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An Analysis of Speech Dysfunctions
in Multiple Sclerosis Patients

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Elizabeth T. I. Akpati

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A DISSERTATION

Submitted to
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DOCTOR OF PHILOSOPHY

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ABSTRACT

AN ANALYSIS OF SPEECH DYSFUNCTIONS IN
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Although it has been documented since 1877 that dysarthria is one of the neurologic signs of multiple sclerosis, little recognition has been given to the disease in the speech pathology literature. The apparent neglect, perhaps, may be due to the fact that the symptoms as well as the neurologic signs may be evanescent. More empirical data are necessary to the knowledge of speech dysfunctions in multiple sclerosis. Thus, the primary purposes of this investigation were:

1. to determine the effects of imitative and spontaneous methods of response elicitation on the speech production of patients with multiple sclerosis,

2. to determine the effects of the position of a phoneme in the articulatory responses of patients with multiple sclerosis.

A purposive sample of multiple sclerosis patients with speech dysfunctions was selected for the study. Each subject had to meet the following criteria to be included in the study: normal hearing sensitivity as measured by audiometric pure tone screening test and speech impairment as determined by two or more misarticulations on an articulation screening test. The sample consisted of 11 females and 5 males

and the subjects had varying degrees of severity and duration of multiple sclerosis. None of the subjects had visual-field defects and they all spoke General American English.

Errors of articulation were assessed by employing a list of 64 meaningful monosyllabic CVC words constructed from 16 singleton consonants and two vowels. Two types of verbal tasks (imitative, spontaneous) utilized 32 monosyllabic CVC words. Each target phoneme was represented two times in the initial position (imitative initial, spontaneous initial) and two times in the final position (imitative final, spontaneous final).

Responses were elicited in the following manner:

1. subjects repeated recorded monosyllabic CVC words under earphones (imitative task)

2. subjects read aloud monosyllabic CVC words printed in one-half inch letters on a 4" x 6" white card (spontaneous task).

Responses for each subject were tape-recorded and scored by six trained graduate speech pathology students for correctness or incorrectness of articulation, employing conventional error categories of substitutions, omissions, and distortions. A phonetic and a distinctive feature inventory were employed to analyze the misarticulations.

Descriptive statistical analyses were employed to

1. determine those consonants that were more susceptible to articulatory errors of substitutions, omissions, and distortions.

2. determine the distribution of errors among the five distinctive features of voicing, duration, affrication, place, and nasality (Miller and Nicely, 1955).

3. determine the predominant type of articulation error in the speech productions of multiple sclerosis subjects.

4. determine the relationship of misarticulations to the acquisition hierarchy of distinctive features.

Inferential statistical analyses involved utilization of

1. a two-way fixed effects analysis of variance in order to

a. determine the differences in the misarticulations of the multiple sclerosis group as a function of type of verbal task.

b. determine the differences in the misarticulations as a function of phoneme position.

2. two one-way fixed effects analyses of variance in order to determine the relationship of misarticulations to the developmental hierarchy of phoneme emergence.

The following are the results on the analyses of variance:

1. There was a main effect for task with imitative being poorer than spontaneous task.

2. There was a main effect for position with final-word position being poorer than initial-word position.

3. No interaction was found between task and position.

4. No convincing evidence was found to the effect that the breakdown in the articulatory productions of the multiple sclerosis group was related to the developmental hierarchy of phoneme emergence.

Based on the findings of this study and related investigations, suggestions were given for further research on speech dysfunctions in multiple sclerosis.

To my parents: for their limitless sacrifice and endless supply of love and encouragement.

To my brother, Ben: my source of inspiration and a great believer in me.

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STATEMENT OF THE PROBLEM

Introduction

Multiple sclerosis, commonly referred to as MS, is one of the most widespread degenerative diseases of the Central Nervous System, often leading to paralysis and loss of coordination over affected parts. It is "a disease of obscure etiology, characterized clinically by symptoms indicating the presence of multiple lesions in the white matter of the brain and spinal cord" (Harrison et al., 1966). It remains today, a century and a third after it was first described, "a demyelinating disease with an unknown cause, an unexplained geographic distribution, an unpredictable course, an undiscovered cure and without a simple laboratory test to confirm its diagnosis" (National Multiple Sclerosis Society, 1969b). Accordingly, Miller (1964) notes that "diagnosis can hardly ever be regarded as absolutely certain short of necropsy findings."

Multiple sclerosis has an unpredictable course, varying widely in its mode of progression. The disease is generally dominated by irregular, fluctuating episodes of exacerbations ("attacks" or "bouts") and remissions. Because of the dramatic nature of the course of the disease, Bailey et al. (1956) made the following comment: "The only predictable thing about the course of the illness is that it is unpredictable and may occur as a steady downhill course over many years, or one characterized by remissions and exacerbations lasting from weeks to years." In certain patients, multiple sclerosis advances characteristically by wave upon wave of attacks. An attack is those episodic exacerbations which may alter the patient's condition generally or locally in the form of deficit symptoms. This definition also includes the concept that there is a remission. Sometimes, symptoms persist with no improvement. The outlook for recovery is very unfavorable although there may be long remissions amounting to practical recovery. Those cases in which there are sudden remissions and relapses have little better prognosis than those of gradual onset which are of long standing (McClure, 1936).

The disease produces a structural change in the nervous system. Patches of scar tissue develop throughout the brain stem and spinal cord. These areas vary in size from a pinpoint to no more than 1 cm in diameter (Chusid, 1973). The lesions are numerous in the brain and are especially well marked in the pons, medulla and cerebellar peduncles. The term "disseminated sclerosis" has thus been applied to the illness because of the scattered location of the individual lesions. When the involved area is large, the condition is associated with more subsequent gliosis or scarring. It is the last process which gives the name "sclerosis" to the illness since at autopsy the lesions appear as hard areas (because of the scarring). Depending upon the site of the patches of demyelination, various clinical symptoms are produced; and when they occur within the cerebellar system, the signs and symptoms of cerebellar disease become prominent.

Disturbances of the cerebellar function will result in defects of coordination and balance. Some of the cerebellar signs which may be seen include nystagmus, clumsiness of the hands with intention tremor (i.e., tremor on movement), and ataxia of gait. Speech becomes slurred, typically with a scanning or staccato type of dysarthria. Other signs include difficulty performing rapidly repetitive and alternating movements (disdiadochokinesis) (Espir and Rose, 1970). The muscles of articulation may also be affected by cerebellar incoordination, resulting in ataxic dysarthria. In mild forms this begins as slurring of speech, and the articulation of consonants is particularly difficult. The ataxic patient frequently exhibits a head tremor which is communicated to the whole vocal tract, thus causing a tremulous voice. In other cases, the respiratory and phonatory musculatures may be tremulous themselves, with the tremor triggered by the speech attempt. The patient may experience sudden hypertonic laryngeal spasms during speech (Canter, 1967).

Because of poor motor control of rhythm, there is difficulty in blending sound sequences for connected speech. There is a tendency to produce scanning speech, wherein almost every syllable is pronounced separately and emphasis is put on the wrong syllables, some being produced too loudly and others too softly (staccato speech). Dysrhythmic articulation may result from dysmetria, or the inability to stop articulatory movements smoothly at the desired point. The resulting articulatory contacts are made abnormally tightly, so that sound prolongations and sometimes complete blockages of speech occur. This behavior may accompany other types of dysfluency in the patient's speech, and a neurologic form of stuttering may occur (Canter, 1967).

There is a controversy over the terminology about articulatory problems observed in patients with multiple sclerosis. However, it is generally agreed upon that these disturbances are distinct from those based on disturbance of higher centers of the brain related to faulty programming of movements and sequences of movements (apraxia of speech) and the inefficient processing of linguistic units (aphasia).

Because speech changes seldom occur until multiple sclerosis is well advanced, the speech pathologist rarely participates in rehabilitation programs of multiple sclerosis patients. Up to the present time little recognition has been given to multiple sclerosis in the speech pathology literature. Perhaps this neglect stems from the presumption that the disease is progressive and a program of speech retraining would not likely keep up with its "progression" (Guilford, 1956) and from lack of knowledge concerning the etiology and treatments for multiple sclerosis. West et al. (1968) point out that the disease is an active cause of dysarthria. These authors report that because of the widely scattered lesions throughout the central nervous system, the effect on speech is unpredictable.

Manifestations of multiple sclerosis affecting other parts of the nervous system include visual and sensory symptoms, vertigo, loss of bladder control, and upper motor neuron signs due to plaques in the spinal cord (Espir and Rose, 1970).

Rationale for the Study

There is absence of empirical data in much of the speech pathology literature on the dysarthric speech of patients with multiple sclerosis. Despite the documented importance of dysarthria as a neurologic sign of the disease, few authors have described the speech of these patients. Many of the conclusions (usually in the medical literature) concerning locus and type of the lesion producing dysarthric speech have been based on gross clinical evaluations of the speech signals. Studies by Scripture (1916), Jenson (1960), Zemlin (1962), and Darley et al. (1972) employed objective evaluations and qualitative measures to varying degrees in investigations of speech problems in patients with multiple sclerosis. Much more research is needed to pinpoint subtle deficits in the speech and/or language behavior in patients with this neurological disease. Such an endeavor will lead to a better understanding of the speech characteristics of this population and will provide insight into the commonality between error phonemes in their production violation. These data are of current importance in relation to developing clinical intervention procedures that could help the patient maintain a high level of functioning. The present research could contribute to the small amount of precise information available.

Purpose of the Study

The primary purpose of the present investigation was to describe articulation errors made by a selected group of patients with multiple sclerosis. Specifically, the aim was to investigate the effects of imitative and spontaneous methods of response elicitation and the effects of position of sounds on articulation for a group of multiple sclerosis patients. To this end, both a distinctive feature analysis and the conventional phonetic analysis were used. The following questions were addressed in this investigation:

1. Which speech sounds are predominantly susceptible to articulation errors of substitutions, omissions, and distortions?
2. Which distinctive features account for the misarticulations that occur in the speech productions of multiple sclerosis patients?
3. Which is the predominant type of error (i.e., substitutions, omissions, and distortions) made by multiple sclerosis patients?

4. Is there a significant difference in the misarticulations that occur as a function of the type of verbal task?
5. Is there a significant difference in the misarticulations that occur as a function of the position of a sound in context?
6. Is the distribution of misarticulations related to the developmental hierarchy of phoneme emergence?
7. Is the distribution of misarticulations related to the acquisition hierarchy of distinctive features?

Definition of Terms

Degenerative Disease. A disease in which an essential organ prematurely ages or involutes.

Disseminated Sclerosis. Lesions appearing in the brain stem and spinal cord.

Distortion. The substitution of a standard speech sound by the one which is not normally used in the language.

Distinctive Features. Those attributes that distinguish or contrast one phoneme from others. They are "the physical (articulatory or acoustic) and psychological (perceptual) realities of the phoneme" (Singh, 1976).

Exacerbation or Relapse. Aggravation of earlier existing symptoms and signs at least three months after the disease had become static (Oftedal, 1965). An increase in the severity of any symptoms or disease.

Incidence. The number of new cases of a disease occurring in a given time period per unit population. In this study, the incidence rate of multiple sclerosis is expressed as the number of new cases per

100,000 population per year. Incidence rate reflects the risk of developing the disease in the population.

Omission. The replacement of a standard speech sound by a slight pause equal in duration to the omitted sound (Van Riper, 1972).

Onset of the Illness. The appearance of the first symptoms or signs which later could be suggestive of multiple sclerosis.

Prevalence Rate. It is the product of the incidence and the duration of the illness. It is a reflection not only of the risk of developing the disease in the population but also of patient survival which depends on the quality and availability of medical treatment. In this study, prevalence refers to the number of cases per 100,000 inhabitants in a community at a given time.

Remission. Earlier symptoms or signs are no longer present, or the patient is in a position to do what could have been impossible if earlier symptoms and signs had persisted.

Substitution. An articulation error in which one speech sound is replaced by another.

Organization of the Study

Chapter I provides a description of multiple sclerosis, some of the physical and speech manifestations of the disease. The rationale and purpose of the study are addressed in this chapter. Pertinent terms used in the study are defined.

Chapter II highlights the relevant literature that has emerged in the area of speech characteristics of multiple sclerosis. The epidemiology, etiological consideration, clinical types, physical symptomatology, and psychological effects of the disease are discussed. This chapter also focuses on investigations that have applied distinctive feature analysis as a tool for evaluative and corrective purposes when problems of sound production and/or perception are involved.

Chapter III discusses the selection of subjects, the criteria for selection, the materials and the means used to obtain the data.

Chapter IV provides the data analyses and results. Pertinent charts and tables are presented to support the data.

Chapter V summarizes the study and provides conclusions drawn from the research. Recommendations for future investigations are given.

The Appendices consist of the raw data employed in the study. A list of references is also included.

CHAPTER II

REVIEW OF THE LITERATURE

Epidemiology

The first comprehensive and integrated description of the clinical and pathologic aspects of multiple sclerosis was made by Charcot (1877). Charcot considered that multiple sclerosis was characterized by spastic paraplegia, ataxia, intention tremor, disturbance of speech, ocular abnormalities, and nystagmus. Subsequent literature came to consider "Charcot's triad" of scanning speech, nystagmus and intention tremor as being characteristic of multiple sclerosis.

Epidemiological investigations on the distribution of multiple sclerosis have uncovered many features of the disease. It has been possible, on the basis of these investigations, to calculate a possible critical starting point for the process (Kurtzke, 1968a). On the other hand, the epidemiological investigations have built up a framework which is necessary for studying possible etiological factors (Kurland, 1970).

In Scandinavian countries, reports on the prevalence of multiple sclerosis have been published since the 1930's. These studies show that the south-west of Finland formed a region with a high prevalence rate of the disease (Parnelius, 1965).

The first investigations into the distribution of multiple sclerosis were made by comparing the number of patients who had multiple sclerosis with the total number of patients in various neurological clinics. These investigations, made mostly at the beginning of this century, indicated that multiple sclerosis is rather common, for example, in the western and central parts of Europe but uncommon in southern Europe (Hyllested, 1956). Behrend (1969a) collected reports on multiple sclerosis in Europe. He noted that there was an increase from North Germany southward to northern Switzerland. This increase produced a high prevalence belt in the Rhine River basin. A survey of the frequency of multiple sclerosis by the French Multiple Sclerosis Society (1967) disclosed a frequency of 62.8 per 100,000 population in Haute-Garonne (44 degrees N) and 40.6 per 100,000 in Bas-Rhin (49 degrees N). A comparative study was carried out in two communities by Behrend (1966). The prevalence per 100,000 population was 72.7 in Hamburg, the northern city, and 20.7 per 100,000 in Marseille, the southern city. In Scotland, Sutherland (1956) reported a rate of multiple sclerosis of 67 per 100,000 population. A study was carried out by Poskanzer et al. (1963b) in Northumberland and Durham. Northumberland is the most northerly English county, whereas Durham lies just south of Northumberland. The prevalence rate in the two counties was 50 per 100,000 population. In Cornwall in southern England, Hargreaves (1961) noted an overall prevalence of 63 per 100,000 inhabitants. Millar (1971) put the prevalence figure for northern Ireland at 80 per 100,000.

The first estimate of the prevalence of multiple sclerosis in a restricted population was based on United States veterans. The frequency was 14.5 cases per 100,000, and it was greatest among veterans from the north-eastern part of the United States (Davenport, 1922). This characteristic distribution was confirmed in other studies (Acheson and Bachrach, 1960; Beebe et al., 1967). There are only a few studies describing multiple sclerosis among blacks in the United States. Kolb (1942) presented five cases from Baltimore which had rather typical features; and Alter et al. (1960) reported several cases among blacks in Charleston. Breland and Currier (1967) found cases in Mississippi and Alabama. Kurland and Westlund (1954) noted one case of autopsy proven multiple sclerosis in a black from Boston; and Acheson et al. (1960) mentioned three other cases among United States military personnel. One salient fact has emerged from these studies. In general, blacks in the United States have a slightly lower multiple sclerosis frequency than whites in the same area. In general, blacks have a lower socio-economic status than whites and thus may not share identical environments, an important etiological factor (Leibowitz and Alter, 1973).

With better facilities for diagnosis and more accurate statistics available, it has been possible to evaluate the distribution of multiple sclerosis by comparing the mortality rate for this disease in different countries. According to these figures, multiple sclerosis is either a rare or non-existent disease in tropical and subtropical zones of the world but rather common in the temperate zone, especially above 38 degrees in North America and Australia and above 45 degrees in Europe (Limburg, 1950; Acheson, 1965; Kurland et al., 1965). In the artic zone, the frequency is not higher than in the temperate zone (Alter, 1968).

Studies on multiple sclerosis in tropical regions of the world are of special interest in view of the widespread impression that multiple sclerosis is practically non-existent in the tropics. In Jamaica, an island with 1,700,000 inhabitants, Cruishank et al. (1961) found seven cases of multiple sclerosis in approximately a decade. Three of

these were Europeans; and in two of the Europeans, the disease commenced prior to their leaving Europe (Leibowitz and Alter, 1973). Multiple sclerosis is said to be rare in tropical Africa (Georgi and Hall, 1960). Foster and Harries (1970) found two cases in Kenya.

South Africa has been of special interest with respect to multiple sclerosis frequency because of its unusual population. Several distinct ethnic groups live in the country including English, Afrikaners, Bantu, Asians, and colored inhabitants. Thus, South Africa has many characteristics similar to those found in Israel. Dean (1967) reported that in immigrants to South Africa from the United Kingdom and Europe, the rate of multiple sclerosis per 100,000 population was 46.1; English-speaking native-born South Africans had a rate of 10.9; and Afrikaans-speaking native-born South Africans had a rate of 3.1 per 100,000 inhabitants. Among the colored, which include mixed black and white, and among the Bantu, no autopsy confirmed cases have yet been recognized. Immigrants to South Africa from Europe had high rates of multiple sclerosis, like European immigrants to Israel where extensive studies of the two major ethnic groups have been conducted. The prevalence of multiple sclerosis among the European immigrants (largely Ashkenazim) was about five times more common than among the Afro-Asian immigrants (largely Sephardim). A difference in the frequency of multiple sclerosis between immigrant groups (of different ethnic stock) in Israel is compatible with either an environmental or genetic etiology in multiple sclerosis (Goldschmidt, 1963; Brunner and Lobl, 1958; Kallner, 1958).

On the basis of available information on the distribution of multiple sclerosis, the world has been divided into three frequency bands or risk zones (Kurtzke, 1964; Acheson, 1965). The "high risk zone" (prevalence rate 30-60 per 100,000) includes the northern parts of North America (i.e., northern United States and southern Canada) and western Europe north of Switzerland, especially the countries bordering the North Sea. The "medium risk zone" (5-15 per 100,000) includes southern Europe, the United States, and southern Australia; and the "low risk zone" (0-4 per 100,000) includes Asia and most of Africa, with most reported values being 1 per 100,000 population.

Classification

It has long been the practice to set apart a group of diseases in which demyelination is a prominent feature. They are believed to possess characteristics that point to a unique etiology and pathogenesis, as yet unknown. The commonly accepted criteria of a demyelinative disease are (1) destruction of the myelin sheaths of the nerve fibers; (2) relative sparing of the other elements of nervous tissue, i.e., axis cylinders, nerve cells and supporting structures; and (3) a distribution of lesions either in multiple, disseminated foci throughout the brain and spinal cord or in single foci spreading from one or more centers. This last attribute, which is not explicit in most definitions, is nonetheless shared by all the generally accepted members of this group of diseases.

Two large types of demyelinating diseases have been described (Chusid, 1973): the multiple sclerosis type and the diffuse sclerosis type. The multiple sclerosis type includes (1) classic multiple sclerosis, which may be acute or chronic, is usually slowly progressive and has its onset in early adult life; (2) acute encephalomyelitis, with a rapid and often fatal course, is characterized by acute onset of neurologic signs and symptoms as a result of demyelination of the CNS; and (3) neuromyelitis optica, which is characterized by demyelinating lesions in the optic nerves, brain and spinal cord. The diffuse sclerosis type shows degeneration of the white matter of the brain of a diffuse type and is probably related to genetically determined metabolic disturbances. Two large subgroups of the diffuse type have been noted: (1) myelinoclastic (Schilder's disease), in which there is destruction of normally formed myelin of the cerebral hemispheres, and (2) leukodystrophies, in which there is a defect in the formation of myelin, usually associated with pigment deposition in the degenerated areas and occasionally also in nerves and other organs of the body. The onset of the symptoms is common in infancy or early childhood, and the disease is steadily progressive, with death occuring within a few months or years after onset.

Diagnostic Category of Multiple Sclerosis

Patients with multiple sclerosis are often divided into four diagnostic categories, based on Allison and Millar's (1954) diagnostic criteria:

(1) Early Probable or Latent Multiple Sclerosis: This includes patients showing as yet slight or no physical disability and few physical signs but in whom there is a recent history of remitting symptoms of the kind that are commonly associated with onset of the disease, for example, transient blindness, double vision, vertigo, ataxia, numbness, difficulties with bladder control, weakness in one or more limbs.

