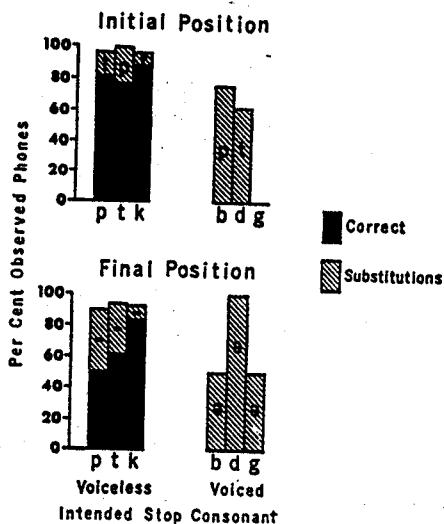

FIGURE 2. Positional effects on production of voiced and voiceless stop consonants in CVC syllables.

all three consonants, the error usually takes the form of a period of voicing which sounded similar to schwa and was possibly terminated by a glottal stop. The results demonstrate the existence and form of characteristic "strategies" of production of stop consonants.

Polysyllabic words were typically produced in the testing situation with relatively long silences at syllable boundaries. The production of individual syllables in these words seemed generally to adhere to the rules already outlined.

The patient's rate of speech was considerably slower than normal, both because of periods of silence between and within syllables, and because durations of individual sounds were often greater than normal. When asked to repeat individual syllables such as /ki/ and /ka/ as rapidly as possible, the patient was also considerably slower than normal subjects. This deficiency was not limited to upper articulatory action since it was noted during production of a series of schwa-like neutral vowels separated by silence. The deficiency is rather one that applies to all types of complex voluntary movement as it was frequently observed in nonspeech functions such as successive apposition of the four fingers to the thumb and high speed finger tapping. (Movement complexity is defined in this paper as proportional to the number of concurrent but independently varying actions of muscles required for the act.)

The circumstances under which the patient is speaking are in many ways

influential in determining her production. If she is allowed to make repeated attempts to produce the same syllable, she usually repeats the same deficient version, and seems aware that it is deficient. But changes sometimes occur and improvement occasionally occurs when the examiner provides a spoken example to mimic. Improvements, however, appeared to be transitory. The strategy of an attempt to produce a given sound varied occasionally from day to day. These varying strategies probably consist of ad hoc attempts to approximate sounds that she makes little effort to produce in her usual speech environment. In a familiar environment the patient speaks at rates more like those of normal subjects. But on those occasions her speech consists almost entirely of an alternation of vocalic portions resembling vowels and diphthongs, and glottal stops. Relatively normal sounding intonation is used liberally on these occasions to supply, with the relatively normal durational features, much useful prosodic information to the listener. Thus in her usual communicative attempts, the patient relies more on prosodic than on phonological information.

Electromyography. Figures 3, 4, and 5 show average voltage patterns for the patient (E) and the normal subject (N.S.) during production of the consonant-vowel-consonant monosyllables beginning with /p/, /t/, and /k/. Averages were computed from 6-10 tokens of each syllable. Records for /b/—vowel—/p/ syllables were not presented because they were very similar to those for /p/—vowel—/p/ syllables.

One general finding was that the patient showed little of the expected variation in pattern of muscle activity during the three successive phonological com-
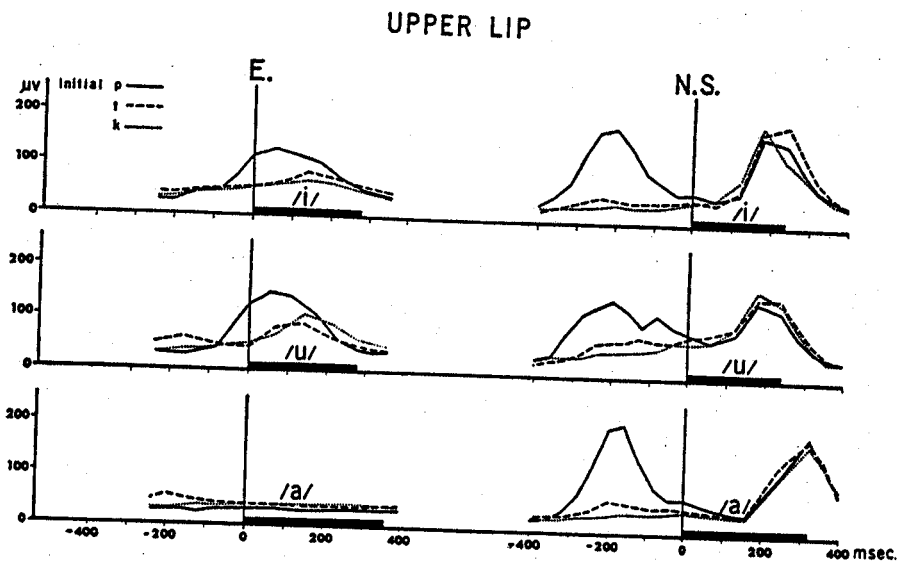