(2) Probable Multiple Sclerosis: All the patients in this category are physically handicapped in general, and there is no reasonable clinical doubt as to the diagnosis. In general, the case history

contains notes on remissions.

(3) Possible Multiple Sclerosis: This group is composed of patients showing physical handicap and presenting definite physical signs indicative of CNS disease, clinically suggestive of multiple sclerosis. Reasons for exclusion from the probable group are the lack of sufficient evidence of multiple lesions at various levels and the chronic progressive rather than remitting course of the disease. However, in spite of careful examinations, no other cause for the symptoms and signs can be established in these patients.

(4) Unaccepted or Discarded Patients: The diagnosis for the discarded patients include cases in which investigation reveals some other neurological disease which could anatomically and pathologically explain the symptoms and physical signs, despite their apparent similarity to multiple sclerosis.

Etiological Considerations

Many theories and opinions have been advanced regarding the etiology and the mechanisms by which multiple sclerosis is produced (McAlpine et al., 1955, 1965). The assumption has been made that multiple sclerosis is probably multifactorial in origin. Theories are based on the similarity of this disease to other diseases, on the response of individuals to certain environmental factors, on the examination of blood, and on tissue and cells revealed at autopsies.

There is a growing body of knowledge concerning the theory that this disease is due to an autoimmunological process or that it is a "slow virus" infection with a long latent phase (Tourtellotte and Parker, 1968). This viral theory suggests that a specific virus latent within the nervous system becomes activated through trauma or infection and in turn generates the process of demyelination.

Autoimmune diseases are thought to be caused by something misleading the normally protective immune mechanism of the body into producing antibodies against some of its own tissue. Other theories that have been advanced include the following:

1. Metabolic disturbance
2. Loss or inactivation of enzymes necessary to the formation of myelin or their replacement
3. Thrombophlebitis, venule spasm, or some imbalance in the blood
4. Allergens
5. Intoxications
6. Nutritional deficiency states
7. Some unidentified poisonous agent

None of these theories has yet been validated.

Physical Symptomatology

The early symptoms of multiple sclerosis are so varied in character, intensity, and duration that any classified description must fail to convey the diverse and often subtle manner in which the disease may first disclose itself (McAlpine et al., 1965). Although the diagnosis is made at an earlier stage than was the custom at the end of the 19th century, several years usually elapse before the patient comes under treatment.

The individualized symptoms are similar to those caused by any localized lesion of the CNS. It is, however, the pattern of their behavior which renders multiple sclerosis unique among the organic diseases of the nervous system. Certain common characteristics include the fact that signs and symptoms may be "transient" (Poser et al., 1966), thus causing difficulty in clinical diagnosis. The signs and symptoms include disturbances (such as nystagmus, diplopia, blurred vision, dimunition of visual acuity, visual field defects, etc.), muscle weakness, gait ataxia, nonequilibratory disturbances (intention tremor, dysdiadochokinesia, incoordination of fine movements, etc.), dysarthria (neither cortical in origin nor due to local conditions such as vocal cord paralysis), urinary disturbances, parasthesia (any spontaneous subjective disturbance of sensation), emotionalism and often euphoria. A positive Babinski sign, ankle clonus, and increased tendon reflexes are all indicative of a lesion of the pyramidal tract. "The real problem seems to lie with the fact that symptoms, as well as neurologic signs, may be evanescent and mild enough so that medical advice may not be sought by the patient unless some moderately severe degree of functional disability occurs" (Poser et al., 1966).

One of the problems which arise from the unclear and shifting symptom picture centers around the issue of credibility of the symptoms to the patient, his family and, at times, health workers. This aspect of the illness is documented by Simmons, Associate Director of the National Multiple Sclerosis Society, with the following sensitive observation: "Unless these vacillating features of the disease are known, the one caring for the patient is likely to be either bewildered by the rapidly changing character of the patient's complaints or suspicious of the validity of them" (cited in Parnelius, 1969).

The cerebellum and its connections control coordination of movements and influence muscle tone. There are important connections with the vestibular mechanism and cranial nerve nuclei concerned with movements of the eyes and neck. Because of this, the maintenance of balance and coordination of movements are dependent upon the integrity of the cerebellum and its connections. Lesions in the cerebellar peduncles cause cerebellar incoordination evidenced by nystagmus, intention tremor, and scanning speech (Kraft and Wessman, 1974). Diplopia, strabismus and ptosis are caused by patches of sclerosis in the midbrain (Boyd, 1970).

Age of Onset

It has been hypothesized that the process which later manifests itself in clinical symptoms of multiple sclerosis actually begins considerably early in life (McAlpine et al., 1965). Based on the data from the Israeli studies (Alter et al., 1962, Alter et al., 1966), it was calculated that the incubation period for the European immigrants to Israel was at least nine years. Schapira et al. (1963) also calculated a mean incubation period of 20.9 years and a "critical exposure period" and came to the conclusion that multiple sclerosis is acquired at about the age of fourteen. Poskanzer et al. (1963b) and Poskanzer (1968b) report that the disease is rare in childhood. The risk of getting multiple sclerosis rises sharply from 15 to 30 and falls even more sharply after that. The mean age at onset for "certain" or "probable" cases is about 30 (Acheson, 1965, Oftedal, 1965, Gudmunsson and Gudmunsson, 1962). It is rather uncommon to find the disease in a patient under 15 years old. In information about 4,000 cases, only 40 occurred under 15 (Gall et al., 1958). On the other hand, the onset of multiple sclerosis after 50 is very rare too. Of great importance from the point of view of pathogenesis is the established fact that children are especially susceptible to the acute and sometimes rapidly fatal forms of the disease, for example, neuromyelitis optica and diffuse multiple sclerosis (Chusid, 1973).

Sex Distribution

Although the literature reports as many males as females with multiple sclerosis, some studies have found it to have a greater preference for females (Allison and Millar, 1954; Hyllested, 1961; McAlpine and Compston, 1952; Kurland and Westlund, 1954; Miller et al., 1960), McCall et al. (1968) reported a high female to male ratio in Australia. Kurland (1952b) and Stazio and Kurland (1962) suggested that the apparent higher prevalence among females might be due to their seeking medical advice earlier. Espir and Rose (1970) found a ratio of 3:2 against females.

Psychological Factors

There has been little agreement of opinion as to the incidence, severity and nature of the changes seen in the mental state of patients with multiple sclerosis. There are reports of the presence of emotional lability and psychological problems. Early investigators like Charcot (1877) regarded intellectual deficits as the main disturbance and noted that emotional lability was not infrequently present. Vulpian (1886) was the first to record the occurrence of "morbid optimism" in patients with multiple sclerosis. Towards the end of the nineteenth century, there were numerous reports of acute psychosis resembling what is today called schizophrenia, occurring in cases of multiple sclerosis.

Sachs and Friedman (1922) noted that psychic abnormalities occurred in 15.6% of 141 patients. By contrast Brown and Davis (1922) spoke of mental alterations in about 90% of patients, of whom 70% were euphoric. The literature seems to maintain that the most prominent change is euphoria. Cotterell and Wilson (1926) in a penetrating analysis of 100 patients, found 63% to be euphoric, 10% depressed, and 84% to show abnormal optimism. They also found general intellectual deterioration in only 29%. The investigators distinguished a eutonia as well as a euphoria -- a prevailing sense of well-being as well as emphasis on the pleasant versus the unpleasant side of every incident. They concluded that the cardinal symptoms of multiple sclerosis are not neurological but are emotional, affective, and visual in nature. Hallucinosis, delusions, excitement, and dementia are rare. However, in progressive forms of multiple sclerosis, lack of responsibility, poor judgment, and poor memory have been noted (Denny-Brown, 1952). Brain (1930) reported a frequency of hysterical symptoms in the disease.

The effects of frontal lobotomy have helped to delineate the psychiatric disorders in patients with this disease. Braceland and Griffin (1950) relate the case of a young man with severe obsessive compulsion neurosis which vanished with the onset of multiple sclerosis. Failures in judgment are common. This is evident in such obvious features as concern over minor parasthesias, while disregarding disabling symptoms. Memory defect is a symptom only of gross disorder. In some patients hysterical symptoms may characterize the early stages of the disease (Brain, 1930; Langworthy, 1941).

Surridge (1969) described the psychic states of 108 patients with multiple sclerosis selected from records of the United Oxford Hospitals in Kingston, Ontario, Canada. He found intellectual deterioration to be present in almost two-thirds of the patients, depression in about

25%, and euphoria to be strongly associated with intellectual deterioration and denial of disability.

In general, the literature has maintained that a sizeable proportion of patients exhibit lability in which exaggerated laughing or crying behaviors are emitted at inappropriate times. The presence of these emotional behaviors which are elicited by even minimal stimulation of the patient, frequently are involuntary and beyond the control of the patient (Grinker et al., 1950; Brain, 1962).

Hearing Deficits

A thorough search of the literature did not reveal current studies on auditory impairment in multiple sclerosis. The research available reveals a diverse and confusing picture of auditory behavior associated with the disease. There are reports of both conductive and sensori-neural types of hearing loss, as well as no hearing loss related specifically to multiple sclerosis. This diversity in the literature is not unexpected when one recalls that multiple sclerosis is a fluctuating, although progressive, disease of the central nervous system. Possibly, the best justified conclusion for the time being on the status of hearing in patients with multiple sclerosis is that advanced by LeZak and Selhub (1966): "there is a reason to conclude this population as a whole demonstrates hearing similar to that found in the general population of the same age." However, reviews of the research available have shown that auditory aberrations in some persons with multiple sclerosis mimics that of cases with VIIIth nerve tumor.

One of the earliest descriptions of a hearing problem in multiple sclerosis was made by Hess (1888) on a single case of sudden bilateral hearing loss. One ear was permanently involved and hearing returned in the other ear after twenty-four hours. In England, Dundas-Grant (1922) reported a case of multiple sclerosis in which unilateral "nerve deafness" occurred. His study investigated the effect of multiple sclerosis on the auditory mechanism of 92 patients with the disease. Average age in 78 of these (85%) was less than 40 years. The study clearly indicated that defects of the auditory field, comparable to defects in the perimetric field, occur in patients with multiple sclerosis. The study further demonstrated the destructive effects of the disease on the VIIIth cranial nerve and the associated nuclei.

Von Leden and Horton (1948) tested 92 patients with clinical multiple sclerosis and found that 39 (43%) had some degree of hearing loss (more than 25 dB) in one or both ears. He further stated that these findings had a pathologic basis. Kentner (1954) noted a dome-shaped audiogram, (convex upwards) in about 50% of the patients in his study. He suggests that this is indicative of brain-stem disease. Simpkins (1961) looked at the audiometric profile in patients with multiple sclerosis. He was concerned with whether there is a characteristic audiometric curve in this group of patients. Twenty-eight hospitalized patients with multiple sclerosis were routinely tested by pure-tone audiometry. Their audiometric curves revealed a tendency to form a specific configuration of depressed acuity for 2000 Hz and 125 Hz. To determine whether these findings were due to chance or whether a curve that tended downward from high to low frequencies was characteristic of the air-conduction thresholds in patients with multiple sclerosis, an audiometric survey was made of 78 multiple sclerosis hospitalized patients over a three-year period. About 68% of these demonstrated the curve, 14% did not, and another 14% were borderline patients. Philips (1952) claimed that vertigo, headache, tinnitus, and hearing loss were not infrequent otologic symptoms in multiple sclerosis. Rose and Daly (1964) did an eighteen-month evaluation of 20 patients with various VIIIth nerve and brain-stem lesions. They discovered definite, reversible temporary threshold shift in two of the ten patients with multiple sclerosis. It has been demonstrated that tone decay from retrocochlear lesions first becomes manifest in the higher frequencies. A greater degree of damage is necessary before the lower frequency decay occurs. Rose and Daly (1964) inferred that the auditory damage in multiple sclerosis occurred in the VIIIth nerve between the spinal ganglia and the insertion of the nerve trunk into the cochlear nucleus. The authors made this inference on the basis of marked tone decay and on the demonstrable reversibility of such decay and of the pure-tone loss. They suggested that the remissive nature of the symptoms was attributable to either a reversible demyelination or a perimyelinic edema, i.e., an edemic pressure on the nerve which occurred during the active stages of the disease. The two patients in this study had almost total tone decay despite a normal pure-tone audiogram.

Many of the investigations report audiometric patterns not unlike those associated with presbycusis. Dix (1968) reported severe loss in the right ear (of a multiple sclerosis patient) characterized by a drop-off to no hearing by 4000 Hz. The left ear had only a slight high frequency hearing loss. Hallpike (1967) claimed that "the lesions of multiple sclerosis are confined to the central nervous system. They may occur in the cranial nerves but are then restricted to the zone of the so-called glial protrusion which is correctly regarded as an extension of the central nervous system" (p. 492). Sakamoto and Ichiro (1968) reported excessive adaptation from two multiple sclerosis patients during Bekesy audiometry, thus indicating the possibility of VIIIth nerve lesion. Parker et al. (1962) speculated that hearing impairment due to multiple sclerosis results from damage to "second order neurons." Instances of poor speech discrimination in spite of pure-tone sensitivity have also been observed in cases of multiple sclerosis (Antonelli and DeMitri, 1963).

It has long been recognized that the vestibular system may be highly susceptible to multiple sclerosis. Patients with the disease may report vertigo, dizziness, and tinnitus as some of the presenting symptoms. Unfortunately, sometimes, these symptoms have resulted in erroneous diagnosis of Meniere's disease or acoustic neurinoma. The fact remains that varieties of nystagmus have been reported with an incidence of 5 to 57% (Rose and Daly, 1964). Dissociated and ataxic nystagmus are also not uncommon in some patients with the disease (Parker et al., 1962). Dayal et al. (1966) reported spontaneous and lateral gaze nystagmus. These varieties of nystagmus, as well as the dizziness and unsteadiness often described by patients with multiple sclerosis, are probably due to foci of demyelination which may occur anywhere from the cerebellum and root of the VIIIth nerve up through the remainder of the central vestibular system (Ward et al., 1965).

The implications of the foregoing review makes clear the fact that multiple sclerosis lesions vary from case to case and in a single individual from time to time. It also highlights the heterogeneity of the auditory and vestibular behaviors associated with multiple sclerosis. Many different suggestions about the type and site of lesion have been offered. Such diversity is due partly to the episodic nature of the disease and partly to differences in the sites and extents of the lesions; and finally it is due partly to the variety of test procedures used by investigators.

Phonatory Dysfunctions

It is said to be characteristic of multiple sclerosis that the speaking voice is strikingly monotonous and scanning. Collet (1946) found that the vocal range may be reduced by about three tones -- one cause of vocal monotony. The other factor may be explained by reduced tension of the vocal folds. According to Collet (1946), the vocal folds close well in such patients. What is peculiar, however, is the alternation between a tense and flaccid appearance of the vocal folds.

In contrast to the frequent and typical finding of vocal monotony, other observers have described a chanting perserveration of vocal melody within certain specific intervals. Barth (1911) noted that multiple sclerosis may begin with vocal signs of spastic dysphonia. Leutenegger (1975) reported that the "odd" sounding quality seen in patients with multiple sclerosis was due to aperiodic vibrational patterns, nasal voice quality (due to disturbed resonance characteristics), reduced pitch variability (due to monotone and severely restricted pitch range), weak voice (related to respiration), and trouble initiating vocal fold vibration (due to glottal spasticity).

Speech Characteristics

Dysarthria has always been recognized as a prominent neurologic feature of multiple sclerosis. The neurological causes of dysarthria are classified according to which part of the neuromuscular system is affected. The disorders may involve (1) muscles, (2) lower motor neurons, (3) upper motor neurons, (4) extrapyramidal system, (5) cerebellum and its connections, (6) cerebral cortex (motor speech area).

Dysarthria may affect the processes of respiration, phonation, articulation, resonance, and prosody. In the field of communication disorders, dysarthria implies any impairment of articulation caused by damage to the nerve centers or tracts (other than those of the language areas of the cerebral cortex) immediately involved in direct control of the musculature used in the enunciation and pronunciation of vowels and consonants (West et al., 1968). Its basis is some type of abnormality of the central or peripheral nervous system controlling the speech mechanism.

Darley et al. (1969a, 1969b) have greatly clarified this speech problem as it occurs in adult patients with neurological disorders. The clinical neurological diseases include pseudobulbar palsy, amyotrophic lateral sclerosis, bulbar palsy, cerebellar ataxia, dystonia, and choreoathetosis. Each of these diseases affects specific parts of the motor nerve tracts from the cerebellum to the spinal cord. In these studies, Darley et al. described seven speech typology which are useful in differential diagnosis of dysarthria. They are ataxic dysarthria due to cerebellar ataxia, spastic dysarthria due to pseudobulbar palsy, flaccid dysarthria due to bulbar palsy, hyperkinetic dysarthria due to dystonia, hypokinetic dysarthria due to choreoathetosis and combined spastic and flaccid dysarthria due to amyotrophic lateral sclerosis.

Lesions in the cerebellum affect its regulatory functions such as timing, range, force, and direction of peripheral movements. A type of dysarthria results producing a coarse, forcibly strained voice. The speaking rate may be too slow or too rapid. Acceleration of the speaking rate results from the loss of inhibition, which is typical for all cerebellar diseases. The slow rate arises from poor coordination among the articulators, and between articulatory, phonatory, and respiratory systems (Leutenegger, 1975). The patient is unable to move his tongue with the rapidity and precision needed for many phonetic adjustments necessary for intelligible speech. A functional disuse atrophy, if present, will also contribute to greater speech dysfunction (Farmakides and Boone, 1960).

Because the lesions of multiple sclerosis are primarily of the white matter of the brain and spinal cord and less frequently encroach upon the grey matter, there seldom are symbolic language deficits and gross intellectual deterioration. The term "scanning" or "staccato" speech is often used to describe the speech of patients with multiple sclerosis. It implies that the individual is talking as if reciting poetry, often pronouncing every syllable of every word separately (Canter, 1967).

One of the earliest research efforts aimed at describing speech changes as a function of multiple sclerosis was done by Charcot, a French neurologist. In 1877, in his classic description of the symptomatology of multiple sclerosis, he listed scanning as one of the neurological symptoms. Charcot felt that speech difficulties which result from the onset and progression of the disease were an important aid for diagnosis. He described what he considered to be the characteristic triad of signs of multiple sclerosis -- intention tremor, nystagmus, and scanning speech. Since Charcot's day, it has been commonly accepted that scanning speech is typical of multiple sclerosis. This view is reflected in many contemporary neurology textbooks. "In multiple sclerosis the speech is characteristically scanning in type; with slowness, stumbling, halting, slurring, and ataxia of a cerebellar type. The spacing of the words with perceptible pauses between words and irregular accenting of the syllables give the sing-song or scanning character which has been described as pathognomonic of the disorder" (DeJong, 1967).

Further evidence concerning the dysarthric speech of multiple sclerosis was reported by Merritt (1973): "The characteristic scanning speech of multiple sclerosis is the result of cerebellar incoordination of the palatal and labial muscles combined with dysarthria of cortico-bulbar origin." West et al. (1968), alluding to the dysarthria associated with multiple sclerosis, state: "The most frequent type of dysarthira that results from multiple sclerosis is a drawling, labored articulation, classically described as scanning." The authors consider multiple sclerosis to be the only progressive neurologic disease which "progresses slowly enough to warrant a program of speech rehabilitation."

Some neurology textbooks and studies are not in agreement that scanning speech is characteristic of multiple sclerosis. Scripture (1916) did an instrumental analysis, using the phonautograph method, of the vocal changes in multiple sclerosis. Analysis of recordings of sustained vowels demonstrated that there is a presence of peculiar vibrations in recorded speech of patients with disseminated sclerosis "regardless of whether any speech defect could be detected by the ear or not." Scripture attributed the peculiar vibrations to laryngeal ataxia. He decried the use of the term "scanning" speech often attributed to multiple sclerosis. The term "scanning" he emphasized "is applied to prosody to the marking off of the long and short or the loud and weak syllables, that is, to indicate the maxima and minima. In scanning a line or verse with the voice, the speaker exaggerates the differences between the two kinds of syllables, making the emphatic syllables more emphatic (longer and louder) and the unemphatic ones less marked (shorter or weaker). This is exactly what the patient with multiple sclerosis does not do.... The speech is thus neither scanning, nor anti-scanning, nor staccato nor rhythmic." Rather, Scripture concluded that the subjects used in his study displayed irregular timing, faulty emphasis and variable articulatory errors.

Grinker and Sahs (1966) also report that scanning, along with nystagmus and intention tremor (the Charcot triad), is rarely seen in the early stages but is symptomatic of advanced multiple sclerosis. Janvrin and Worster-Drought (1932) extended Scripture's research strategy, using both smoked-paper tracing technique and film sound tracks. They also found irregularities indicative of laryngeal ataxia. According to Brain (1962), "Dysarthria may be due either to spastic weakness or to ataxia of the muscles of articulation or to a combination of these factors. In the early stages, articulation may be slurred, later it may become explosive and almost unintelligible. The 'syllabic' or 'scanning' speech, sometimes regarded as typical is exceptional." Farmakides and Boone (1960) reviewed the case histories of 82 patients with multiple sclerosis and found five characteristics generally contributing to dysarthria: nasal voice quality, weak phonation of voice and poor respiration cycle, changes in pitch, slow rate, and intellectual deterioration coupled with emotional lability. They reported that among the 68 of the 82 who received speech retraining, 85% (58 patients) demonstrated improvement, especially in terms of increased rate of speech and louder phonation.

Two studies, Schumacher (1950) and Gordon (1951) show that neural impairments to the muscles used for speech and feeding (respiratory, laryngeal, pharyngeal, and oral) produce weakness and incoordination, reducing the intelligibility of speech. Along with this organic impairment, Gordon (1951) implies that there is usually a functional overlay of disuse atrophy contributing to the overall involvement. The implication is that this inactivity results in disuse atrophy of the muscles used for speech and feeding, so that there is a greater speech dysfunction than can be attributed only to organic impairment. This disuse atrophy which produces a more severe picture of dysarthria and prevents the patient from using his residual capacities efficiently is highly vulnerable to remedial speech training. Darley et al. (1969a) described a group of unique speech deviations characteristic of certain neurological disorders. Of these, they noted that ataxic dysarthria, due to cerebellar dysfunction, is characterized by imprecise consonants, stress disturbances, irregular articulation breakdown, distorted vowel, and harsh voice. The research of Zemlin (1962) addressed the acoustic aspects of multiple sclerosis. Zemlin did a spectrographic and motion picture sound track analysis of both contextual speech and prolonged vowels. The results demonstrated that 14 of the 33 subjects manifested no wave pattern that differentiated them from normal subjects. Others had vibration patterns showing extreme variability in period functions. Also found were gross changes in energy distribution in vowel production by patients as contrasted with normal subjects.

Jenson (1960) studied the motor speech of 50 patients with multiple sclerosis. He found that 38% made errors (mean 1.72 errors) on an articulation test and 35% made articulation errors on a contextual speech task. Darley et al. (1972) observed, over a 38-month period, speech problems in 168 patients with confirmed diagnosis of multiple sclerosis. In contrast to early reports, the authors observed that dysarthria does not contribute to an "almost constant" part of the symptom picture of multiple sclerosis. Fifty-nine percent of their subjects showed overall normal speech adequacy. Furthermore, they found that the most frequent speech deviations were impaired loudness control and harshness; and less frequently occurring deviations were defective articulation, restricted use of vocal variations for emphasis, poor pitch control, hypernasality, inappropriate pitch level, and breathiness. Accordingly, the so-called scanning speech was not a prominent characteristic of multiple sclerosis. They added that speech deviations were solely attributable to cerebellar involvement, becoming more marked as additional motor systems were implicated.

Effects of Drug Therapy on Speech

Various treatments based upon the etiologic and pathologic theories have been tried with disappointing results (Chusid, 1973). Drug therapy in multiple sclerosis is directed toward the control and amelioration of symptoms. This symptomatic therapy is used to control spasticity and reflex spasms, to relieve bladder dysfunctions, to ameliorate visual disturbances, and to help the patient cope with emotional distress of depression and apprehension. One of the more common treatment methods which has been employed is isoniazid. In a preliminary report on the effects of this drug in the treatment of multiple sclerosis, Kurtzke and Berlin (1954) reported evidence which indicated that the drug produced beneficial effects. Matthews et al. (1960) reported the effects of isoniazid on the speech of 12 experimental subjects who received dosages of this drug over a period of at least 3 months and 10 control subjects who received dosages of a placebo over the same length of time. The speech samples were rated by 42 listeners. The results indicated that there was no significant difference between the two groups as far as changes in speech behavior were concerned. It was concluded that the use of isoniazid did not improve the speech of the experimental group. This finding was consistent with that reported by Nagler et al. (1957) and by Kurtzke and Berlin (1957).

Distinctive Features and Communication Disorders

Traditionally, research into misarticulation of sounds has been concerned with discovering which speech sounds are most vulnerable to omissions, distortions, substitutions and additions. In recent years, linguists have argued that the speech sound or phoneme should not be regarded as the primary unit of linguistic analysis. Rather, each phoneme should be described as a bundle of phonetic features, each of which is given a value of either plus or minus (Chomsky and Halle, 1968). The phonetic feature, then, is considered to be the primary unit of analysis. This approach has been used to advantage by a number of investigators in the field of communication disorders who have sought to apply the linguistic concept of distinctive features to various problems of speech acquisition and speech therapy. Snow (1964) and Singh and Frank (1972) used this approach in studying the articulation of individuals with normal speech, whereas McReynolds and Huston (1971) and Menyuk (1968) applied distinctive features to pathologies. Compton (1970) used phonetic features as well as phonologic rules in the analysis of misarticulations. Some of the most influential exponents of distinctive feature theory have been Pole Jan de Courtenay of the late 19th century; Jakobson, Fant and Halle (1951); Halle (1964); and Chomsky and Halle (1968).

Several reasons have been offered for analyzing correctness or incorrectness of phoneme production by means of a distinctive feature system:

(1) an identification of the nature of misarticulations of a phoneme permits therapy to be directed specifically to the one violated characteristic of that phoneme,

(2) an identification of feature violations common to several phonemes facilitates speech therapy,

(3) the system provides greater descriptive economy than the traditional method of enumerating misarticulated phonemes,

(4) the system permits clarity and completeness of a phoneme sound,

(5) an analysis of the feature changes which affect substitutions provides insight into the aspects of speech sounds which are vulnerable to changes.

Distinctive features provide the basis for specifying the relevant attributes of the phonemes in a language. Each attribute consists of two or more discrete and mutually exclusive values. For example, a binary feature such as voicing has just two values, and every phoneme is either voiced or unvoiced. A complete feature system distinguishes all phonemes from each other.

Various systems of distinctive feature analysis have been developed to describe the phonemic systems of world languages. These systems vary in the number of features used to distinguish phonemes. They include Jakobson, Fant and Halle (1951); Miller and Nicely (1955); Halle (1964); Singh and Black (1966); Wickelgren (1966); Peterson and Shoup (1966); and Chomsky and Halle (1968). The more complex systems of distinctive feature analysis are the acoustic-based system of Jakobson, Fant and Halle (1951) and the articulatory-based system of Peterson and Shoup (1966). Their complexity makes them less suitable for routine articulatory testing.

Jakobson, Fant and Halle (1951) suggest that phonemic systems of all languages can be described by the use of 12 features, of which only 8 apply to 21 English consonants described by them. Halle (1964) and Wickelgren (1966) use 8 of the 12 features to describe 23 consonants of English. Wickelgren's system attempts to predict short-term memory errors among 23 English consonants. Wickelgren posited five values for the place feature, one ternary feature (openness), and two binary features (voicing and nasality). The Miller and Nicely (1955) system predicts confusion among 16 English consonants. Singh and Black (1966) extended the number of Miller and Nicely features by adding liquid (to distinguish /d/ from /r,l/), glides (to distinguish /b/ from /w/ and /g/ from /j/), and retroflexion (to distinguish /r/ from /l/); and added a fourth value to the place feature (to distinguish /tʃ/ from /h/). The resulting system (Singh and Black, 1966; Singh, 1968, 1970) distinguishes all phonemes from each other. Chomsky and Halle (1968) expanded the list of distinctive features to more than 30, with 13 features listed as applicable to English. Their system can be interpreted at two levels. As binary features, the system specifies the phonemes as they are used in lexical entries. The entries can be quite abstract since complex phonological rules are required to convert them into phonetic representations. As non-binary parameters, the features "provide a representation of an utterance which can be interpreted as a set of instructions to the physical articulatory system or as a refined level of perceptual representation" (Chomsky and Halle, 1968, p. 65). In a recent article (1972), Stevens and House proposed between 25 and 30 features.

From the studies cited above, it is apparent that there is a theoretical disagreement among linguists regarding how many features are needed for coding all phonemes in all languages of the world.

Walsh (1974) is not in agreement that the use of existing distinctive feature systems is economical when applied to clinical speech diagnosis and therapy. Walsh contends that distinctive features are abstract, often far removed from the physical surface realities of human speech. Furthermore, such a system does not serve an advantage for explaining speech sounds that deviate grossly from normal speech patterns. Walsh advocates a classificatory system of feature analysis based on speech production rather than the existing system which is motivated by a concern for optimum notational economy.

However, Pollack and Rees (1972) made strong claims for the use of distinctive features. They suggest that the "distinctive feature concept may be applied constructively at every stage of clinical management of a child with an articulatory disorder." McReynolds and Huston (1971) and McReynolds and Bennet (1972) cite descriptive economy as one of the virtues of distinctive features.

CHAPTER III

SUBJECTS, INSTRUMENTATION, MATERIALS, AND PROCEDURES

This chapter discusses the selection of subjects, the criteria for selection, the instrumentation, the procedures used to construct the speech stimuli, and the means used to obtain the data.

Subjects

A total sample of 16 subjects with a confirmed diagnosis of multiple sclerosis participated in the present study. There were 11 females and 5 males selected from a total population of 51 multiple sclerosis patients who were screened. The remainder of the subjects were rejected on the basis of failing to meet the stated criteria for the study such as lack of demonstrable speech problems, impaired vision which did not allow them to perform the tasks, and hearing impairments as determined by a pure-tone hearing screening test. Nine of the 16 subjects who met the criteria were residents in nursing homes, medical care facilities, and seven resided in private homes in the mid-Michigan area. The subjects ranged in age from 23 to 66 years with a mean age of 49 years. Seven patients in the group had had the symptoms of the disease for at least ten years, and three of the patients had had the symptoms for twenty years or more. All of the subjects in the sample were mentally alert as determined by the investigator's conversation with each subject and by simple structured questions designed to elicit specific answers. An example of the form used to obtain background information from the subjects is given in Appendix A.

Current medical information (which included medication taken, psychological problems, and the presence of neurological disease other than multiple sclerosis) was obtained from the attending director of nurses at the nursing homes and medical care facilities. For subjects who resided in private homes current medical information was determined by the subject's verbal account since no other means was available for obtaining this information.

Other background information such as the onset and duration of the illness was obtained directly from the patients. Thirteen patients were receiving medications for the symptomatological control of multiple sclerosis at the time of the testing. Table 1 gives the summary of pertinent background information on each patient.

Criteria for Selection

All subjects included in the sample were given a bilateral audiometric pure-tone screening test at 20 dB HL at octave intervals of 1000 Hz, 2000 Hz, and 4000 Hz (re ANSI - 1969). The pure-tones were presented via TDH-39 earphones mounted in MX 41/Ar cushions. A calibrated pure-tone audiometer (Beltone Model 10C) was used. According to these criteria, all subjects in the present study had hearing thresholds within normal limits. The criterion for failure was lack of response at any of the frequencies in either ear. Furthermore, all subjects included in the research sample were given an articulation screening test. All subjects demonstrating defective speech as

TABLE 1

BACKGROUND INFORMATION ON 16 MULTIPLE SCLEROSIS SUBJECTS

Subject	Sex	Age	Duration of Illness
B.M.	F	58	5 years
D.H.	M	30	11
P.G.	F	57	25
D.M.	F	63	18
C.M.	F	45	13
G.T.	M	27	7
K.B.	F	27	7
J.M.	F	49	20
J.J.	F	63	14
J.S.	M	56	4
E.P.	F	53	11
J.E.	M	66	17
V.M.	F	55	12
S.L.	M	23	4
C.B.	F	43	14
D.M.	F	64	25

determined by the case history reports as well as contributing two or more errors on the articulation screening test were considered to meet the criteria for selection. _The Fisher-Logemann Test of Articulation Competence Sentence Articulation Test_ (1971) was the instrument of measurement.

None of the subjects in the sample demonstrated any visual-field defects nor did the medical report on any of the patients indicate any premorbid psychological problems or senility. All subjects were native speakers of General American English, and all were from Michigan. Thus, the confounding variable of dialectal differences was eliminated.

No effort was made to classify subjects according to type and severity of multiple sclerosis since the purpose of this study was not to compare phoneme production between patients with different types and degrees of severity of multiple sclerosis but rather to analyze overall phoneme production in multiple sclerosis.

Instrumentation

The equipment used to collect the data included the following:

1. Reel to Reel Tape Recorder (Crown Transport, Model 700)
2. Electrovoice Microphone (Model 545)
3. Nakamichi Cassette Tape Recorder (Model 350)
4. Portable Cassette Tape Recorder (Wollensak 2520)
5. Portable Cassette Tape Recorder (Panasonic)
6. Portable Audiometer (Beltone Model 10C)
7. Sound Level Meter (Bruel and Kjaer, Type 2240)

Speech Stimuli

A list of 64 monosyllabic (CVC) English words was used to assess articulation errors made by multiple sclerosis patients on both imitative and spontaneous tasks. Thus each task consisted of 32 words. Since certain consonants cannot occur at the beginning and end of a syllable, a workable list of 16 true singleton consonants was constructed on the basis of their ability to form cognates and to occur in the initial and final positions. The following exceptions were made: /ŋ/ and /ʒ/ do not occur in the initial position in English; /w/ and /h/ are not terminal in English; and /ʃ/ was excluded from the list of true consonants used in this study because its voiced cognate /ʒ/ was also excluded. According to Singh and Frank (1972), /h/, /w/, /j/, /l/, and /r/ are non-true consonants and since they have a vowel-like quality, they were excluded from the construction of the word list.

An attempt was made to control not only for the phonetic environment of the vowels used but also the type used. To this end, only two types of vowels were used in generating the CVC word list: /e/, a mid-front vowel, and /o/, a mid-back vowel. It was felt that these two vowels are less resistant to dialectal variations than other pure vowels in American English; thus, their interpolation would minimize slight differences in enunciation.

The probabilities of some sounds following others in English are unequal. It was impossible to generate a meaningful monosyllabic CVC word for /θ/ initial using either /e/ or /o/ as the interpolating vowel. Furthermore, no meaningful monosyllabic CVC words could be generated for /ð/ initial and /z/ initial in the spontaneous task using either /e/ or /o/. For this reason, other vowel types were used: /ɔ/ "thought" in the imitative task; /ʌ/ "thud", /ɛ/ "them", and /I/ "zip" in the spontaneous task. The 64 words in which the 16 singleton consonants were tested are presented in Appendix C.

In summary, the list of 64 monosyllabic (CVC) words consisted of 16 initial and 16 final consonants for the imitative task; 16 initial and 16 final consonants for the spontaneous task.

Procedures

Stimulus Generation

The 32 stimuli used in the imitative task were first recorded on a reel-to-reel tape recorder (Crown Transport, Model 700) by a Caucasian male who spoke General American dialect. The recording was done in a sound-treated recording booth. An Electrovoice microphone (Model 545) was used. The 32 stimuli were then put in random order by a program run on the PDP-11/40 computer system. The PDP-11 was able to play back the 32 stimuli automatically for the imitative task in the random order chosen by the randomizing program.

Each stimulus used in the spontaneous task was then matched with the corresponding stimulus used in the imitative task with respect to the type of phoneme and the position of the phoneme in a word. Thus the order of presentation of the stimuli for the two types of verbal tasks was randomized for each subject. In Appendix D a sample of the randomized stimuli is illustrated.

An interstimulus-interval of 8 seconds was inserted to allow for listener response and to eradicate the effect of articulatory transition from one stimulus to another.

From the Crown Transport reel-to-reel tape recorder the 32 stimuli used in the imitative task were transferred to a Nakamichi cassette tape recorder (Model 350).

Speech production of the 16 subjects in the present study was assessed in the imitative and spontaneous conditions. The subjects were tested individually in a nursing home, medical care facility, or in a private home. All testing was administered by the same examiner. Each singleton consonant was tested two times in the initial position and two times in the final position. Four different stimulus words were used to test four representations (two initial and two final) of a given phoneme. Each phoneme included in the study was tested within a single stimulus item. The 64 test words were randomly assigned to the two treatment conditions as explained in the section titled "Stimulus Generation." Thus, each subject was given an opportunity to produce each of the 64 test words once in the imitative task and once in the spontaneous task. All subjects were tested in the imitative condition first and in the spontaneous condition last.

Method of Stimulus Presentation (Imitative Task)

All testing was done in a quiet room at the various testing locations. Each subject was seated facing the microphone which was placed on a table with the tape recorder. The examiner sat facing the subject. A practice session was provided prior to the presentation of the test words. The volume of the tape recorder was set at a comfortable listening level for each subject. For each subject a set of instructions (See Appendix E) was given orally by the investigator. Formal testing began after the subjects demonstrated comprehension of the task. The subjects were asked to repeat with a single response after each stimulus word. The 32 stimulus words were presented via earphones using a Wollensak (Model 2520) cassette tape recorder. The responses given by the subjects were tape-recorded on Maxell C60 cassettes using a Panasonic portable tape recorder.

Method of Stimulus Presentation (Spontaneous Task)

The testing environment and recording procedures were the same as for the imitative task. There was an interval of two minutes between the presentation of the two types of verbal tasks. In an effort to reduce the degree of visual complexity of the words employed in the spontaneous task, letters were printed in block form. Each stimulus word appeared alone in one-half inch letters on a 4" by 6" white card. The cards were presented one at a time to the subjects who were instructed to read the word aloud once. A practice session was also provided prior to formal testing.

Assessment of Articulation Errors

The responses for both the imitative and spontaneous tasks were evaluated and scored by the investigator at the time of the testing. All responses for the two types of verbal tasks were treated in the same manner. If the response was correct, a check was placed in the appropriate section of the response sheet. If the subjects substituted a sound for the one which would have been correct, the phonetic symbol for the substitution was used. If the target sound was omitted, a dash (—) was used to indicate the error of omission; and if the subjects distorted a sound, a phonetic symbol and diacritical marks and written explanations were used to indicate the nature of distortion. Any peculiar articulatory or phonatory behaviors demonstrated by a subject were noted.

The tape-recorded words were subsequently scored independently for type of error by six graduate students in Speech Pathology at Michigan State University. Each judge was required to pass a bilateral hearing screening test. As part of her educational training, each judge had completed at least one course in phonetics and one course in articulation disorders before being trained as a judge for the present study. The six judges listened to the tapes individually at two different sessions. They were required to indicate whether a response was correct, substituted, omitted, or distorted. A response recording sheet was provided for each judge. Symbols of the International Phonetic Alphabet were used to denote the consonant errors.

In order to reduce the effect of order-of-tape and familiarity effect with the stimulus words, the tapes were randomized for listening during the second session. The second listening session for each judge occurred not less than one month after the first listening session. None of the judges was allowed to view the score sheet of the first listening session. The six judges assessed the articulation errors by applying the response technique used by the investigator at the time of the testing. An agreement by four of the six judges constituted the criterion of acceptance of the correctness or incorrectness of a phoneme.

The scored utterances for each subject used in the study were tabulated as confusion matrices. Only the errors of substitution were submitted to confusion matrices. For a given subject, a separate confusion matrix was tabulated for substitution errors in the initial position, and a separate one was done for sounds in the final position (regardless of the type of verbal task). In other words, all substitution errors of sounds in the initial position for both the imitative and spontaneous tasks were pooled and tabulated in a single confusion matrix. The same procedure obtained for all substitution errors of sounds in the final position for the two types of verbal tasks. Group confusion matrices were also tabulated for responses in the initial-word position, final-word position, initial- and final-word positions combined, imitative task, and spontaneous task.

Each confusion matrix for each subject summarizes 256 potential confusions for the initial position and the same number for the final position, thus making a total of 512 potential confusions per subject. The matrix shows the frequency with which each phoneme was correctly produced or substituted by another phoneme. Each row of the matrix indicates the phonemes presented, and each column of the matrix shows the response of the subject. Each cell of the matrix represents one of 256 possible phoneme response pairs, and the number of correct responses was obtained by totaling the frequencies along the main diagonal. All errors of production contribute to the off-diagonal pattern. From the other cells to the right of the confusion matrix, the degree to which misarticulated sounds fall into categories of articulation errors is presented. Details of the confusion matrices can be found in Appendix F.

As part of the organization of the raw data for this investigation, a distinctive feature chart was constructed for each subject. The Miller and Nicely (1955) five-feature system was used with slight modifications. The features are Voicing, Duration, Affrication, Place, and Nasality. The phonemes /ʃ/ and /ʒ/ used by Miller and Nicely were not included in the present study. It will be recalled that these two phonemes cannot form a pair since /ʒ/ does not occur in the initial position in English. Thus, in the present study, the phonemes /tʃ/ and

/dʒ/ replaced the Miller and Nicely /ʃ/ and /ʒ/. Similar classifications were retained for the affricates /tʃ/ and /dʒ/ as those used by Miller and Nicely for /ʃ/ and /ʒ/ except with respect to the feature of Duration. Whereas Miller and Nicely treated /ʃ/ and /ʒ/ as having the feature Duration, the present investigator treated /tʃ/ and /dʒ/ as not having the feature of Duration.