FIGURE 3. Mean voltage levels recorded from the upper lip of the patient (E) and a normal subject (N.S.) during production of CVC monosyllables.
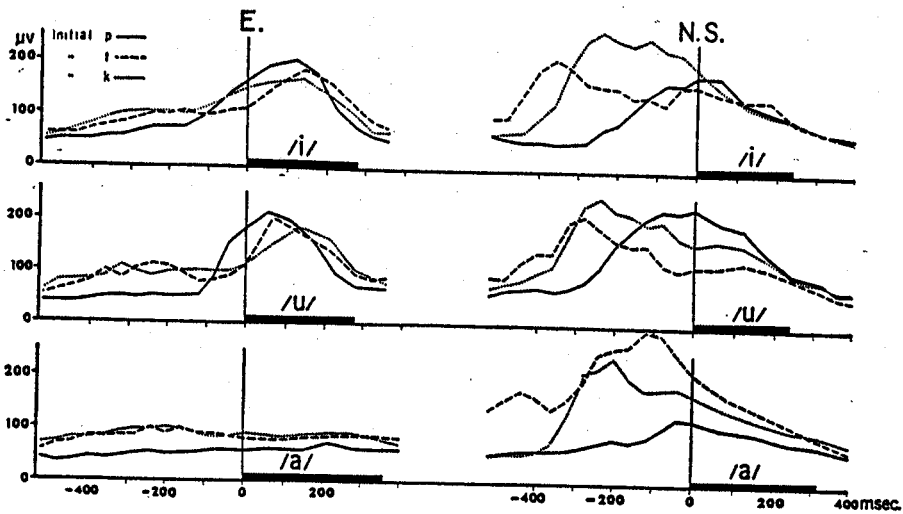
FIGURE 4. Mean voltage levels recorded from the tongue tip of the patient and a normal subject during production of CVC monosyllables.
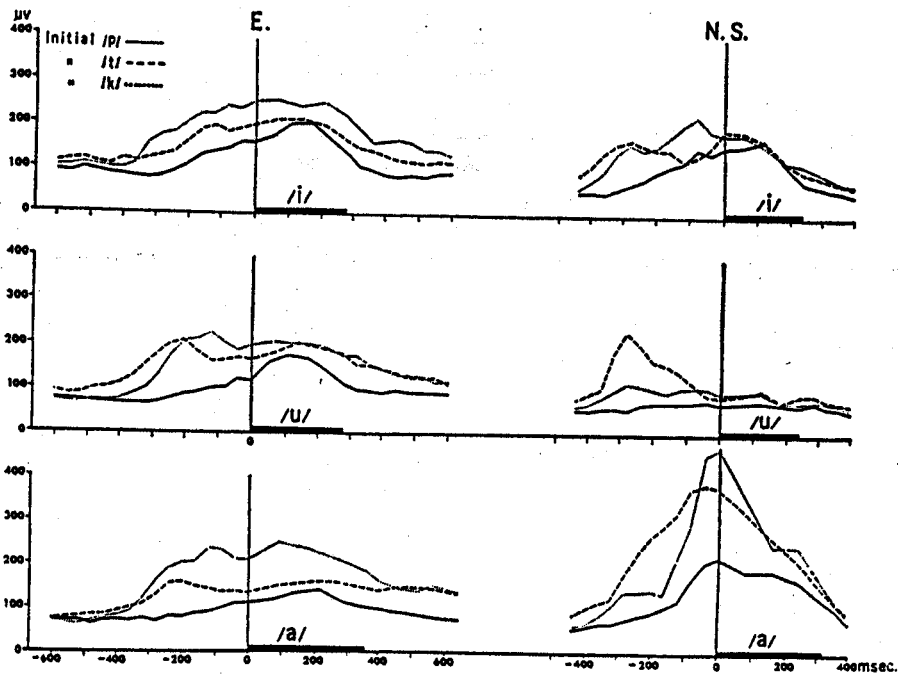

FIGURE 5. Mean voltage levels recorded from the tongue blade of the patient and a normal subject during production of CVC monosyllables.

ponents of any given syllable. Her typical pattern consisted of a relatively "smoothed" voltage peak during the vowel with sometimes a somewhat distinct but often smaller peak during the initial consonant. In contrast the normal subject shows a large number of variations in pattern which can be related to differences in phonological structure of the syllables. The most noticeable examples are: (a) the familiar voltage peaks at the upper lip (Figure 3) associated with lip closure for initial and final /p/ (Harris, Lysaught, and Schvey, 1965); (b) highest of all levels of activity at the tongue blade (Figure 5) just before voicing in /tap/ and /kap/ associated with high amplitude tongue movements from consonantal occlusion to the low back vowel position. These findings suggest that one aspect of the patient's motor deficit is a lack of temporal differentiation of motor output.

A second general finding can be described as a lack of spatial differentiation of motor output. The patient shows much less difference between patterns of activity at the three electrode sites than does the normal subject. In particular, her upper lip patterns are almost identical to her tongue tip patterns. The possibility that the motor output to these two sites had predominantly a single controlling origin was suggested by the finding of significant positive correlation coefficients ($P = <0.05$; $N = 6$-10 tokens) between activity levels at the two sites for a number of syllable types. No significant correlations were found for the normal subject, emphasizing the abnormality of the relationship observed in the patient. The patterns observed were ones relatively appropriate to the tongue tip for the gestures they accompanied but not to the upper lip. The relation between the patterns therefore seems to result from a spreading of activity directed toward the tongue, to the upper lip. This finding takes on more significance because of the different cranial nerve innervation of the two areas (the tongue is innervated by the hypoglossal nerve and the lip by a branch of the facial).

It should be noted, however, that there is not a total lack of spatial differentiation of activity at these two sites. Figures 3 and 4 show that the proportion of lip to tongue tip voltage is highest in /pip/ and /pup/ where the tongue was not involved in production of the consonant as well as the vowel. Also the highest rank correlations, and the only ones beyond the 0.01 level of significance were observed during the vowels of /pip/ and /pup/ (and also during /bip/ and /bup/). This suggests that the patient can produce slightly more differentiation of spatial distribution of activity in the other, more complex cases, where the tongue is required to act for both initial consonant and vowel.

Electromyographic results for disyllables were, in general terms, similar to those shown in monosyllables. The patient showed about the same level and pattern of activity at all electrode sites as she showed for the corresponding phonemic elements when they occurred in monosyllables. On the other hand the normal subject showed more variation with contextual features peculiar to the disyllables (e.g., /t/ and /k/ in intervocalic position).

Despite the abnormal patterning of muscle activity during the patient's speech, which has already been described, she appeared to be within normal

limits on a number of basic parameters of muscle activity. It can be seen for instance that overall amounts of activity during the patient's vowels, on which her intelligibility was closest to normal, were roughly similar to those of the normal subject. The form of the raw muscle action potentials also appeared grossly similar in the two subjects. A bilateral comparison of voltage levels on both the tongue and the upper lip showed no significant asymmetry of voltage level or pattern.

Cinefluorography. The results of this examination have been described in detail by Bosma (1967). One particular aspect of production deserves mention here because it seems to relate to electromyographic findings already described. It was observed that movements of the soft palate toward velopharyngeal closure were highly correlated with the extent to which the tongue was concurrently moving away from its rest position. For instance, the patient typically articulates /k/ in a highly abnormal manner, with the mouth opening very widely and the tongue moving to occlude the vocal tract in the mesopharyngeal region. During such a production, considerable velar movement towards velopharyngeal closure is typically (though not always) observable. Production of /t/ typically involved massive elevation of the body of the tongue to a position approximating or reaching mid-palatal closure. A considerable velar movement towards velopharyngeal closure accompanied this gesture on one occasion. On the other hand, when little tongue movement away from rest accompanied attempts at consonant production, no velopharyngeal closure motion was observed. And during vowels, which for the tongue typically involved either little further movement or movement towards its resting position, the palate descended, leaving the velopharyngeal valve wide open. This was true even for vowels immediately adjacent to the consonant featuring velopharyngeal closure.