The Miller and Nicely distinctive feature system is a combination of binary and ternary features. The authors consider the features Voicing, Duration, Affrication, and Nasality as strictly binary; and the Place feature is considered as a three-category feature: front, middle, and back. Thus, when the binary feature was used, a designation of zero (0) indicates the absence of a given feature and a designation of one (1) indicates the presence of a feature. However, for the Place feature the ternary system is used where zero (0) indicates the Place feature front of the oral cavity, (1) indicates the Place feature middle of the oral cavity, and (2) designates the Place feature back of the oral cavity. A modified Miller and Nicely distinctive feature system is presented in Figure 1.

Data Analyses

Several analyses were used to provide answers to the various research questions addressed in this study. Descriptive statistical analyses, a two-way fixed effects analysis of variance with repeated measures, two one-way fixed effects analyses of variance with repeated measures were used to analyze the data. When a significant difference was found between two related measures, the critical difference was used to determine the magnitude of the differences. Since the results from the various criterion measures were not directly comparable, all raw scores were converted into percentages for statistical analyses. Furthermore, all

Consonant Specification																
Feature	p	t	k	f	θ	s	tʃ	b	d	g	v	ð	z	dʒ	m	n
VOICING	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
DURATION	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
AFFRICATION	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0
PLACE	0	1	2	0	1	1	2	0	1	2	0	1	1	2	0	1
NASALITY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

Figure 1. A Modified Miller and Nicely (1955) Distinctive Feature System

raw data were submitted to a computer program using the Statistical Package for the Social Sciences (SPSS). The CDC 6500 computer was used to perform the statistical test for significant differences.

Chapter IV discusses the statistical and descriptive analyses and the results of the study.

Summary

The speech output of 16 patients with multiple sclerosis was tape-recorded. Each subject participated in two types of verbal tasks and was required to produce a total of 64 words which were constructed on the basis of monosyllabic CVC combination. Sixteen singleton consonants were tested in the initial and final positions only. The test session lasted approximately fifty minutes during which each subject individually received a hearing screening test, an articulation screening test, and the two types of verbal tasks -- imitative and spontaneous. The responses of the subjects were tape-recorded and subsequently scored by six graduate students in Speech Pathology for correctness or incorrectness of articulation. Each subject's productions were then tabulated as confusion matrices and a modified Miller and Nicely (1955) distinctive feature system was used to summarize the data.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter presents the findings obtained from the 16 multiple sclerosis subjects on two types of verbal tasks. Wherever applicable, descriptive and inferential statistical analyses which were performed to provide answers to the various research questions asked in the study are presented. A visual representation of pertinent data is also provided by the use of tables and figures. Interpretation of the results is discussed with reference to certain limitations of the study.

Results

The following questions were addressed in the present investigation:

1. Which speech sounds are predominantly susceptible to articulation errors of substitutions, omissions, and distortions?

The purpose of the singleton consonant analysis was to determine whether certain consonants were much more impaired than others and what particular difficulty they posed in their production. Difficulty of production was determined by the number of errors of substitutions, omissions, and distortions. Of the total 1024 singleton consonant observations, 238 (23.2%) were produced in error. Table 2 shows the distribution of errors made on each of the 16 consonants. Table 2 reveals that certain consonants contributed to a greater incidence of errors in their production than others. These consonants have been ranked in descending order from the most frequently misarticulated to the least frequently misarticulated. The values obtained for each consonant denote the frequency of misarticulations (out of 64 opportunities for error) made on each error category, i.e., substitutions, omissions, and distortions. The column classified as "No Response" refers to instances when a subject failed to respond to a given stimulus item in the series. The results showed that no phoneme in the inventory is immune to substitution errors. A closer look at the error frequencies for the various phonemes shows the phoneme classes that were most impaired by multiple sclerosis. A glaringly obvious statement that can be made about Table 2 is that the phonemes /ð/, /z/, and /v/ accounted for the high incidence of errors of the substitution type, whereas the phonemes /t/, /k/, and /n/ were the easiest to produce for the majority of multiple sclerosis subjects in the present study. None of the 16 consonants contributed in a significant way to the misarticulations that occurred in the error category of omission. Table 2 further illustrates that no errors attributable to distortions appeared in the data. Details of misarticulations with respect to the three conventional error categories will be discussed in question 3 of the present investigation.

Table 3 shows the frequency of correct production for each of the 16 consonants. It will be recalled that each consonant had a total of 64 opportunities for error. The percentage of error on each consonant, regardless of the type of verbal task and the position of a sound in context, is also given in Table 3.

TABLE 2

FREQUENCY OF PHONEMES MISARTICULATED BY 16 MULTIPLE SCLEROSIS SUBJECTS TABULATED ACCORDING TO CONVENTIONAL ERROR CATEGORIES

Phonemes	Substitutions	Omissions	No Response	Total Errors
ð	27	1	0	28
z	25	0	0	25
v	20	2	0	22
b	15	4	0	19
g	13	5	0	18
θ	13	2	1	16
p	12	2	1	15
d	12	2	0	14
f	12	3	0	15
m	12	0	1	13
dʒ	12	0	0	12
tʃ	11	0	0	11
s	8	0	0	8
k	5	1	1	7
n	5	1	0	6
t	2	5	2	9

TABLE 3

FREQUENCY OF CORRECT PRODUCTION AND PERCENTAGE OF ERROR ON 16 PHONEMES OBTAINED FROM 16 MULTIPLE SCLEROSIS SUBJECTS

Phonemes	Frequency of Correct Production	Percentage Error
n	58	9.3%
k	57	10.9
t	55	14.0
s	56	12.5
tʃ	53	17.1
dʒ	52	18.7
m	51	20.3
d	50	21.8
p	49	23.4
f	49	23.4
θ	48	25.0
g	46	28.1
b	45	29.6
v	42	34.3
z	39	39.0
ð	36	43.7

The percentage correct production for the 16 phonemes regardless of the type of task and the position of the phoneme in context was 76.8%. In Table 3, the frequency of correct production of 64 observations ranged between 58 for /n/ and 36 for /ð/. Table 4 summarizes the performance of the 16 multiple sclerosis subjects on a total of 1024 productions.

TABLE 4

FREQUENCY COUNT OF PHONEME PRODUCTIONS BY 16 MULTIPLE SCLEROSIS SUBJECTS

Type of Production	Frequency	Percentage
Correct	786	76.8%
Substitution	204	19.9
Omission	28	2.7
No Response	6	.6

The present investigator was interested in determining whether the subjects in this study demonstrated a wide range of difficulty in their ability to produce singleton consonants. The type of verbal task and the position of a phoneme in context were disregarded in this analysis. Table 5 shows that there was a great deal of variability in the group's error productions. This table presents the frequency error count attributable to each subject elicited from 16 singleton consonants. The conventional categories of errors (i.e., substitutions, omissions) and no response constituted the data used to quantify the types of errors that occurred. The values to the extreme right in Table 5 indicate the percentage errors attributable to each subject. The percentages have been extrapolated from each subject's confusion matrix. Inspection of Table 5 reveals that subject G.T. had the most severe articulatory impairment of all subjects, contributing a total of 32 errors. Subject C.B., on the other hand, was the least affected. The remaining subjects fell between these two. G.T. showed serious problems of articulation which were consistent with the degree of severity of weakness of his speech musculature. This is in accord with the findings of Darley et al. (1972) that severity of dysarthria in multiple sclerosis is positively related to severity of neurologic involvement.

Analysis of Subphonemic Features

It was felt that a gross phonetic feature analysis of the data would highlight the relationship of the misarticulated phonemes and their articulatory features. To this end, a simplifying three-parameter system of classification was employed; and it consists of place of articulation, manner of production, and voicing characteristics. The term subphonemic feature used in the present analysis applies to the particular speech gestures in conventional phonetic terms.

The three subphonemic feature system are the articulatory features of the phonemes of a language. They employ a binary system for manner of production and voicing features, and a non-binary system for the place of articulation. A binary system has only two specifications, one antithetic in nature to the other. For example, a phoneme is either +voice or -voice, +nasal or -nasal. In a non-binary system the use of the binary specification (+) or (-) is inconceivable for the place feature. In the present analysis, the binary system was employed for the manner and voicing features, whereas a non-binary system was applied to the

TABLE 5

FREQUENCY OF ERROR PRODUCTIONS AND PERCENTAGE OF ERROR OBTAINED FROM 16 MULTIPLE SCLEROSIS SUBJECTS

Subjects	Substitutions	Omissions	No Response	Cumulative Error	Percentage Error
G.T.	28	4	0	32	50.0%
D.M.	20	2	2	24	37.5
D.M.	18	6	0	24	37.5
J.M.	20	2	1	23	35.9
J.S.	18	0	2	20	31.2
K.B.	16	3	0	19	29.6
B.M.	12	5	0	17	26.5
V.M.	14	1	1	16	25.0
S.L.	7	5	0	12	18.7
J.J.	10	0	0	10	15.6
E.P.	10	0	0	10	15.6
J.E.	10	0	0	10	15.6
D.H.	7	0	0	7	10.6
P.G.	5	0	0	5	7.8
C.M.	5	0	0	5	7.8
C.B.	4	0	0	4	6.2

place feature. Only errors of substitution were analyzable in terms of subphonemic features. Percentage scores were obtained for five phonetic categories of place of articulation, four phonetic categories of manner of production, and two phonetic categories of voicing.

The place feature described in the present analysis has five specifications according to the integral parts of the speech mechanism involved in the production of the 16 phonemes. The place feature consists of bilabial, labiodental, interdental, alveolar, and velar. Emphasis is placed on the anatomy. Thus, a bilabial involves the use of both lips; labiodental - between the lower lip and upper teeth; interdental - tongue between teeth; alveolar - tongue tip articulating against the alveolar ridge; and velar - articulated with the velum, or soft palate.

The factor manner of production represents a second criterion of classification. It consists of four specifications such as plosive, affricate, fricative, and nasal. Manner of production infers the kinesiological behavior which determines the movements of the machinery to accomplish the placement of articulators. Emphasis then, is on the neuromuscular apparatus. Such terms as plosive, affricate, fricative, and nasal suggest movement rather than position or auditory sensation.

The voicing feature is a third means of classifying consonants. Each consonant is either voiced or voiceless. A voiced phoneme is produced with the vocal folds vibrating, and an unvoiced phoneme is produced with the vocal folds abducted. In this analysis, the voiced - voiceless dichotomy was employed. Figure 2 illustrates the matrix of 16 English phonemes included for analysis in this study with respect to place of articulation and manner of production features. The phonemic system outlined in this matrix consists of two axes.

Manner of Production

	PLACE OF ARTICULATION					
	Bilabial	Labio-dental	Inter-dental	Alveolar	Velar	Percentage of Error
Plosive	p b			t d	k g	15.4%
Affricate				tʃ dʒ		18.0%
Fricative		f v	θ ð	s z		27.3%
Nasal	m			n		13.3%
Percentage of Error	20.3%	25.0%	31.3%	16.7%	14.1%	

Figure 2. Matrix of 16 English Singleton Consonants

The x-axis represents the place of articulation feature and the y-axis represents the manner of production feature. A third coordinate which is the voicing feature could not be represented in this matrix, but its relationship to the other two features is clearly outlined in Table 6.

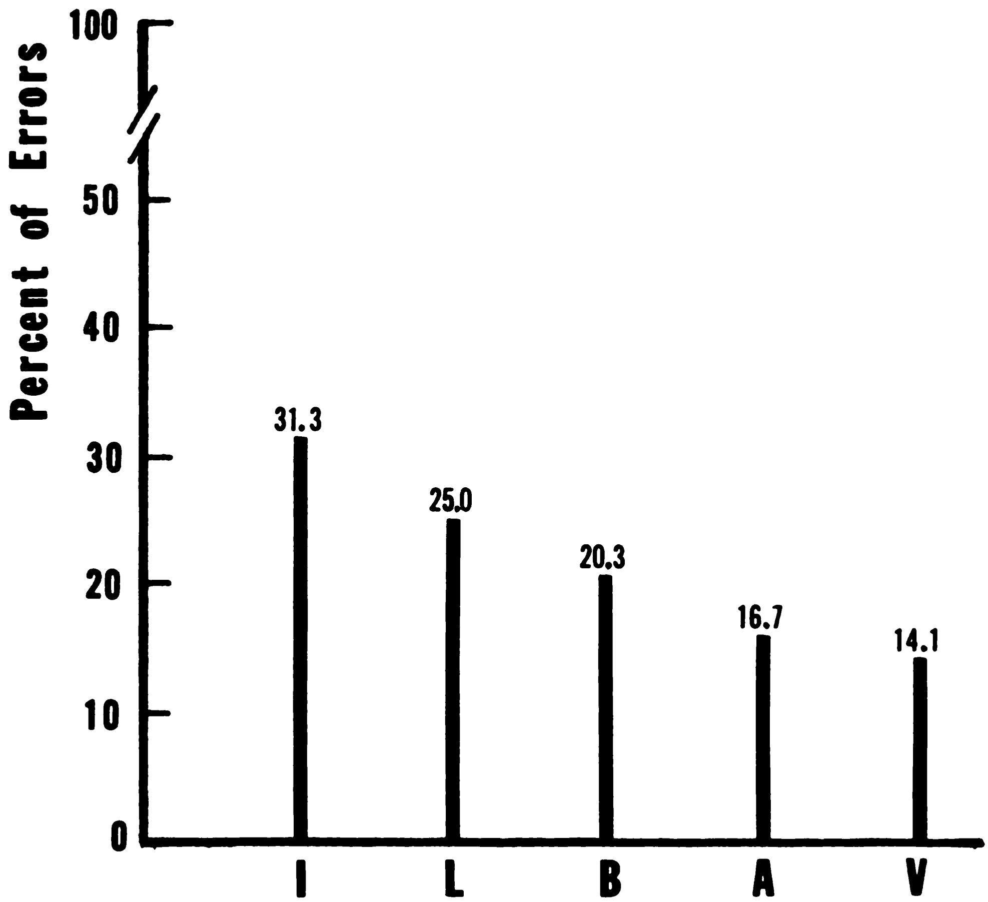
Of the total 64 errors of substitution made with respect to the place of articulation feature, the ordering revealed that velar place was the least easily disturbed and that interdental place component showed greater deterioration. Labiodental place was second in the frequency of features in error. Figure 3 shows the percentage of errors made on the five place specifications. It is encouraging to note that the place feature alveolar was second to last in the frequency of features in error. This represents a less serious articulation problem because many English consonants are alveolar.

TABLE 6

CLASSIFICATION OF PHONEMES BY PLACE OF ARTICULATION, MANNER OF PRODUCTION, AND VOICING FEATURES.

Phonemes	Place	Manner	Voicing
p	bilabial	plosive	−
b	bilabial	plosive	+
m	bilabial	nasal	+
f	labiodental	fricative	−
v	labiodental	fricative	+
θ	interdental	fricative	−
ð	interdental	fricative	+
t	alveolar	plosive	−
d	alveolar	plosive	+
tʃ	alveolar	affricate	−
dʒ	alveolar	affricate	+
s	alveolar	fricative	−
z	alveolar	fricative	+
n	alveolar	nasal	+
k	velar	plosive	−
g	velar	plosive	+

Note: The designation of a minus (-) indicates the absence of vocal fold vibration and plus (+) indicates the presence of vocal fold vibration.



Subphonemic Place Feature

Figure 3. Percentage Error Rates According to Place Features

I= Interdental

L= Labiodental

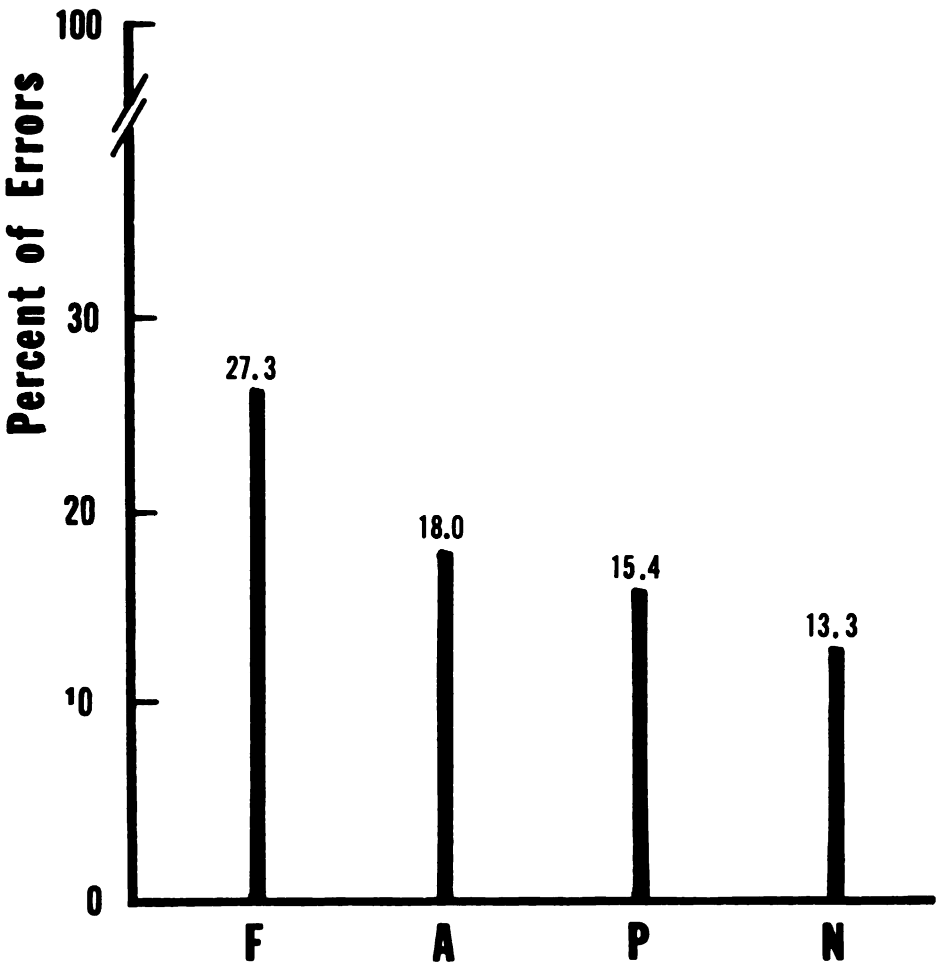
B= Bilabial

A= Alveolar

V= Velar

Reviewing the results according to substitution made with respect to the manner of production, it was found that fricatives posed the greatest difficulty in their production. The error percentage for manner, as shown in Figure 4, ranged from 27.3% for fricatives to 13.3% for nasals. Affricates were the next highest in percentage error. It is not unreasonable to expect a high error rate for fricatives and affricates. These two classes of speech sounds are among the most impaired class of sounds and are among the most difficult to perceive correctly. The manner of production of fricatives and affricates makes them much more susceptible to articulation errors. Fricatives are produced by constriction of the articulators to allow for a narrow opening through which air is forced under pressure. The result is a friction-like noise. Sounds in this class require the use of more muscles and closer control of the amount and timing of movement than for any classes of speech sounds (Shankweiler and Harris, 1966). Affricates combine a plosive and fricative noise. Of the sounds in the fricative class, the phonemes /ð/ and /z/ were the most impaired. These two fricatives, as most speech pathologists are well aware, are frequently disturbed by articulation disorders of peripheral or central origin. Furthermore, they are among the last to be added to a child's repertoire of speech sounds (Templin, 1957). The high incidence of fricative errors is consistent with the findings of Shankweiler and Harris (1966) and Luchsinger and Arnold (1965) that fricative errors represent a considerable number of speech disorders.

Of the total 97 voicing errors made, 80 (13.9%) involved the substitution of voiceless for voiced sounds and 17 (3.8%) involved the substitution of voiced for voiceless sounds. Figure 5 indicates that there were more errors of the voiceless for voiced constrast than vice versa.



Subphonemic Manner Feature

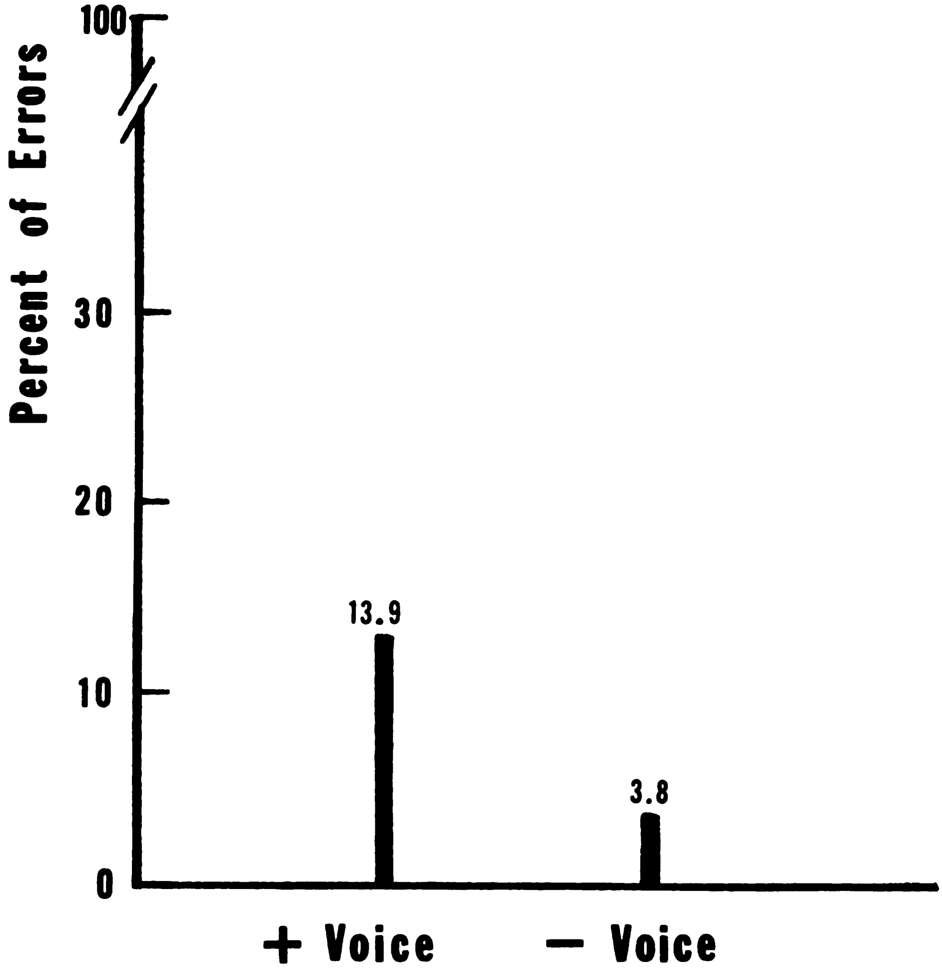
Figure 4. Percentage Error Rates According to Manner Features

F= Fricative

A= Affricate

P= Plosive

N= Nasal



Subphonemic Voicing Feature

Figure 5. Percentage Error Rates According to Voicing Features

+ Voice: Substitution of the negative value (—) for the positive value (+)

— Voice: Substitution of the positive value (+) for the negative value (—)

The phonemes /ð/ and /z/ again, contributed to the high incidence of errors made on voicing feature. This finding is in agreement with many studies in the areas of phonological acquisition and articulation problems which show that when there is a voicing error, there is a greater probability that - voice will replace + voice rather than vice versa (Singh and Frank, 1972). In addition, developmental data show that + voice feature is generally acquired later than – voice feature (Templin, 1957).

Some measure of the degree of similarity between phonemes was of interest to the present investigator. Thus, further analysis of misarticulations was done to determine the extent to which the response phonemes approximated the target phonemes. Specifically, the relationship of misarticulated phonemes and their targets was closely inspected with respect to the physiological, articulatory movements involved in speech production. The errors were classified according to the proximity of the response phonemes to their targets with respect to place of articulation, manner of production, and voicing characteristics. Only errors of substitution were considered in this analysis. With the subphonemic feature system it was possible to examine the distinctive feature spread between phonemes. For example, the substitution of /t/ for /p/ is an error of one feature (place) only; /d/ for /dʒ/ is an error of one feature (manner) only; /v/ for /f/ is an error of one feature (voice) only; /v/ for /b/ is a two-feature error (place and manner); /t/ for /g/ is a two-feature error (place and voice); /s/ for /d/ differs by two features (manner and voice); and finally, /b/ for /f/ is a three-feature error (place, manner, and voice).

Of the total 204 substitution errors noted, 125 (61.2%) involved the change of one-feature value, 44 (21.5%) involved the change of two features, 5 (2.4%) involved the change of three features; and 30 (14.7%) involved other substitution errors such as /st/ for /z/; /ʒ/ for /dʒ/. Thus, it appears that in the great majority of cases, one-feature errors were the most common. Substitutions were found to be in close proximity to the target phonemes with a minimum of feature changes. The apparent relatedness of many of the substituted sounds to their targets, together with the consistency of the substitutions, is consistent with the predictability of articulation defects in adult dysarthrics (Johns and Darley, 1970). Figure 6 shows the percentage error made on the subphonemic feature distance. The group of multiple sclerosis subjects, as a whole, were rarely off-target as to produce three-feature errors. On the basis of these findings, conclusions can be drawn that the majority of multiple sclerosis subjects give responses in close approximation to target phonemes. One-feature substitutions can be considered a smaller magnitude of articulation problem than two-feature or three-feature substitutions.

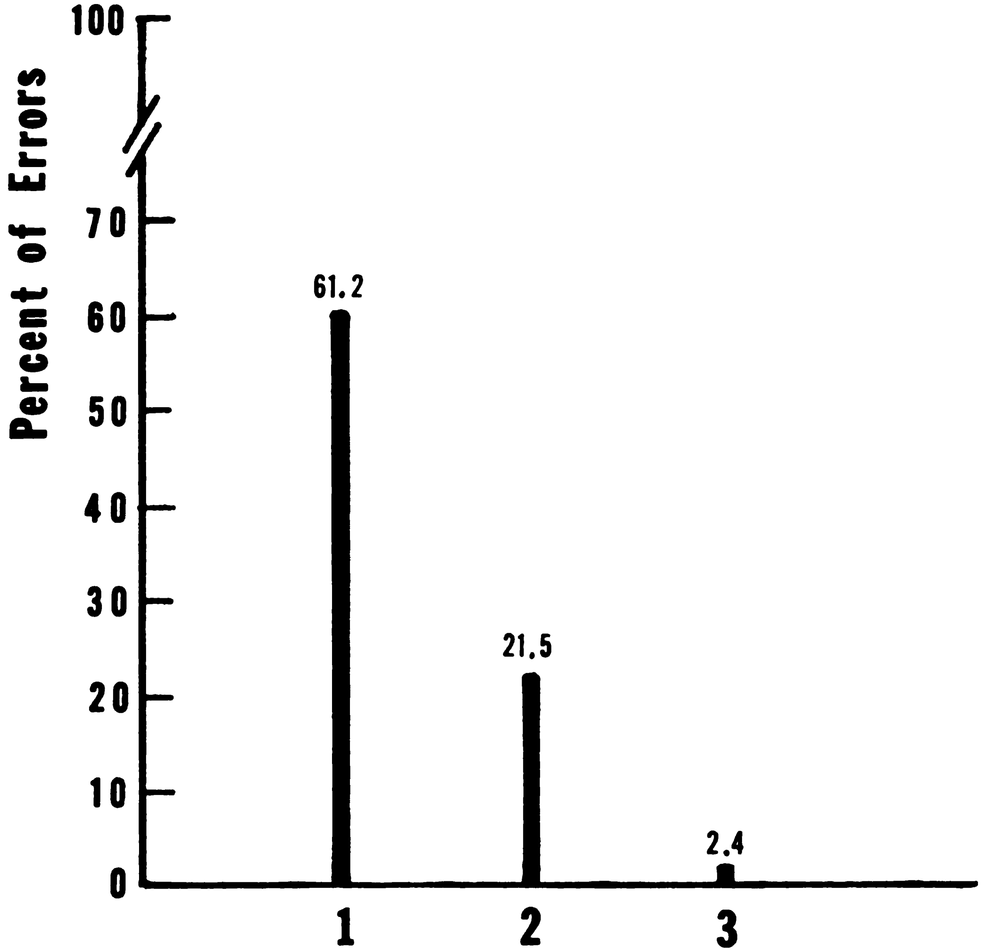
2. Which distinctive features account for the misarticulations that occur in the speech production of multiple sclerosis subjects?

The primary purpose of the distinctive feature analysis was to determine the distribution of the misarticulated consonants among distinctive features. Distinctive features are those attributes that distinguish one phoneme from another or discriminate a large number of phonemes. Distinctive features provide an economic analysis of errors and make possible the number of generalizations regarding articulatory behaviors of multiple sclerosis subjects used in the present investigation that would not be possible in the framework of phonetic analysis.

Given that multiple sclerosis has differential effects on individuals, one would expect certain features to be affected more than others. The distinctive feature system employed in the present analysis was modification of the Miller and Nicely (1955) five-feature system. The distinctive features consist of voicing, duration, affrication, place of articulation, and nasality. All of these, except place of articulation, are binary. Miller and Nicely (1955) proposed a ternary feature for place of articulation. Four of their distinctive features are described in terms of articulatory features and one in terms of acoustic feature. The articulatory features are voicing, affrication, place, and nasality; the acoustic feature is duration.

The distinctive feature system used in the present investigation is by no means an exhaustive and precise list of the features necessary to describe completely all of the phonemes in the English language. Rather, Miller and Nicely (1955) designed this system to aid in describing the role of distinctive features in the act of production and/or perception of selected English consonants.

The rationale for selecting this feature system over other feature systems was purely arbitrary. The present investigator felt that the Miller and Nicely (1955) distinctive feature system is explicit in the description of articulatory behaviors in the most simple and straightforward manner. The nomenclature used in other distinctive feature systems are often subjective and imprecise. In employing the Miller and Nicely (1955) feature system, the present investigator accepted the judgments of the authors who devised it in determining the presence or absence of the features.



Subphonemic Feature Distance from Target Phonemes

Figure 6. Subphonemic feature distance of 204 errors of substitution made by 16 multiple sclerosis subjects

1 - One-feature distance

2 - Two-feature distance

3 - Three-feature distance

Analysis of the Voicing Feature

The feature voicing is an articulatory feature and implies the action of the vocal folds in production. The distribution of articulatory errors was obtained from the pooled errors on voicing regardless of the type of verbal task and the position of the phoneme in context. It must be recalled that the voicing feature is described in terms of a binary system of plus (+) voice, and minus (-) voice. Table 7 shows the distribution of substitution errors of -voice for +voice. This table illustrates instances where a phoneme should have been but was not produced with vocal fold vibration. The percentage errors contributed by each phoneme is presented to the right of the frequency table. Table 8 shows instances of the substitution of +voice for -voice. In other words, the phonemes presented in this table should not have been but were produced with vocal fold vibration. The percentage of errors for each phoneme is also presented. When Tables 7 and 8 are compared, it can be seen that a greater number of errors occurred on the substitution of -voice for +voice than the reverse. These results would be expected because the substitution of + voice for -voice would involve additional effort than vice versa. In the literature, analysis of children's articulation errors rarely reveals substitution of +voice for -voice. A close look at Table 7 reveals that the majority of the substitution errors occurred during the production of fricatives /z/ and /ð/ and affricate /dʒ/. Furthermore, this result is consistent with the notion of the markedness theory (Chomsky and Halle, 1968; Cairns, 1969). It is generally believed that the plus (+) specification of a phoneme is a marked feature specification. Presence of markedness implies greater articulatory complexities. Thus, in Table 7, it can be seen that the

TABLE 7

FREQUENCY OF SUBSTITUTION OF THE FEATURE –VOICE FOR +VOICE BASED ON 64 OBSERVATIONS FOR EACH PHONEME

Substitution – V for + V	Frequency Error	Percentage Error
z	23	35.9%
ð	16	25.0
dʒ	10	15.6
g	9	14.1
d	8	12.5
b	6	9.4
v	6	9.4
m	1	1.6
n	1	1.6
	80	

TABLE 8

FREQUENCY OF SUBSTITUTION OF THE FEATURE +VOICE FOR –VOICE BASED ON 64 OBSERVATIONS FOR EACH PHONEME

Substitution + V for – V	Frequency Error	Percentage Error
f	4	6.3%
θ	4	6.3
k	3	4.7
p	2	3.1
t	2	3.1
tʃ	1	1.6
s	1	1.6
	17	

voiced phonemes /z/, /ð/, and /dʒ/ were replaced more readily by -voice. The highest error rates occurred for /z/ which is marked for voicing and was substituted by its unmarked counterpart /s/ in 20 of 64 (31.3%) observations; /ð/ is marked for voicing and was substituted by its unmarked cognate /θ/ in 14 of 64 (21.8%) productions. It is clear in the analysis of the voicing feature that the minus (-) specification of the feature consistently showed better articulatory performance than the plus (+) specification. The greater magnitude of the substitution errors of voiced sounds lends support to the concept of the markedness theory.

Analysis of Duration Feature

The feature duration is primarily an acoustic feature of some fricative consonants and it implies the ability to prolong certain consonants more than others. Of the 16 consonants used in the present study, only two: /s/ and /z/ have a greater amount of duration than other consonants.

The binary system of plus and minus was used in the analysis of duration feature. The data presented in Tables 9 and 10 show instances of the substitution of - duration for + duration and the substitution of + duration for - duration respectively. All other consonants that were not produced with the feature ± duration were excluded from Tables 9 and 10. Each frequency value indicates the number of times (out of 64 opportunities for error) a particular consonant was produced in error with respect to the feature duration.

Of 22 total errors of duration, 7 involved the substitution of - duration for + duration, and 15 involved the substitution of + duration for - duration.

TABLE 9

FREQUENCY OF SUBSTITUTION OF THE FEATURE – DURATION FOR + DURATION BASED ON 64 OBSERVATIONS FOR EACH PHONEME

Substitution – D for + D	Frequency Error	Percentage Error
s	4	6.3%
z	3	4.7
	7	

TABLE 10

FREQUENCY OF SUBSTITUTION OF THE FEATURE + DURATION FOR – DURATION BASED ON 64 OBSERVATIONS FOR EACH PHONEME

Substitution + D for – D	Frequency Error	Percentage Error
tʃ	8	12.5%
d	2	3.1
θ	2	3.1
b	1	1.6
dʒ	1	1.6
f	1	1.6
	15	

Analysis of Affrication Feature

The feature affrication is an articulatory feature which involves a partial closure between a given articulator and the point of articulation. Because the closure is incomplete, a turbulence is heard during the production of consonants designated as having the feature affrication. Eight consonants /f/, /v/, /θ/, /s/, /z/, /ð/, /tʃ/, and /dʒ/ are produced with affrication. Tables 11 and 12 show how the errors of affrication distributed themselves among certain consonants. It can be observed that there was a greater frequency of the replacement of − affrication for + affrication than + affrication for − affrication. Substitutions of − affrication for + affrication occurred because the breathstream was completely impeded during the production of sounds having the feature + affrication. Conversely, substitutions of + affrication for − affrication occurred because the breathstream was not completely impeded during production of sounds with the minus specification of affrication. Close inspection of the data reveals that the majority of the substitution of − affrication for + affrication occurred in /v/, /ð/, and /θ/.

Analysis of Place of Articulation Feature

The place of articulation refers to the point or area of the oral cavity where constriction is made during production of sounds. As has been mentioned before, Miller and Nicely (1955) proposed a ternary feature for place of articulation. The authors designated a score of zero (0) if the constriction was made in the front of mouth, such as in the production of /p/, /b/, /f/, /v/, and /m/; a score of one (1) if the constriction was in the middle of the oral cavity such as in /t/,

TABLE 11

FREQUENCY OF SUBSTITUTION OF THE FEATURE – AFFRICATION FOR + AFFRICATION BASED ON 64 OBSERVATIONS FOR EACH PHONEME

Substitution – A for + A	Frequency Error	Percentage Error
v	15	23.4%
ð	9	14.1
θ	8	12.5
f	5	7.8
z	3	4.7
tʃ	2	3.1
dʒ	1	1.6
s	1	1.6
	44	

TABLE 12

FREQUENCY OF SUBSTITUTION OF THE FEATURE + AFFRICATION FOR – AFFRICATION BASED ON 64 OBSERVATIONS FOR EACH PHONEME

Substitution + A for – A	Frequency Error	Percentage Error
g	6	9.4%
d	3	4.7
b	2	3.1
t	1	1.6
k	1	1.6
	13	

TABLE 13

FREQUENCY OF SUBSTITUTION OF THE FEATURE PLACE OF ARTICULATION BASED ON 64 OBSERVATIONS FOR EACH PHONEME

Place Features	Phonemes	Error Rate for 6 Place Feature Specifications*					
		1/0	2/0	0/1	2/1	1/2	0/2
Front Place	p	1	10	-	-	-	-
	b	2	3	-	-	-	-
	f	6	-	-	-	-	-
	v	-	-	-	-	-	-
	m	8	-	-	-	-	-
Middle Place	t	-	-	-	1	-	-
	d	-	-	2	1	-	-
	θ	-	-	1	2	-	-
	ð	-	-	4	-	-	-
	s	-	-	1	6	-	-
	z	-	-	-	2	-	-
	n	-	-	3	2	-	-
Back Place	k	-	-	-	-	-	1
	g	-	-	-	-	4	1
	tʃ	-	-	-	-	2	-
	dʒ	-	-	-	-	1	-
		17	13	11	14	7	2

* 1/0: Middle for Front (5.3%) 2/1: Back for Middle (3.1%)

2/0: Back for Front (4.1%) 1/2: Middle for Back (2.7%)

0/1: Front for Middle (2.5%) 0/2: Front for Back (.8%)

/d/, /θ/, /ð/, /s/, /z/, and /n/; and a score of two (2) for sounds made with the constriction in the back of the oral cavity such as in /k/, /g/, /tʃ/, and /dʒ/. In Table 13, the phonemes have been examined in terms of the area of the oral cavity constricted during production. In this analysis, six combinations of substitution errors were possible: substitution of middle for front of the oral cavity (1/0); back for front (2/0); front for middle (0/1); back for middle (2/1); middle for back (1/2); and front for back (0/2). Table 13 shows the frequency of substitution errors made in each place specification. The data revealed that there was a greater tendency for the middle place specification to substitute the front place (5.3%) than front for middle (2.5%). Also, there was a greater incidence of the substitution of the back place for the front place (4.1%) than the front place for the back place (.8%) and a greater incidence of the substitution of the back place for the middle place (3.1%) than the middle place for the back place (2.7%).

Although the place feature substitutions showed a non-unidirectional tendency, there was a greater incidence of the substitution of the less fronted place for the more fronted place in the same manner series. For example, /k/ is produced with constriction in the back of the oral cavity and replaced the fronted /p/ 9 of 64 opportunities (14.1%) for error. There was hardly any substitution of /p/ for /k/ in the data. This strange phenomenon of the substitution of the back /k/ for the front /p/ may be attributable to the distinctive feature similarities between /k/ and /p/. A phoneme is usually replaced by another it is similar to in terms of distinctive features. The phonemes /k/ and /p/ differ only by one feature: place of articulation. Both phonemes involve considerable aspiration in their production, and thus the acoustic nature of these two phonemes may be reflected in the difficulty in differentiating them. The substitution of /k/ for /p/ was highly unidirectional and occurred in the imitative task only. (See confusion matrix, Figure 11, Appendix F). The place specification middle for front (as exemplified by the substitution of /θ/ for /f/ and /n/ for /m/) was another instance in which there was a greater substitution of the less fronted place for the more fronted place. The acoustic difference between /θ/ and /f/ are among the most difficult to distinguish (Miller and Nicely, 1955), and it is not surprising that they were confused with regard to the place feature. This finding of the greater incidence of the substitution of the less fronted place for the more fronted place is not in agreement with observations of Singh and Frank (1972) whose analysis of consonant articulation problems in children showed a tendency for the substitution of the more fronted place for the less fronted place. For example, a substitution of labial for alveolar, alveolar for back, interdental for alveolar.

Analysis of Nasality Feature

Two consonants /m/ and /n/ are produced by nasal resonance. Nasality, as an articulatory feature, employs the binary system of plus and minus. Neuromuscular disturbances, identified as the dysarthrias of the speech mechanism, can affect the velopharyngeal closure through paresis or paralysis of the musculature or a lack of coordination with other speech movements. Nasality results from this reduced or lack of velopharyngeal control. The data presented in Tables 14 and 15 represent the frequency with which nasal consonants were produced without nasal resonance and non-nasal consonants were produced with nasal resonance,

TABLE 14

FREQUENCY OF SUBSTITUTION OF THE FEATURE − NASALITY FOR + NASALITY BASED ON 64 OBSERVATIONS FOR EACH PHONEME

Substitution − N for + N	Frequency Error	Percentage Error
m	4	6.3%
n	1	1.5
	5	

TABLE 15

FREQUENCY OF SUBSTITUTION OF THE FEATURE + NASALITY FOR − NASALITY BASED ON 64 OBSERVATIONS FOR EACH PHONEME

Substitution + N for − N	Frequency Error	Percentage Error
b	3	4.7%
v	2	3.1
ð	2	3.1
	7	

respectively. Errors on the nasal consonants occurred because the velopharyngeal port was occluded during production of /m/ and /n/, whereas errors on non-nasal consonants occurred because the velopharyngeal port was open during their production. Tables 14 and 15 show that there was slightly more substitution of + nasality for – nasality than vice versa. This finding is consistent with the notion that dysarthria affects the production of non-nasal sounds because adequate velopharyngeal closure is compromised by muscle weakness or incoordination. In addition, the small error rate for nasality is consistent with the findings of Darley et al. (1972) that resonatory problems are low on the list of problems affecting speech processes in multiple sclerosis.

Summary of Distinctive Feature Analysis

In general, the results of the distinctive feature analysis showed that the substitution errors that occurred for the features voicing and affrication would be predicted from the markedness principle. It will be recalled that the unmarked specification of a feature involves less complex articulatory gestures than its marked counterpart. Thus, for the feature voicing, it is not surprising that the feature – voice (unmarked) replaced + voice (marked) more frequently than vice versa. The marked feature for voicing calls for an additional phonetic gesture, i.e., vocal fold vibration. The markedness principle also obtained for the articulatory feature affrication. The feature nasality showed slightly more errors of the substitution of + nasality for – nasality. The acoustic feature duration also showed more errors of the substitution of the + specification for the – specification. With regard to the place feature specifications, the markedness principle did not hold true.