In contrast to these palatal actions, unpublished observations show that the soft palate of the normal subject moves to a position of velopharyngeal closure whatever the movement required for the consonant, and remains in roughly the same position during the vowel. Thus the patient's patterns of palatal behavior seem analagous to those observed electromyographically at the upper lip. In both cases, action of the smaller of two articulators does not appear to be independent of concurrent action of the nearby larger articulatory structure.

At no time during cinefluorography was the patient observed to move the anterior part of her tongue with any independence from the body of the tongue, such as is required for normal /t/ production. This conforms with the observation of inability to make specific tongue movements, made in the neurological examination. It also relates to many findings of the phonological examination. For instance the patient was totally unable to produce /l/, or any affricates, and seldom produced any other sounds requiring selective shaping of the front of the tongue (/t/ and /n/ are exceptions but the cinefluorographic results suggest they were produced by movement of the body of the tongue alone). Therefore the lack of spatial differentiation already observed in other parts of

the musculature is also present in the anterior portion of the tongue, a region critical for many speech gestures.

Speech Perception

In a preliminary test to determine whether the patient had any gross perceptual deficit, an articulation test was administered in which each stimulus was a consonant-vowel-consonant monosyllable, and the patient chose which syllable had been spoken, from a written set of six syllables, five differing from the test syllable by one consonant (House et al., 1965). After the patient had responded to about 40 stimuli without an error, under ordinary listening conditions, the test was discontinued.

Phoneme Perception. Figures 6, 7, and 8 show the results of the phoneme identification tests. The patient performed at a somewhat lower level than the normal groups on all identification tests except the "ruby-rupee" test (Figure 8) in that she did not achieve the same degree of unanimity of identification. But the fact that she did perform as well as normal on the "ruby-rupee" test suggests that the patient has no overall perceptual deficit. However the precise meaning of this result is not clear as the "ruby-rupee" test is similar to the "rabid-rapid" test on which the patient's performance was somewhat lower. The significant factor here may be that the "ruby-rupee" test stimuli consisted of natural speech segments modified by tape cutting procedures, whereas the stimuli for the "rabid-rapid" test were synthetic stimuli generated by the pattern playback. It should be noted that the normal control groups,
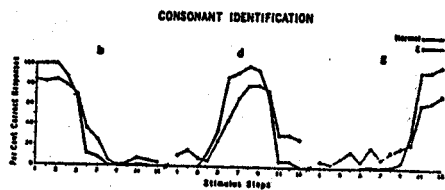

FIGURE 6. Percentages of identifications of consonantal stimuli as either /b/, /d/ or /g/ by the patient (E) and a normal control group.

FIGURE 7. Percentages of identification of vowel stimuli as either /i/, /ɪ/ or /ɛ/ by the patient (E) and a normal control group.
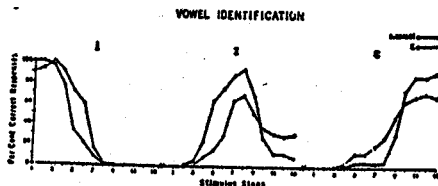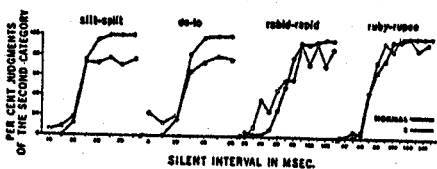

FIGURE 8 Comparison of performance by the patient and normals on a number of tests of identification of voiced and voiceless stop consonants.

whose results are presented for comparison, were either groups of college students or Haskins Laboratories staff members, whereas the patient was a grade school student with an intelligence test score of about 90. The higher levels of performance of the control groups may therefore have been due to their higher test-taking sophistication and motivation, and a higher intelligence level than the patient. There is, therefore, no clear evidence that the patient has a gross deficit in level of perceptual identification performance.