TABLE 16

OVERALL DISTINCTIVE FEATURE ERRORS MADE BY 16 MULTIPLE SCLEROSIS SUBJECTS (TASK AND POSITION COMBINED)

Features	Number Presented	Error Rate	Percentage Error
Voicing			
– Voice	448	17	3.8%
+ Voice	576	80	13.9
Duration			
– Duration	896	15	1.7
+ Duration	128	7	5.5
Affrication			
– Affrication	512	13	2.5
+ Affrication	512	44	8.6
Place of Articulation			
1 for 0	320	17	5.3
2 for 0		13	4.1
0 for 1	448	11	2.5
2 for 1		14	3.1
1 for 2	256	7	2.7
0 for 2		2	.8
Nasality			
– Nasality	896	7	.8
+ Nasality	128	5	3.9

There is evidence, both in language developmental data and in the patterns of articulation errors of children, that the place feature front of the oral cavity which involves fewer maneuvers of the articulators are less frequently produced in error than the place feature for which there is a complex articulatory maneuver. Singh and Frank (1972) observed that place 3 (back of the oral cavity) is substituted more often by place 2 (middle of the oral cavity) than vice versa and that place 2 is substituted more often by place 1 (front of the oral cavity) than vice versa. Thus, in terms of the markedness theory, place 1 is unmarked and place 2 may be considered unmarked when compared to place 3 which is considered marked. Similar statements cannot be made regarding the findings of the place feature specifications in the present analysis and the markedness theory. Table 16 presents the overall distinctive feature errors made by the group.

3. Which is the predominant type of error (i.e., substitutions, omissions, and distortions) made by multiple sclerosis patients?

The present research question examines the distribution of the misarticulated consonants among the conventional error categories. Generally, phonemic errors are described as being of four types: substitutions, omissions, distortions, and additions. The error category addition was excluded for consideration in the present study because of its rarity of occurrence as an articulation error (Byrne and Shervanian, 1977). Addition involves adding another phoneme to the target phoneme(s). According to Van Riper and Irwin (1958), addition, as an articulatory error, is much more common in aphasics and foreign language speakers. Furthermore, since the errors of additions were non-existent in the present data, its elimination was justified. Substitutions are the result of a process whereby one phoneme from the store of phonemes in the language is substituted for the target phoneme.

Comparisons of the categories of articulation errors on the two types of verbal tasks and the two positions of a sound in context constituted the data in the present analysis. It was felt that pooling the data from the two tasks and the two positions might overlook real differences in the misarticulations that occurred as a function of task and/or position.

Of the total 1024 phoneme observations, 238 (23.2%) were misarticulated by the group of multiple sclerosis subjects. Contrary to expectations, the errors did not distribute themselves among the three conventional error categories of substitutions, omissions, and distortions. Rather, substitution category accounted for a significant number (19.9%) of errors made by the multiple sclerosis group. Articulation errors of the omission type (2.7% error) were rarely the basis for articulation errors in the present study. The surprising finding in the data was the total absence of distortion errors. The substitution of target phonemes by other phonemes which were not selected for observation in the present investigation constituted the category classified as "Other Substitutions" in the confusion matrices (Appendix F). Errors due to other substitutions (a total of 30 out of 1024 observations) were combined with the conventional error of substitutions to yield a total of 204 substitution errors made by the multiple sclerosis subjects. An example of "Other Substitution" errors was the replacement of /ʃ/ for /s/. It will be recalled that the phoneme /ʃ/ was excluded from the present study because its voiced cognate /ʒ/ does not occur in the initial-word position in English. Errors due to "No Response" involved instances when a subject failed to respond to a given stimulus and this constituted .6% of misarticulations. Table 17 shows the cumulative errors and percentage distribution of errors made on the 16 consonants. The percentages are based on the total of 238 errors made.

Of interest to the present investigator was the distribution of the categories of misarticulations with respect to the type of verbal task and the position of a sound in context. Table 18 shows how the articulation errors distributed themselves among the 16 consonants as a function of task. It is clear that there was a greater incidence of substitution errors in the imitative task (23.6%) than in the spontaneous task (16.2%). Table 19 shows the distribution of the types of articulation errors made on the 16 consonants as a function of the position of a sound in context. It is evident that substitution errors accounted for more (22.5%) of the total errors made in the final-word position than did the initial-word position (17.4%). Furthermore, more misarticulations for the omission type occurred in the final-word position (5.1%) as compared to omission errors in the initial-word position (.4%).

TABLE 17

CUMULATIVE ERRORS AND PERCENTAGE DISTRIBUTION OF THE CATEGORIES OF ERRORS MADE ON 16 CONSONANTS

Error Category	Cumulative Error	Percentage Error
Substitution	204	19.9%
Omission	28	2.7
No Response	6	.6

The most striking result to emerge from the present analysis was the significantly greater incidence of errors of the substitution type. Since multiple sclerosis, as a disease process, affects the articulators, the results might be interpreted to mean that substitution errors are more representative of the basic physiological impairment in the group of multiple sclerosis subjects used in the present investigation. This result is not in agreement with the observations of Johns and Darley (1970) that distortion of consonants is most characteristic of the speech of dysarthric subjects. It is interesting to note that the clustering of errors in the substitution category was attributable to only a few subjects. The range was between a total of 28 substitution errors (subject G.T.) and 4 (subject C.B.). Table 5, page 54, shows that three subjects accounted for the high error rate of substitutions, making 20 or more errors of the substitution type.

There are certain considerations in examining the patterns of articulation errors that occurred. The basis for the differing results may be attributable to the different terminologies involved in the present study and other investigations. A possible explanation as to why the distribution of articulation errors was highly skewed toward the substitution type could be due to the concept of distortion in the speech pathology literature. The definition of distortions is arbitrary depending on the experimenter. Imprecise production of consonants constitute distortion in certain research investigations (Darley et al., 1969; Johns and Darley, 1970). This arbitrary classificatory term often leads to different concepts of distortion. In the present investigation, the term distortion was defined in the strict sense of the replacement of a standard speech sound by one not normally

TABLE 18

THE DISTRIBUTION OF THE CATEGORIES OF ARTICULATION ERRORS MADE ON 16 CONSONANTS BASED ON THE TYPE OF VERBAL TASK*

Error Category	Imitative Task	Spontaneous Task
Substitution	121 (23.6%)	83 (16.2%)
Omission	14 (2.7%)	14 (2.7%)
No Response	6 (1.2%)	0 (0.0%)
	141	97

* Each type of verbal task involved a total of 512 observations.

TABLE 19

THE DISTRIBUTION OF THE CATEGORIES OF ARTICULATION ERRORS MADE ON 16 CONSONANTS BASED ON THE POSITION OF A SOUND IN CONTEXT*

Error Category	Initial Position	Final Position
Substitution	89 (17.4%)	115 (22.5%)
Omission	2 (.4%)	26 (5.1%)
No Response	2 (.4%)	4 (.8%)
	93	145

* Each type of position involved a total of 512 observations.

used in a given language. Furthermore, substitution, as operationally defined in this study, had to be the replacement of the target phoneme by another well-articulated standard English phoneme. Thus, the substitution of an implosive /ɓ/ for /b/ would be considered a distorted /b/ sound since implosive /ɓ/ is non-existent as a standard sound in English.

A second possible reason for the absence of distortion errors in the data might rest with the criterion of acceptance of judging a response phoneme as correct or incorrect. Although there were isolated cases in which a judge or two scored certain phonemes as distorted (for a total of 11 distortions), these scores were disregarded because there was no agreement by 4 of the 6 judges with respect to a given phoneme.

Another possible reason for the patterns of articulation errors that occurred might be the interaction of task and/or position of a sound in context. This would also lend itself to an explanation as to why there were more substitution errors in the final-word versus initial-word position and in the imitative task versus the spontaneous task. It must be pointed out that only a selected group of consonants were tested in this study. The total absence of distortion errors in the data could be that distortions might not be reflected in a monosyllabic CVC context. The presentation of consonants in monosyllabic initial-word and final-word positions is rather contrived such that the majority of the multiple sclerosis subjects produced well-articulated substitutions of other standard sounds for the target consonants.

One interesting finding to emerge from these data was the demonstration by one subject (E.P.) of the articulatory behavior somewhat similar to what Charcot (1877) described as "scanning speech." Scanning involves increased stress on usually unstressed words or syllables. Darley et al. (1972) refer to this articulatory speech dimension as impaired emphasis. Whether this subject (E.P.) displayed this articulatory behavior is questionable. The present investigator is of the opinion that the "exaggerated" precise consonant articulation by this particular subject was perhaps a compensatory technique to allow for acceptable acoustic impressions. A possible therapeutic implication of this articulatory behavior is that scanning could be used to improve the speech of multiple sclerosis patients whose speech is "unscanning" and thus unintelligible.

4. Is there a significant difference in the misarticulations that occur as a function of the type of verbal task?

The analysis of the misarticulations as a function of verbal task was designed to determine the effects of imitative (repetition of words) and spontaneous (reading of words) methods of response elicitation on the patterns of errors that occurred for the 16 multiple sclerosis subjects. In other words, under what type of treatment condition were subjects more apt to make more articulation errors? Table 20 compares the subjects' performances on the two types of verbal tasks. The results revealed that the group performed better in the spontaneous task than in the imitative task. This held for both initial- and final-word positions. The results also revealed that the type of verbal task was a factor in the categories of articulation errors that occurred. For instance, there was a greater incidence of

TABLE 20

A COMPARISON OF THE PERFORMANCE ON TWO TYPES OF VERBAL TASKS BY 16 MULTIPLE SCLEROSIS SUBJECTS

Subjects	Imitative Errors	Spontaneous Errors
G.T.	17	15
D.M.	15	9
D.M.	16	8
J.M.	12	11
J.S.	13	7
K.B.	8	11
B.M.	8	9
V.M.	13	3
S.L.	7	5
J.J.	5	5
E.P.	7	3
J.E.	7	3
D.H.	5	2
P.G.	4	1
C.M.	1	4
C.B.	3	1
	141	97

errors of the substitution type in the imitative task, whereas errors of omission showed no difference as a function of task.

Tables 21 and 22 show the breakdown of the categories of articulation errors made on 16 consonants as a function of task. Although there is no general agreement in the literature concerning the most efficient method of response elicitation, the finding in the present analysis is not in agreement with the popular notion that response elicitation is easier in the imitative than the spontaneous method of presentation. Templin (1947), in an investigation of the influence of imitative and spontaneous methods of stimulus presentation on the articulation of 100 pre-school children, concluded that neither the imitative nor the spontaneous testing method was superior. Siegel et al. (1963) found the imitative method to result in better articulatory performance on at least 8 of the 40 sounds presented to 100 kindergarten children. Kresheck and Socolofsky (1972) found articulatory responses to be superior in the imitative method. Paynter and Bumpas (1977) investigated the effects of the two methods of stimulus presentation on the articulatory responses of 3 and 3½ year old children. They found no significant differences in articulatory responses as a function of type of stimulus presentation.

To the knowledge of the present investigator, no study has been done regarding the effects of the two methods of stimulus presentations on the articulatory responses of adults with articulation problems.

Further analysis revealed that the group's articulation errors on individual phonemes kept essentially the same order of difficulty regardless of the type of verbal task. A comparison was also made of the groups' responses in the initial and final positions for the

TABLE 21

TYPES OF MISARTICULATIONS AS A FUNCTION OF IMITATIVE TASK BASED ON 32 OBSERVATIONS FOR EACH PHONEME

Phonemes	Substitutions	Omissions	No Response	Total Error
z	15	-	-	15
ð	14	-	-	14
p	11	1	1	13
b	10	2	-	12
g	9	2	-	11
d	8	-	-	8
dʒ	8	-	-	8
v	8	1	-	9
f	7	2	-	9
θ	7	2	1	10
tʃ	6	-	-	6
m	5	-	1	6
n	5	1	-	6
s	4	-	-	4
k	3	1	1	5
t	1	2	2	5
	121	14	6	141

TABLE 22

TYPES OF MISARTICULATIONS AS A FUNCTION OF SPONTANEOUS TASK BASED ON 32 OBSERVATIONS FOR EACH PHONEME

Phonemes	Substitutions	Omissions	No Response	Total Error
ð	13	1	-	14
v	12	1	-	13
z	10	-	-	10
m	7	-	-	7
θ	6	-	-	6
b	5	2	-	7
tʃ	5	-	-	5
f	5	1	-	6
d	4	2	-	6
g	4	3	-	7
dʒ	4	-	-	4
s	4	-	-	4
k	2	-	-	2
p	1	1	-	2
t	1	3	-	4
n	-	-	-	-
	83	14	-	97

imitative and spontaneous tasks. The results showed that the subjects performed better in the initial position for both tasks than in the final position. Only three subjects (G.T., J.J., and C.B.) deviated slightly from the above pattern, their responses being slightly better in the final position than in the initial.

In terms of distinctive features, the subjects' responses were essentially the same for both the imitative and spontaneous tasks. Table 23 illustrates the misarticulations that occurred with respect to the five distinctive features and mode of stimulus presentation. The number of observations, the cumulative error, and the percentage of error for each feature specification of a given distinctive feature is presented. Table 23 shows that the feature place of articulation deviated slightly from the patterns of errors that occurred as a function of verbal task. Subjects' responses on the imitative place feature were poorer (with a total of 48 place errors) than on the spontaneous place feature (with a total of 16 place errors).

The diagnostic and therapeutic implications of the findings of the present analysis are that the multiple sclerosis subjects in this study might benefit more from visual (spontaneous) model than pure auditory (imitative) model.

5. Is there a significant difference in the misarticulations that occur as a function of the position of a sound in context?

The analysis of the misarticulations as a function of phoneme position was designed to compare the errors made by the 16 multiple sclerosis subjects when a consonant appeared in the initial versus the final position of a word. Table 24 shows the frequency of errors made by the group as a function of phoneme position. The errors made in the initial-word position for the two types of verbal tasks

TABLE 23

DISTINCTIVE FEATURE ERRORS MADE AS A FUNCTION OF TYPE OF VERBAL TASK

Features	Number Presented	Imitative Error Rate	Percentage Error	Spontaneous Error Rate	Percentage Error
Voicing					
– Voice	224	6	2.7%	11	4.9%
+ Voice	288	44	15.3%	36	12.5%
Duration					
– Duration	448	11	2.5%	4	.9%
+ Duration	64	5	7.8%	2	3.1%
Affrication					
– Affric.	256	9	3.5%	4	1.6%
+ Affric.	256	26	10.2%	18	7.0%
Place of Articulation					
1 for 0	160	12	7.5%	5	3.1%
2 for 0		13	8.1%	0	0.0%
0 for 1	224	6	2.7	5	2.2%
2 for 1		10	4.5%	4	1.8%
1 for 2	128	5	3.9%	2	1.6%
0 for 2		2	1.6%	0	0.0%
Nasality					
– Nasality	448	3	.7%	4	.9%
+ Nasality	64	3	4.7%	2	3.1%

(imitative and spontaneous) were pooled for this analysis as were the errors in the final-word position. The data in Table 24 show there were more errors in the final-word position (145) than in the initial-word position (93). This held for errors of substitutions and omissions (Tables 25 and 26). The percentage error for the 16 consonants in the initial position was 18.5%, and the percentage error for the final consonants was 28.3%. There were 512 opportunities for error in each type of position.

Several points should be stressed here. The first was that there was a high degree of similarity in the misarticulations as a function of position in the two types of verbal tasks. This finding would appear to indicate that the same or similar processes were in operation in the observed misarticulations. The second point was the surprising finding that errors tended to be greater in the final-word position than initial. The findings in the present analysis are consistent with the linguistic theory of regression hypothesis of Hughlings Jackson (Ed. Taylor, 1958), Jakobson and Halle (1956) and of Wepman and Jones (1964) that final consonants, appearing later than initial consonants in a child's repertoire, are more difficult. In addition, the findings lend support to reports by Templin (1957) that more errors occur in the final-word position.

Although the data in Table 24 showed some consistencies existing across subjects of the greater vulnerability of final-word position, there were some differences. Two subjects (J.J. and C.B.) deviated from this pattern, contributing to more phoneme errors on the initial-word position than on the final-word position. Two other subjects (G.T. and J.E.) showed essentially no difference in their

TABLE 24

POOLED ERROR BY POSITION FOR 16 MULTIPLE SCLEROSIS SUBJECTS

Subjects	Initial Position	Final Position
G.T.	16	16
D.M.	10	14
D.M.	10	14
J.M.	7	16
J.S.	8	12
K.B.	8	11
B.M.	1	16
V.M.	5	11
S.L.	3	9
J.J.	7	3
E.P.	4	6
J.E.	5	5
D.H.	2	5
P.G.	2	3
C.M.	2	3
C.B.	3	1
	93	145

TABLE 25

TYPES OF MISARTICULATIONS AS A FUNCTION OF INITIAL-WORD POSITION BASED ON 32 OBSERVATIONS FOR EACH PHONEME

Phonemes	Substitutions	Omissions	No Response	Total Error
ð	11	-	-	11
f	11	-	-	11
v	10	-	-	10
d	8	-	-	8
z	8	-	-	8
tʃ	7	-	-	7
p	6	-	-	6
g	5	-	-	5
θ	5	1	1	7
dʒ	4	-	-	4
m	4	-	1	5
k	3	-	-	3
s	3	-	-	3
b	2	1	-	3
n	2	-	-	2
t	-	-	-	-
	89	2	2	93

TABLE 26

TYPES OF MISARTICUATIONS AS A FUNCTION OF FINAL-WORD POSITION BASED ON 32 OBSERVATIONS FOR EACH PHONEME

Phonemes	Substitutions	Omissions	No Response	Total Error
z	17	-	-	17
ð	16	1	-	17
b	13	3	-	16
v	10	2	-	12
g	8	5	-	13
dʒ	8	-	-	8
θ	8	1	-	9
m	8	-	-	8
p	6	2	1	9
s	5	-	-	5
d	4	2	-	6
tʃ	4	-	-	4
n	3	1	-	4
t	2	5	2	9
k	2	1	1	4
f	1	3	-	4
	115	26	4	145

responses in both positions.

Individual consonants were also examined with regard to the difficulty they posed in their production in the initial- and final-word positions. A comparison of Tables 25 and 26 demonstrates that the majority of consonants were misarticulated in the final than in the initial-word position. The consonants /b/, /g/, /ǰ/, and /z/ were the most impaired in the final-word position. The consonants /tʃ/, /d/, and /f/ showed shifts in the reverse of the overall pattern. In other words, there were more errors on these consonants in the initial-word position than in the final.

Further analysis was done to determine the distribution of errors among the five distinctive features with respect to the position of a sound in context. Table 27 shows the distinctive feature errors made as a function of phoneme position. Overall subjects' responses showed that the distinctive features were more vulnerable in the final-word position than initial. Each distinctive feature is examined in terms of the number of observations, the cumulative error, and the percentage of error made on each feature specification as a function of phoneme position.

The implications of the findings of the present research question are that, as a group, the multiple sclerosis subjects in this study have more difficulty with sounds in the final-word position. This could be interpreted to mean that multiple sclerosis subjects have less difficulty with sounds in the initial position, perhaps, because they have more time and energy to set the articulators in a suitable position prior to production. The difficulty experienced by this group of multiple sclerosis subjects with sounds in the final position

TABLE 27

DISTINCTIVE FEATURE ERRORS MADE AS A FUNCTION OF PHONEME POSITION

Features	Number Presented	Initial Error Rate	Percentage Error	Final Error Rate	Percentage Error
Voicing					
— Voice	224	10	4.5%	7	3.1%
+ Voice	288	28	9.7%	52	22.8%
Duration					
— Duration	448	9	2.0%	6	1.3%
+ Duration	64	4	6.3%	3	4.7%
Affrication					
— Affric.	256	3	1.2%	10	3.9%
+ Affric.	256	25	9.8%	19	7.4%
Place of Articulation					
1 for 0	160	10	6.3%	7	4.4%
2 for 0		5	3.1%	8	5.0%
0 for 1	224	6	2.7%	5	2.2%
2 for 1		5	2.2%	9	4.0%
1 for 2	128	3	2.3%	4	3.1%
0 for 2		0	0.0%	2	1.6%
Nasality					
— Nasality	448	3	.7%	4	.9%
+ Nasality	64	2	3.1%	3	4.7%

might be attributable to the difficult transition they have to make from one articulatory gesture to another.

Analysis of Variance of Subjects' Responses as a Function of Type of Verbal Task and Phoneme Position

Further analysis was done to determine whether the results were clear-cut enough to demonstrate definite significant differences in the misarticulations as a function of the type of verbal task and the position of a sound in context.

A two-way fixed effects (2 x 2) analysis of variance with repeated measures was computed to determine the differences that existed in the responses of the 16 multiple sclerosis subjects as a function of task (imitative, spontaneous) and position (initial, final). The results (Table 28) indicate that there was a significant main effect for task at the .01 level of confidence, and a significant main effect for position at the .05 level of confidence. The mean of errors for the effect of task and the mean of errors for the effect of position were computed to determine the direction of the difference between tasks and the direction of the difference between positions. Figure 7 shows that the group's performance was poorer in the imitative task than in the spontaneous task. Furthermore, Figure 7 shows that the group's performance was poorer in the final position than in the initial position. No interaction was found between task and position.

6. Is the distribution of misarticulations related to the developmental hierarchy of phoneme emergence?

The present analysis attempts to determine the order in the breakdown of articulation in adult multiple sclerosis subjects with respect to the acquisition hierarchy of sounds in children. The 16 phonemes were tabulated (Table 29) on the basis of the age at which they are acquired.

TABLE 28

TWO-WAY FIXED EFFECTS (TASK x POSITION) ANALYSIS OF VARIANCE WITH REPEATED MEASURES FOR RESPONSE ELICITATION BY ONE GROUP OF MULTIPLE SCLEROSIS SUBJECTS

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Ratio	F-Probability
T (Task)	1	30.250	30.250	9.213	.008*
Error (TS)	15	49.250	3.283		
P (Position)	1	42.250	42.250	8.422	.011**
Error (PS)	15	75.250	5.017		
Interaction (TP)	1	.063	.063	.033	.858
Error (TPS)	15	28.438	1.896		
S (Subjects)	15	257.438	17.163		
Total	63	482.938			

* Significant at the .01 level of confidence.

** Significant at the .05 level of confidence.

Notes: TS = Task x Subjects

PS = Position x Subjects

TPS = Task x Position x Subjects

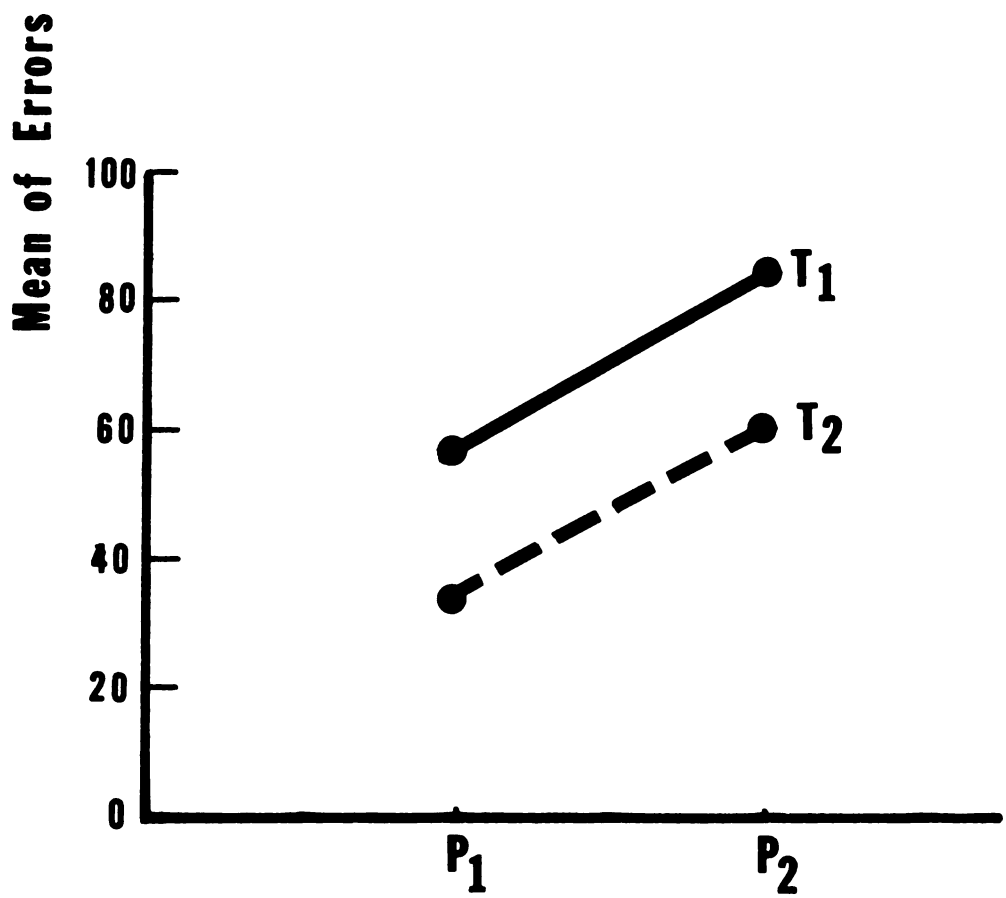


Figure 7. Mean of Errors for Task by Position.

Notes: P_1 = Position 1: Initial

P_2 = Position 2: Final

T_1 = Task 1: Imitative (–)

T_2 = Task 2: Spontaneous (---)

P_1T_1 : 57

P_2T_1 : 84

P_1T_2 : 36

P_2T_2 : 61

TABLE 29

DISTRIBUTION OF ERRORS IN RELATION TO THE DEVELOPMENTAL HIERARCHY OF PHONEME EMERGENCE BASED ON RESPONSES BY 16 MULTIPLE SCLEROSIS SUBJECTS

Period of Acquisition	Age of Acquisition (years)	Phoneme Category	Error Rate	Average Error
Early	3-4	/m, n, f, p, k, b, g, d/	107	13.4
Late	4-7	/s, tʃ, t, θ, v, ð, z, dʒ/	131	16.4

TABLE 30

DISTRIBUTION OF ERRORS IN RELATION TO THE DEVELOPMENTAL HIERARCHY OF PHONEME EMERGENCE BASED ON RESPONSES BY 16 MULTIPLE SCLEROSIS SUBJECTS

Period of Acquisition	Age of Acquisition (years)	Phoneme Category	Error Rate	Average Error
Early	3-4	/m, n, f, p/	49	12.3
Late	4-7	/v, ð, z, dʒ/	87	21.6

TABLE 31

ONE-WAY FIXED EFFECTS (AGE OF ACQUISITION) ANALYSIS OF VARIANCE WITH REPEATED MEASURES FOR RESPONSE ELICITATION BY ONE GROUP OF MULTIPLE SCLEROSIS SUBJECTS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio	F-Probability
A (Age)	1	18.00	18.00	1.280	.276
Error (AS)	15	211.00	14.07		
S (Subjects)	15	514.88	34.33		
Total	31	743.88			

Note: AS - Age of Acquisition x Subjects.

TABLE 32

ONE-WAY FIXED EFFECTS (AGE OF ACQUISITION) ANALYSIS OF VARIANCE WITH REPEATED MEASURES FOR RESPONSE ELICITATION BY ONE GROUP OF MULTIPLE SCLEROSIS SUBJECTS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio	F-Probability
A (Age)	1	45.13	45.13	5.019	.041*
Error (AS)	15	134.88	8.99		
S (Subjects)	15	136.00	9.067		
Total	31	316.00			

* Significant at the .05 level of confidence.

Note: AS - Age of Acquisition x Subjects.

The error rate and average error for the 8 phonemes in each developmental period are also presented. A one-way fixed effects analysis of variance with repeated measures was computed to determine if there were any differences in the errors that occurred with respect to the developmental period. Table 31 indicates no significant difference between the 8 phonemes acquired early and the 8 phonemes acquired late. However, the average errors for the first 4 of the phonemes acquired early and the last 4 of the phonemes acquired late were computed (Table 30). A one-way fixed effects analysis of variance (Table 32) with repeated measures revealed a significant difference at the .05 level of confidence.

7. Is the distribution of misarticulations related to the acquisition hierarchy of distinctive features?

Table 33 represents age in years, acquired phonemes, and the present investigator's analysis of the acquisition hierarchy of distinctive features. It is well to keep in mind that only 16 consonants were selected for observation in the present study. Thus, the fricative /h/, all glides, and all semivowels not intended for distinctive feature analysis have been excluded from the present research question. Any interpretation of distinctive feature acquisitional patterns is limited since only a selected number of English consonants have been considered.

Table 33 was based on a combined Templin (1957) distinctive feature system and the Miller and Nicely (1955) distinctive feature system. According to the Templin (1957) phonemic acquisition data, the earliest age at which a phoneme could be considered acquired was three years. However, it is well established that "most phonological learning occurs in the first three years of life" (Berko and Brown, 1960, p. 526). It is therefore assumed that by age three, most children have acquired the contrasts of phonemes that contribute to differences in meaning. Table 33 shows that the phonemes /m/, /n/, /f/, /p/, /k/, /b/, /g/, and /d/ indicate the acquisition of the features nasality, labiality, voicing, and the feature front/back place of articulation. At age 4-7, the feature affrication, represented by /s/, /z/, /tʃ/, /dʒ/, /θ/, /ð/, and /v/, is added to a child's articulatory repertoire. In addition, the features duration (represented by /s/ and /z/), the feature middle/back place contrast (represented by /t/, /d/, /tʃ/, and /dʒ/), and the voiced/voiceless contrast (represented by /s/, /z/, /t/, /d/, /θ/, /ð/, /tʃ/, and /dʒ/) are acquired.

TABLE 33

DISTRIBUTION OF ERRORS IN RELATION TO THE ACQUISITION HIERARCHY OF DISTINCTIVE FEATURES BASED ON RESPONSES BY 16 MULTIPLE SCLEROSIS SUBJECTS

Period of Acquisition	Age of Acquisition (years)	Phoneme Category	Distinctive Features
Early	3-4	/m, n, f, p, k, b, g, d/	Nasality, Labiality, Voicing, Front/Back Place
Late	4-7	/s, tʃ, t, θ, v, ð, z, dʒ/	Affrication, Duration, Middle/Back Place, and Voicing

An overall examination of Table 33 reveals that the features nasality, front/back place contrast, and voicing are acquired earlier than the features affrication, duration, middle/back place contrast. Since the phonemes in the two periods of acquisition (early, late) share certain features in common, it cannot be ascertained that there is a tendency for articulatory breakdown to occur in one period versus another. It is difficult to determine feature acquisition from phonemic acquisition data not originally intended for distinctive feature analysis. One conclusion that can be drawn from Table 33 is that no obvious trend could be seen in the breakdown of articulation as a function of acquisition hierarchy of distinctive features. Further future research is recommended that might group phonemes with identical distinctive features with respect to acquisition hierarchy.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Multiple sclerosis is a neurological disease which leads to demyelination of afferent neural fibers. It is usually a diffuse, chronic, slowly progressive neurological disorder which affects predominantly the white matter of the central nervous system but may also involve the gray matter. Demyelination or destruction of the myelin sheath surrounding the nerve fiber causes complete interruption of nerve impulses, thus producing paralysis to parts of the body supplied by the nerve.

The cause of the disease is unknown, as is the explanation for the patchy distribution of plaques throughout the brain and spinal cord. Multiple sclerosis is dominated by episodes of "attacks." In certain attacks, the course can be of a very dramatic nature. The other side of the clinical picture, namely the quieter progression of the condition, usually escapes the attention of the patient and physician.

The symptoms of multiple sclerosis are similar to those caused by any localized lesion of the central nervous system. It is, however, the pattern of its behavior which renders multiple sclerosis unique among the organic disease of the nervous system. One of the unique features of the disease and one of major importance in diagnosis is the manner in which early symptoms tend to clear partially or completely, only to return on one or more occasions.

The pattern of occurrence suggests that it is very likely caused by a viral infection early in life. But no one has ever isolated a virus that, when injected in animals produces multiple sclerosis. In the past five years much more direct evidence has been obtained that associates the disease with a virus. Many investigators have found traces of the measles virus at different sites in the bodies of multiple sclerosis patients. Some of the results conflict with each other and some are controversial. Nonetheless, these findings promise that a firm identification of the causative agent of the disease may be made in the foreseeable future.

Multiple sclerosis characteristically affects the young adults between the ages of 20 and 45 years but occasionally starts in the late teens and less frequently in middle age. A peculiar feature of the disease is its predilection for persons living in temperate climates.

The plaques involving the cerebellum and its brain-stem connections cause a variety of cerebellar signs. Among these are the so-called Charcot triad of symptoms: nystagmus, intention tremor, and scanning speech.

The disease disrupts the normal processes of speech such as respiration, phonation, articulation, resonance, and prosody. It reduces or interferes with the kinesthetic feedback information necessary for delicate motor adjustments such as those involved in phonation. Muscles not receiving proper neural innervation are impaired and eventually, because of disuse, become weaker than the organic impairment justifies. The disuse atrophy can affect the musculatures used for speech.

Speech intelligibility is adversely compromised as the progress of the disease affects neural impairment to the muscles used for talking. When the muscles of articulation are involved because of cerebellar incoordination, ataxic dysarthria manifests itself in distortions and substitutions of speech sounds. In mild forms ataxic dysarthria begins as slurring of speech and the articulation of consonants become particularly difficult. A "scanning" or lalling type of speech has been described as typical of multiple sclerosis. The term "scanning" implies a tendency to accent every syllable of a word, giving a sing-song or scanning characteristic to speech. It is believed that scanning is attributable to poor control of rhythm, incoordination of palatal and labial muscles combined with dysarthria of central origin (West et al., 1968).

Literature on speech dysfunctions in multiple sclerosis reveals a dearth of clinically useful findings. Despite the fact that multiple sclerosis has been shown to have adverse effects on the processes of speech, little recognition has been given to multiple sclerosis in the speech pathology literature. More empirical data are needed to ascertain the specific deficits of speech in the disease. Thus, the primary purpose of the present investigation was:

1. to determine the effects of imitative and spontaneous methods of response elicitation on the speech production of patients with multiple sclerosis.

2. to determine the effects of the position of a phoneme on the articulatory responses of patients with multiple sclerosis.

A purposive sample of 16 patients with multiple sclerosis was selected for the present study. The sample consisted of 11 females and 5 males selected on the basis of meeting the criteria for the study.

Each subject had to pass a bilateral hearing screening test, exhibit two or more articulation errors on an articulation screening test, and speak General American English. Some of the patients resided in nursing homes and medical care facilities. The sample included patients with varying degrees of severity and duration of multiple sclerosis.

Since the primary purpose was to describe articulation problems in patients with multiple sclerosis at the phonological level, the present investigation was limited to analysis of the production of monosyllabic CVC words. Furthermore, since vowel differences were not one of the concerns of this study, it was assumed that slight differences in vowel articulation were not a significant source of variability in the data. Thus, a list of 64 meaningful English words was constructed. The list consisted of 16 consonants and two vowels. The rationale for using two vowels /o/ and /e/ was to eradicate the phonetic variability of vowels between speakers of the same language. Each consonant phoneme occurred two times in the initial position and two times in the final position. Responses were elicited from the subjects by employing two types of verbal tasks. In the imitative task the subjects were required to repeat recorded monosyllabic CVC words presented to them under earphones. In the spontaneous task the subjects were instructed to read aloud monosyllabic CVC words printed in one-half letters on a 4" x 6" white card.

The responses of each subject were tape-recorded at the time of the testing and were subsequently scored by six trained graduate speech pathology students at Michigan State University. There were 64 response events for each subject. Pooling the 16 subjects, a total of 1024 observations was obtained for the two types of verbal tasks. The initial imitative, initial spontaneous, final imitative, and final spontaneous utterances constituted the data for the analyses. A phonetic inventory and a distinctive feature inventory were employed to group the articulation errors in terms of some common attributes of each misarticulated sound.

Descriptive and inferential statistical procedures were employed in the analyses of the data. The results presented here are general. The findings of this study are presented in detail in Chapter Four. The descriptive statistical analyses provided interpretation of research questions designed:

1. to determine the difficulty that certain consonants pose in their production. Of the 16 consonants observed in this study, some were more difficult than others in the articulatory responses of multiple sclerosis subjects.

2. to determine the misarticulations that occurred in terms of their subphonemic features of place of articulation, manner of production and voicing. Although subphonemic feature errors have been treated as entities, they are by no means exclusive. Speech is a dynamic process, and it is possible that the misarticulations observed might have resulted from interrelationships among these subphonemic features. Gross analysis of substitution errors with respect to place, manner, and voicing characteristics showed errors to closely approximate target sounds.

3. to determine the patterns of distinctive feature errors. The findings revealed a tendency for the plus specification of a feature to be more vulnerable than the minus specification. This was obtained for the voicing and affrication features.

4. to determine the categories of articulation errors made by multiple sclerosis subjects. There was a predominance of errors of the

substitution type in the data.

Interpretation of the two-way fixed effects analysis of variance revealed that articulation errors were affected by the type of verbal task and the position of a sound in context. Both task and position showed significant main effects. There was no interaction between them.

Interpretation of two one-way fixed effects analyses of variance yielded the following results: the first one-way analysis of variance was used to determine the relationship between misarticulations and developmental hierarchy of phoneme emergence. A comparison between 8 phonemes which appear early and another 8 which appear late in a child's articulatory repertoire showed a nonsignificant difference in misarticulations as a function of phoneme developmental hierarchy. The second one-way fixed effects analysis of variance was used to determine the differences in errors that occurred in the first 4 phonemes which appear early and the last 4 phonemes which appear late in a child's articulatory repertoire. A significant difference was found at the .05 level of confidence. There were more articulation errors in the late-appearing sounds.

Finally, no clear-cut evidence was found to the effect that there is a relationship between breakdown in articulation by the multiple sclerosis group and acquisition hierarchy of distinctive features.

Conclusions

It is difficult to relate the findings of this study to the results of other studies primarily because of the dearth of literature on the subject. Nonetheless, the results obtained from the various research questions in this study lead to the following conclusions:

1. On the basis of the subphonemic feature analysis the consonants which posed the greatest difficulty in their production share certain features in common: they are fricatives; they are produced by vocal fold vibration; and they are produced in the anterior part of the oral cavity.

2. The 16 multiple sclerosis subjects did not demonstrate identical error tendencies. The wide range of difficulty in their error productions would imply that multiple sclerosis, as a disease process, manifests itself differently in the speech productions of different individuals.

3. With the multiple sclerosis subjects in this study, analysis of errors according to the subphonemic features cannot be attributed solely to place of articulation, manner of production, or voicing but to interrelationships among these three subphonemic features.

4. Tabulation of substitution errors as confusion matrices indicate that substituting phonemes are close approximations of target phonemes. In general, substituting phonemes are simplifications of target phonemes.

5. In general, there is an orderly pattern in the misarticulations of multiple sclerosis subjects. This would appear to be in agreement with the orderly pattern in misarticulations made by dysarthrics.

6. On the basis of the distinctive feature analysis, the features voicing and affrication demonstrate clearly the tenets of the markedness theory. No convincing evidence was found to the effect that the features place and nasality are inconsistent with the markedness theory.

7. The group of multiple sclerosis subjects is homogeneous with respect to the general categories of articulation errors made. The predominance of substitution errors lend support to this conclusion.

Although a careful segment of multiple sclerosis subjects was investigated in this study, the articulation errors observed can be said to be more representative of the speech productions of the multiple sclerosis population from which the segment was derived.

8. Articulation errors appeared to be more influenced by the imitative (recorded) method of stimulus presentation than the spontaneous method. The difficulty of responding to the imitative stimuli infers that recorded monosyllabic CVC words are difficult to discern in the absence of other contextual cues. Furthermore, the propagating medium (tape recorder and/or room characteristics) may cause distortion not present in the speech stimuli.

9. Although the position of a sound in context has different effects on different individuals, phonetic disintegration in multiple sclerosis is influenced more by the final position of a phoneme than the initial.

10. No convincing evidence was found to the effect that misarticulations are related to the developmental hierarchy of phoneme emergence.

11. The breakdown in articulation could not be inferred from the acquisition hierarchy of distinctive features.

Recommendations

On the basis of the findings of the present study, the investigator suggests the need for future research in the following areas:

1. An analysis of the articulatory behavior in spontaneous connected speech and isolated word responses of persons with multiple sclerosis to see whether there are large and real differences between words spoken in connected speech and the same words spoken as isolated

responses. Such a study would help determine the proportion of errors attributable to problems of coarticulation. The phonetic contexts which are observed in the traditional, word-oriented, two-position test are not representative of the phonetic contexts which occur in connected speech.

2. Several studies have suggested that error production increases as the length of utterance increases. Johns and Darley (1970), for example, found that errors increased as the number of syllables increased. Research is recommended on phonetic and phonemic analysis that reflects progressive difficulty to see whether articulation difficulty is best reflected in phonemic and phonetic complexity of words. For instance, the word list should reflect the following phonemic construction: CVC as in "cat"; CVCV as in "today"; CCVCC as in "sponge"; CVCCV as in "dancer".

3. To ascertain the effects of speech defects in multiple sclerosis, it would be necessary to observe and obtain speech samples from multiple sclerosis subjects over time. Given the characteristics of the disease with symptoms coming and going, it would be necessary to measure speech problems during relapses and speech problems during remissions.

4. Research should determine to what extent vowel articulation is preserved by the disease process of multiple sclerosis. Thus, a comparison of the effects of the disease on vowel articulation and consonant articulation is necessary. As many vowels as possible should be utilized with patients who share geographic and social environment so that vowel quality is not the main source of variability between speakers of the same language.