The patient's overall pattern of identification is usually very similar to that of the normal group. In particular, her "crossovers" are usually similar, both in location and in extent, to those of the normal group.

As was the case for identification, the patient's level of performance on the two discrimination tests was somewhat but not markedly lower than that of the normal groups. These results are shown in Figure 9. Again the patterns of performance were in most ways similar to those typical for the normal groups.[3] For instance the patient's level of discrimination was higher for vowels than for consonants as is typically true of normal subjects. But the patient's discrimination level for consonants was relatively higher in the regions of the phoneme boundaries (i.e., stimuli 5 and 6 and 10 and 11) and relatively lower within phoneme categories, when compared with vowel discrimination levels. This is again a standard finding in normal subjects (Liberman et al., 1962). The only
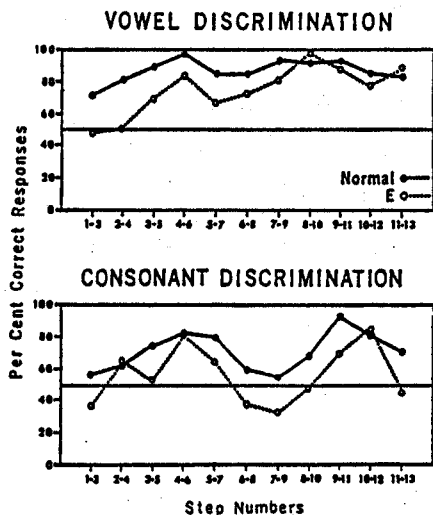

FIGURE 9. Comparison of the patient with normal subjects on percentages of correct discriminations of consonantal and vowel stimuli two steps apart on the stimulus series.

[3]The fact that three of the patient's data points in the consonant two-step discrimination test fell considerably below the 50% or "chance" level of discrimination is an anomalous one. It was not explicable in terms of any obvious peculiarity of the administration of the test, or in terms of any unusual "set" visible in the subject's responses during any phase of the testing. Moreover only one of these points is significantly different from chance expectation (P = <0.05), and no similar tendency towards below chance scores was observed in either the one-step or the three-step discrimination results.

consistent difference in discrimination pattern between the patient and normals is the tendency of the patient to show particularly low levels of discrimination within the /i/ category. This is the category within which the patient is most unanimous in identification. Even here, therefore, the relation between identification and discrimination is typical of that found in normal subjects; the higher the level of identification, the lower the level of discrimination within a phoneme category.

These results show that the patient's levels and patterns of performance on these tests are, in general, similar to those of normal perceivers. There is no tendency for the overall trend of the patient's perceptual judgments to be influenced by her productive disabilities. For example, perception of voiced consonants, which the patient could not produce correctly at all, would be expected to be considerably worse than perception of vowels, but it is not so. In addition, the patient scarcely makes a distinction between voiced and voiceless stop consonants in her production, producing almost all stops as voiceless stops. But she makes relatively normal perceptual distinctions between these two classes. There are only two specific cases where a relation between perception and production seems possible. First, the patient's identification of /i/ is considerably more efficient than identification of /ɪ/ or /ɛ/, just as her production of /i/ is more efficient. Secondly, the very low level of /g/ identification may relate to the fact that the patient never produced this sound correctly and did not even attempt its production in a consistent fashion, though she did fairly consistently substitute the voiceless equivalents (/p/ and /t/) for /b/ and /d/, at least in initial position. These correlations between perception and production could account for only a small part of the patient's perceptual performance.

Dichotic Perception Tests. Table 1 shows the results of the Staggered Spondee Word Test (S.S.W.). All the patient's scores are poorer than those

TABLE 1. The patient's scores on the Staggered Spondee Word Test.

Position of the Word in the Sequence	Right Ear	Left Ear
Lead and come alone	85%	85%
Compete from the leading position	40%	70%
Compete from the trailing position	80%	80%
Trail and come alone	80%	90%

typical for normal subjects. But, relatively speaking, the greatest deficit is in identification of competing words when they are presented to the right ear. Performance on the rhyming test was also worse than that of normal subjects. Again, as in the S.S.W. test, performance was relatively worse on words presented to the right ear. Both results therefore contrast with the normal tendency for lower performance on words presented to the left ear.

General Discussion

There is enough evidence to conclude that the patient has a general deficit in control of complex voluntary movements. The deficit takes 2 forms:

(a) an inability to rapidly vary amount of muscle activity from moment to moment during a sequence of voluntary actions (lack of temporal differentiation of motor activity),

(b) an inability to independently control, and more particularly to restrict, the spatial distribution of motor innervation of the various available muscles (lack of spatial differentiation).

As a consequence of this deficit the patient is able to perform, with relatively normal effectiveness, only the more simple types of voluntary movements, e.g., walking, grasping of objects, and some more complex types of movements at much slower than normal rates; e.g., she writes legibly but very slowly. However, the patient's deficit does not appear to result primarily from damage of the motor system itself. There are no abnormalities of movement characteristic of "extra-pyramidal" or cerebellar system impairment. There is no suggestion of localized damage to motor cortex, pyramidal tract, or peripheral motor nerves. Biopsies and electromyographic records show no deficiencies in structure or function of muscle itself. However deficient the patient may be in reaching normal levels of voluntary motor control, she does usually show considerable consistency in her successive attempts at a given speech gesture, which indicates an ability to conclusively formulate commands of some sort and to initiate them when required.

In contrast to the lack of evidence for direct damage to the motor system there is considerable evidence of damage to the mechanism of somesthetic sensibility. Stereognosis, sensitivity to painful stimuli, tactile localization, and two-point discrimination were all impaired, though light touch, temperature, and position sensation seemed normal. Despite these sensory deficits, sensory receptors and nerves in the skin and oral mucosa had a normal appearance on microscopic examination. The patient's deficits therefore suggest impairment of higher level transmission and/or processing of somatic sensory information. In considering the neurological basis of the impairment it should be noted that Swanson, Buchan, and Alvord (1965) have found a lack of small fibers in dorsal ganglia and dorsal roots and an absence of Lissauer's tract in an analogous case of insensitivity to pain. Despite this analogy we can suggest no single lesion or small group of lesions which would account for the clinical findings in the present case. It can only be said that some damage to somesthetic sensory mechanisms is indicated and that it is probably either congenital or of early neonatal origin.

The evidence for somesthetic deficit, together with the absence of evidence for direct motor system damage, suggests that the patient's inability to produce motor commands differentiated in time or space is a secondary consequence of the somesthetic deficit. It seems likely that sensory information ac-

companying early attempts at speech gestures is necessary in order for the speaker to identify more successful attempts and accordingly modify his program for future productions of the gestures (i.e., to learn). However it should be noted that even if somesthetic information is essential for the learning of speech this does not necessarily mean that the skilled speaker makes extensive use of somesthetic correlates of his moment-to-moment output.

The importance of somesthetic sensory information in speech learning seems to be further emphasized by the fact that even with normal sensory information from the auditory modality about her own vocal attempts and those of other speakers, and in the absence of motor system damage, the patient is still unable to produce even moderately intelligible speech.

Although the patient has not been able to use auditory information to guide successful speech production, she has used it to attain relatively normal speech perception. This finding pertains to the frequently recurring suggestion that aspects of a listener's speech production may play an important part in his speech perception. One of the most specific contentions of this kind has been made by workers from Haskins Laboratories, as part of a motor theory of speech perception (Liberman, 1957; Liberman et al., 1962; Liberman et al., 1964). They have argued that reference to motor information associated with the distinctly different consonantal commands is responsible for the categorical manner of identification of stop consonants (signified by abrupt crossovers in identification). Such motor reference has also been thought to be responsible for the low levels of discrimination of different stimuli within consonantal categories, and the accompanying peaks in discrimination at phoneme boundaries. Conversely, it has been argued that the relative lack of distinct differences between motor commands for different vowels contributes to the less categorical (more continuous) nature of their identification, and to the fact that vowel discrimination levels are higher than those for consonants but include no distinct discrimination peaks at phoneme boundaries (Liberman et al., 1962). The present study has shown that in spite of severely limited speech production capacities, the patient's phoneme perception is qualitatively similar to that of normal subjects in these various aspects of vowel and consonant identification and discrimination. This does not, of course, demonstrate that normal subjects do not use motor information for some of these types of perceptual performance. But it does suggest that motor information is not necessary to such performance.

REFERENCES

BASTIAN, J., EIMAS, P. D., and LIBERMAN, A. M., Identification and discrimination of a phonetic contrast induced by silent interval. *J. acoust. Soc. Amer.*, 33, 842 (A) (1961).

BERLIN, C. I., CHASE, R. A., DILL, ANNE, and HAGEPANOS, T., Auditory findings in temporal lobectomized patients. *Asha*, 7, 386 (1965).

BOSMA, J. F. (Ed.), *Symposium on Oral Sensation and Perception*. Springfield: Charles C Thomas (1967).

CHASE, R. A., An information-flow model of the organization of motor activity. Part 1: Transduction transmission and central control of sensory information. *J. Nerv. Ment. Dis.*, 140, 239-251 (1965).

CHASE, R. A., CULLEN, J. K., JR., OPENSHAW, J. W., and SULLIVAN, S. A., Studies on sensory feedback III: The effects of display gain on tracking performance. *Quart. J. exp. Psychol.*, 17, 194-208 (1965).

COOPER, F. S., Research techniques and instrumentation: EMG. Proc. of Conf.: Comm. Probs. in Cleft Palate. *ASHA Reports*, 1, 153-168 (1965).

FRY, D. B., Experimental evidence for the phoneme. In Abercrombie, D., et al. (Eds.), *In Honour of Daniel Jones*. London: Longmans (1964).

HARRIS, K. S., Rosov, R. J., COOPER, F. S., and LYSAUGHT, G. F., A multiple suction electrode system. *Electroenceph. clin. Neurophysiol.*, 17, 698-700 (1964).

HARRIS, K. S., LYSAUGHT, G. F., and SCHVEY, M. M., Some aspects of the production of oral and nasal labial stops. *Language and Speech*, 8, 135-147 (1965).

HOUSE, A. S., WILLIAMS, C. E., HECKER, M. H. L., and KRYTER, K. D., Articulation-testing methods: consonantal differentiation with a closed-response set. *J. acoust. Soc. Amer.*, 37, 158-166 (1965).

KATZ, J., BASIL, R., and SMITH, J. M., A staggered spondaic word test for detecting central auditory lesions. *Ann. Otol. Rhinol. Laryngol.*, 37, 908-917 (1963).

KIMURA, D., Cerebral dominance and the perception of verbal stimuli. *Canad. J. Psychol.*, 15, 166-171 (1961).

LIBERMAN, A. M., Some results of research in speech perception. *J. acoust. Soc. Amer.*, 29, 117-123 (1957).

LIBERMAN, A. M., COOPER, F. S., HARRIS, K. S., and MacNEILAGE, P. F., A motor theory of speech perception. *Proc. Speech Communication Seminar*. Stockholm: Royal Institute of Technology (1962).

LIBERMAN, A. M., COOPER, F. S., HARRIS, K. S., MacNEILAGE, P. F., and STUDDERT-KENNEDY, M., Some observations on a model for speech perception. *Proc. AFCRL Symposium on Models for the Perception of Speech and Visual Form*, Boston: Nov. 11-14, 1964 (In Press).

LIBERMAN, A. M., DELATTRE, P. C., and COOPER, F. S., Some cues for the distinction between voiced and voiceless stops in initial position. *Language and Speech*, 1, 153-167 (1958).

LIBERMAN, A. M., HARRIS, K. S., EIMAS, P., LISKER, L., and BASTIAN, J., An effect of learning on speech perception: the discrimination of durations of silence with and without phonemic significance. *Language and Speech*, 4, 175-195 (1961).

LISKER, L., Closure duration and intervocalic voiced-voiceless distinction in English. *Language*, 33, 42-49 (1957).

MacNEILAGE, P. F., and SHOLES, G. N., An electromyographic study of the tongue during vowel production. *J. Speech Hearing Res.*, 7, 209-232 (1964).

STUDDERT-KENNEDY, M., LIBERMAN, A. M., and STEVENS, K. S., Reaction time to synthetic stop consonants and vowels at phoneme centers and at phoneme boundaries. *J. acoust. Soc. Amer.*, 35, 1900 (A) (1963).

SWANSON, A. G., BUCHAN, G. C., and ALVORD, E. C., JR., Anatomic changes in congenital insensitivity to pain. *Arch. Neurol.*, 12, 12-18 (1965).