5. There is a need for research that would yield data concerning

identifiable subgroups of patients with articulatory dysfunctions. For instance, multiple sclerosis patients may be grouped into diagnostic categories according to the site of lesion in the central nervous system to see whether certain articulatory profiles emerge as a function of diagnostic categories. Such a study will have diagnostic and therapeutic values.

6. The acoustic difference between phonemes, for example, /f, θ/, /v, d/, is the most difficult for listeners to hear particularly in recorded stimuli. It seems that in most natural situations, the verbal context and the visual observation of the speaker's lips play an important part in distinguishing consonant pairs. Future research should employ the auditory-visual method of stimulus presentation (i.e., speech models from the visible experimenter) rather than the auditory stimuli (i.e., recorded speech stimuli). The use of live-modelling by the experimenter will mitigate the difficulties of determining phonemic productions.

7. The use of nonsense syllables or nonsense words as stimuli in a future research might rule out top-of-the-head effect (memory) due to meaningful syllables or words.

8. There is a need for a spectrographic analysis of the acoustic properties of speech sounds produced by multiple sclerosis subjects. This acoustic viewpoint should examine such properties as formant structure, fundamental frequency, duration, and intensity. Such a study may help the clinician to predict which changes in pitch, voice, intensity, and timing are needed to improve intelligibility.

9. Instrumental measurements of velopharyngeal closure competency or incompetency in multiple sclerosis should determine resonance deviations in patients with the disease.

10. Given that multiple sclerosis affects each patient differently, it is necessary to determine whether there is any idiosyncratic production of particular sounds in clusters and in polysyllables. The analysis should examine the speech productions from a phonetic and a distinctive feature viewpoint.

11. One of the limitations of this study relates to the small sample size. The use of only 16 subjects limits the conclusions that can be drawn. Further research should use a larger number of patients.

12. It would be of interest to explore potential articulatory compensatory techniques employed by multiple sclerosis subjects that could be integrated into therapy programs to increase speech intelligibility.

13. Research should determine how the incidence of phonetic errors varies according to age and sex of each patient. For example the categories of articulation errors (i.e., substitutions, omissions, and distortions) could be examined to see whether these errors occur in differential proportions as a function of age and sex.

14. Further research should determine whether the breakdown in articulation could be inferred from the acquisition hierarchy of distinctive features. The study might group phonemes with identical distinctive features to see whether there is a definite pattern in the breakdown of articulation with respect to distinctive feature acquisition hierarchy.

15. Given the odd audiogram configurations of some multiple sclerosis patients reported in the literature, an analysis of phonetic errors based on such factors as those stemming from auditory processing problems is necessary.

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APPENDICES

APPENDIX A

CASE HISTORY INFORMATION

CASE HISTORY INFORMATION

1. Name____

2. Date of Birth____________ Age______________ Sex_____________

3. Address____________________________________ Phone___________

4. Patient's Educational Level___________________________________

5. Date of Illness______________________ Medication_____________

6. Does the patient have any history of neurological disease other than multiple sclerosis?________________________________

7. Does the patient have any premorbid psychological problems?

____

8. Is the patient senile?_______________________________________

9. Does the patient have any history of cerebrovascular disease?

____

10. Interview notes____

APPENDIX B

ARTICULATION SCREENING TEST

THE FISHER-LOGEMANN TEST OF ARTICULATION COMPETENCE SENTENCE ARTICULATION TEST

1. PETE'S JOB WAS TO KEEP THE BABY HAPPY.
2. TODAY DICK TOLD PATTY ABOUT IT.
3. THE GIRLS WERE BAKING THE BIGGEST CAKE FOR MR. TAG.
4. THEIR BROTHER WOULDN'T BATHE BECAUSE HE THOUGHT A BATH WOULD MAKE HIS TOOTHACHE WORSE.
5. IN HALF A DAY, HE REPAIRED FIVE TELEVISION SETS, TWO TELEPHONES, AND A VERY OLD STOVE.
6. SUZIE SEWED ZIPPERS ON TWO NEW DRESSES AT BESSIE'S HOUSE.
7. SHE USUALLY RUSHES TO PUSH THE GARAGE DOOR CLOSED.
8. GEORGE IS AT THE CHURCH WATCHING A MAGIC SHOW.
9. WE RODE WITH LUCY AROUND THE TALL TOWER IN HER NEW YELLOW CAR.
10. WHY HAVEN'T YOU LOOKED ANYWHERE BEHIND THE HOUSE OR BEYOND THE HILL YET?
11. NANCY FOUND SOME FINE HANGERS AMONG THE MANY THINGS AT THE SALE.
12. LET ME KEEP A LITTLE OF THIS WEDDING CAKE TO EAT LATER.
13. FATHER ASKED HOW MUCH MONEY TOM HAD SAVED TO BUY A BIRD CAGE.
14. RUTH CAUGHT A COLD BECAUSE SHE WOULDN'T WEAR HER NEW WARM WOOL COAT.
15. I FOUND A HUGE TOY MUSIC BOX OUTSIDE ROY'S HOUSE.

APPENDIX C

MONOSYLLABIC CVC WORD LISTS USED FOR THE TWO TYPES OF VERBAL TASKS

32 MONOSYLLABIC CVC WORD LIST FOR THE IMITATIVE TASK

	INITIAL POSITION		FINAL POSITION
1.	/p/	POKE	MOPE
2.	/b/	BONE	ROBE
3.	/t/	TALE	BAIT
4.	/d/	DATE	FADE
5.	/k/	COPE	SOAK
6.	/g/	GAZE	ROGUE
7.	/tʃ/	CHOKE	COACH
8.	/dʒ/	JADE	PAGE
9.	/f/	FAKE	LOAF
10.	/v/	VAGUE	SHAVE
11.	/θ/	THOUGHT	BOTH
12.	/ð/	THOSE	BATHE
13.	/s/	SOAK	CASE
14.	/z/	ZONE	DOZE
15.	/m/	MOAN	CAME
16.	/n/	NAME	TONE

32 MONOSYLLABIC CVC WORD LIST FOR THE SPONTANEOUS TASK

INITIAL POSITION			FINAL POSITION
1.	/p/	POLE	SOAP
2.	/b/	BAIL	GABE
3.	/t/	TAKE	FATE
4.	/d/	DOME	LOAD
5.	/k/	CAPE	RAKE
6.	/g/	GATE	VOGUE
7.	/tʃ/	CHAIN	POACH
8.	/dʒ/	JOKE	CAGE
9.	/f/	FOAM	SAFE
10.	/v/	VEIL	CAVE
11.	/θ/	THUD	FAITH
12.	/ð/	THEM	LOATHE
13.	/s/	SAKE	FACE
14.	/z/	ZIP	HOSE
15.	/m/	MANE	DAME
16.	/n/	NOSE	CAIN

APPENDIX D

SCORE FORM FOR MONOSYLLABIC CVC WORD LIST

SCORE FORM FOR MONOSYLLABIC CVC WORD LIST

IMITATIVE	POSITION	NO ERROR	SUBST.	OMISS.	DISTORT	OTHER	SPONTANEOUS
POKE	INIT.						POLE
DOZE	FINAL						HOSE
TONE	FINAL						CAIN
ZONE	INIT.						ZIP
GAZE	INIT.						GATE
VAGUE	INIT.						VEIL
MOPE	FINAL						SOAP
COPE	INIT.						CAPE
BOTH	FINAL						FAITH
DATE	INIT.						DOME
FAKE	INIT.						FOAM
NAME	INIT.						NOSE
LOAF	FINAL						SAFE
THOSE	INIT.						THEM
TALE	INIT.						TAKE
ROBE	FINAL						GABE
ROGUE	FINAL						VOGUE
BAIT	FINAL						FATE
CASE	FINAL						FACE
BATHE	FINAL						LOATHE
JADE	INIT.						JOKE
SOLE	INIT.						SAKE
SOAK	FINAL						RAKE
MOAN	INIT.						MANE
PAGE	FINAL						CAGE
CAME	FINAL						DAME
CHOKE	INIT.						CHAIN
FADE	FINAL						LOAD
THOUGHT	INIT.						THUD
BONE	INIT.						BAIL
COACH	FINAL						POACH
SHAVE	FINAL						CAVE

APPENDIX E

INSTRUCTIONS USED FOR THE IMITATIVE AND SPONTANEOUS TASKS

IMITATIVE TASK

YOU SHALL HEAR SEVERAL WORDS SPOKEN BY A MAN. PLEASE REPEAT THE WORDS THAT YOU HEAR. DO NOT TRY TO IMITATE HIS VOICE OR PRONUNCIATION: ONLY REPEAT THE WORDS THAT HE SAYS.

SPONTANEOUS TASK

I AM GOING TO SHOW YOU A SERIES OF WORDS. PLEASE SAY THE WORDS ALOUD ONE BY ONE AS I SHOW THEM TO YOU.

APPENDIX F

CONFUSION MATRICES OF RESPONSES ON 16 SINGLETON CONSONANTS MADE BY MULTIPLE SCLEROSIS SUBJECTS

Initial and Final Consonants Produced (Response)

Initial and Final Consonants Presented	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	49	1	1		9	1											12	3	0	15
b	6	45		1		3				1				1	3		15	4	0	19
t			55	1				1									2	7	0	9
d		2	4	50		1						1	2				10	2	2	14
k	1				57	3											4	2	1	7
g		1	1	3	2	46											7	5	6	18
tʃ			2				53	1									3	0	8	11
dʒ				1			10	52									11	0	1	12
f	2	1							49	2	4		1				10	3	2	15
v	1	12							5	42					2		20	2	0	22
θ		1	5	1	1						48	2	2				12	3	1	16
ð				7					2	2	14	36				2	27	1	0	28
s					1			1	1		1		56				4	0	4	8
z				2									20	39			22	0	3	25
m	1	3													51	8	12	1	0	13
n	1														2	58	3	1	2	6
Total	12	21	13	16	13	8	10	3	8	5	19	3	25	1	7	10	174	34	30	238

Figure 8. Confusion matrix of responses on 16 consonents by 16 multiple sclerosis subjects (Initial and Final Positions Combined).

Initial Consonants Produced (Response)

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	26	1			5												6	0	0	6
b		29		1										1			2	1	0	3
t			32														0	0	0	0
d		2	3	24		1											6	0	2	8
k					29	3											3	0	0	3
g				2	1	27											3	0	2	5
tʃ			1				25	1									2	0	5	7
dʒ							4	28									4	0	0	4
f	2	1							21	2	3		1				9	0	2	11
v	1	6							2	22					1		10	0	0	10
θ		1			1						25		2				4	2	1	7
ð				4							5	21				2	11	0	0	11
s									1				29				1	0	2	3
z				2									5	24			7	0	1	8
m	1														27	3	4	1	0	5
n	1														1	30	2	0	0	2
Total	5	11	4	9	7	4	4	1	3	2	8	0	8	1	2	5	74	4	15	93

Figure 9. Confusion matrix of responses on 16 consonants by 16 multiple sclerosis subjects (Initial Position Only).

Final Consonants Produced (Response)

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	23		1		4	1											6	3	0	9
b	6	16				3				1					3		13	3	0	16
t			23	1				1									2	7	0	9
d			1	26								1	2				4	2	0	6
k	1				28												1	2	1	4
g		1	1	1	1	19											4	5	4	13
tʃ			1				28										1	0	3	4
dʒ				1			6	24									7	0	1	8
f									28		1						1	3	0	4
v		6							3	20					1		10	2	0	12
θ			5	1							23	2					8	1	0	9
ð				3					2	2	9	15					16	1	0	17
s					1			1			1		27				3	0	2	5
z													15	15			15	0	2	17
m		3													24	5	8	0	0	8
n															1	28	1	1	2	4
Total	7	10	9	7	6	4	6	2	5	3	11	3	17	0	5	5	100	30	15	145

Figure 10. Confusion matrix of responses on 16 singleton consonants by 16 multiple sclerosis subjects (Final Position Only).

Consonants Produced (Response) Imitative Task

Consonants Presented (Imitative Task)

	p	b	t	d	k	g	tʃ	dʒ	ʃ	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	19		1		9	1											11	2	0	13
b	3	20		1		3				1				1	1		10	2	0	12
t			27					1									1	4	0	5
d		1	2	24		1							2				6	0	2	8
k	1				27	2											3	2	0	5
g		1	1	2	1	21											5	2	4	11
tʃ			1				26										1	0	5	6
dʒ				1			6	24									7	0	1	8
ʃ									23		4		1				5	2	2	9
v		3							4	23					1		8	1	0	9
θ			5		1						22		1				7	3	0	10
ð				7					1	1	4	18				1	14	0	0	14
s					1			1					28				2	0	2	4
z				2									11	17			13	0	2	15
m		2													26	3	5	1	0	6
n	1														2	26	3	1	2	6
Total	5	7	10	13	12	7	6	2	5	2	8	0	15	1	4	4	101	20	20	141

Figure 11. Confusion matrix of responses on 16 consonants by 16 multiple sclerosis subjects (Imitative Task)

Consonants Produced (Response) Spontaneous Task

Consonants Presented (Spontaneous Task)

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	30	1															1	1	0	2
b	3	25													2		5	2	0	7
t			28	1													1	3	0	4
d		1	2	26								1					4	2	0	6
k					30	1											1	0	1	2
g				1	1	25											2	3	2	7
tʃ			1				27	1									2	0	3	5
dʒ							4	28									4	0	0	4
f	2	1							26	2							5	1	0	6
v	1	9							1	19					1		12	1	0	13
θ		1		1							26	2	1				5	0	1	6
ð									1	1	10	18				1	13	1	0	14
s									1		1		28				2	0	2	4
z													9	22			9	0	1	10
m	1	1													25	5	7	0	0	7
n																32	0	0	0	0
Total	7	14	3	3	1	1	4	1	3	3	11	3	10	0	3	6	73	14	10	97

Figure 12. Confusion matrix of responses on 16 consonants by 16 multiple sclerosis subjects (Spontaneous Task).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		2															0	0	0	0
t			2														0	0	0	0
d			2	0													2	0	0	2
k					2												0	0	0	0
g					1	0											1	0	1	2
tʃ							0										0	0	2	2
dʒ							2	0									2	0	0	2
f									2								0	0	0	0
v									1	1							1	0	0	1
θ											1		1				1	0	0	1
ð											2	0					2	0	0	2
s													0				0	0	2	2
z													2	0			2	0	0	2
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	0	2	0	1	0	2	0	1	0	2	0	3	0	0	0	11	0	5	16

Figure 13. Confusion matrix of responses on 16 consonants by subject G.T. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b	1	0															1	1	0	2
t			1														0	1	0	1
d				2													0	0	0	0
k					2												0	0	0	0
g						0											0	2	0	2
tʃ							2										0	0	0	0
dʒ							2	0									2	0	0	2
f									2								0	0	0	0
v										2							0	0	0	0
θ				1							1						1	0	0	1
ð									2			0					2	0	0	2
s													0				0	0	2	2
z														0			0	0	2	2
m															1	1	1	0	0	1
n																1	0	0	1	1
Total	1	0	0	1	0	0	2	0	2	0	0	0	0	0	0	1	7	4	5	16

Figure 14. Confusion matrix of responses on 16 consonants by subject G.T. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	1				1												1	0	0	1
b		1												1			1	0	0	1
t			2														0	0	0	0
d				1		1											1	0	0	1
k					1	1											1	0	0	1
g						2											0	0	0	0
tʃ							0										0	0	2	2
dʒ								2									0	0	0	0
f									1								0	0	1	1
v										2							0	0	0	0
θ											2						0	0	0	0
ð												1				1	1	0	0	1
s													2				0	0	0	0
z														2			0	0	0	0
m															0	1	1	1	0	2
n																2	0	0	0	0
Total	0	0	0	0	1	2	0	0	0	0	0	0	0	1	0	2	6	1	3	10

Figure 15. Confusion matrix of responses on 16 consonants by subject D.M. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	1		1														1	0	0	1
b		1								1							1	0	0	1
t			0	1													1	1	0	2
d				2													0	0	0	0
k					2												0	0	0	0
g						0											0	0	2	2
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v									1	1							1	0	0	1
θ			1								1						1	0	0	1
ð												1					0	1	0	1
s													2				0	0	0	0
z													2	0			2	0	0	2
m		2													0		2	0	0	2
n																1	0	1	0	1
Total	0	2	2	1	0	0	0	0	1	1	0	0	2	0	0	0	9	3	2	14

Figure 16. Confusion matrix of responses on 16 consonants by subject D.M. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		2															0	0	0	0
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g				1		1											1	0	0	1
tʃ							0	1									1	0	1	2
dʒ								2									0	0	0	0
f									0	1							1	0	1	2
v		1							1	0							2	0	0	2
θ											1						0	1	0	1
ð				1							1	0					2	0	0	2
s													2				0	0	0	0
z														2			0	0	0	0
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	1	0	2	0	0	0	1	1	1	1	0	0	0	0	0	7	1	2	10

Figure 17. Confusion matrix of responses on 16 consonants by subject D.M. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	1					1											1	0	0	1
b		1															0	1	0	1
t			1					1									1	0	0	1
d				2													0	0	0	0
k					2												0	0	0	0
g		1				0											1	1	0	2
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									1								0	1	0	1
v		1								0							1	1	0	2
θ											1						0	1	0	1
ð											2	0					2	0	0	2
s								1					1				1	0	0	1
z													2	0			2	0	0	2
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	2	0	0	0	1	0	2	0	0	2	0	2	0	0	0	9	5	0	14

Figure 18. Confusion matrix of responses on 16 consonants by subject D.M. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	1				1												1	0	0	1
b		1		1													1	0	0	1
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									1	1							1	0	0	1
v										1					1		1	0	0	1
θ		1									1						1	0	0	1
ð												2					0	0	0	0
s													2				0	0	0	0
z				1										1			1	0	0	1
m															1	1	1	0	0	1
n																2	0	0	0	0
Total	0	1	0	2	1	0	0	0	0	1	0	0	0	0	1	1	7	0	0	7

Figure 19. Confusion matrix of responses on 16 consonants by subject J.M. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	1																0	1	0	1
b		0													2		2	0	0	2
t			2														0	0	0	0
d				1													0	1	0	1
k					0												0	1	1	2
g						0											0	0	2	2
tʃ			1				0										1	0	1	2
dʒ								2									0	0	0	0
f									2								0	0	0	0
v		1							1	0							2	0	0	2
θ											2						0	0	0	0
ð											2	0					2	0	0	2
s													2				0	0	0	0
z														2			0	0	0	0
m		1													0	1	2	0	0	2
n																2	0	0	0	0
Total	0	2	1	0	0	0	0	0	1	0	2	0	0	0	2	1	9	3	4	16

Figure 20. Confusion matrix of responses on 16 consonants by subject J.M. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		2															0	0	0	0
t			2														0	0	0	0
d			1	1													1	0	0	1
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f	1								0		1						2	0	0	2
v	1	1								0							2	0	0	2
θ					1						1						1	0	0	1
ð												2					0	0	0	0
s													2				0	0	0	0
z														2			0	0	0	0
m	1														1		1	0	0	1
n	1															1	1	0	0	1
Total	4	1	1	0	1	0	0	0	0	0	1	0	0	0	0	0	8	0	0	8

Figure 21. Confusion matrix of responses on 16 consonants by subject J.S. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b	1	1															1	0	0	1
t			1														0	1	0	1
d				2													0	0	0	0
k					1												0	1	0	1
g			1			1											1	0	0	1
tʃ							2										0	0	0	0
dʒ				1				1									1	0	0	1
f									1		1						1	0	0	1
v		1								1							1	0	0	1
θ			1								1						1	0	0	1
ð												2					0	0	0	0
s					1								1				1	0	0	1
z														2			0	0	0	0
m															0	2	2	0	0	2
n															1	1	1	0	0	1
Total	1	1	2	1	1	0	0	0	0	0	1	0	0	0	1	2	10	2	0	12

Figure 22. Confusion matrix of responses on 16 consonants by subject J.S. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		1															0	1	0	1
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ							1	1									1	0	0	1
f		1							1								1	0	0	1
v		1								1							1	0	0	1
θ											2						0	0	0	0
ð												1				1	1	0	0	1
s									1				1				1	0	0	1
z													2	0			2	0	0	2
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	2	0	0	0	0	1	0	1	0	0	0	2	0	0	1	7	1	0	8

Figure 23. Confusion matrix of responses on 16 consonants by subject K.B. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b	1	1															1	0	0	1
t			1														0	1	0	1
d				2													0	0	0	0
k					2												0	0	0	0
g						1											0	1	0	1
tʃ							2										0	0	0	0
dʒ							2	0									2	0	0	2
f									2								0	0	0	0
v		1							1	0							2	0	0	2
θ											2						0	0	0	0
ð												2					0	0	0	0
s											1		1				1	0	0	1
z													2	0			2	0	0	2
m															2		0	0	0	0
n																1	0	0	1	1
Total	1	1	0	0	0	0	2	0	1	0	1	0	2	0	0	0	8	2	1	11

Figure 24. Confusion matrix of responses on 16 consonants by subject K.B. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		2															0	0	0	0
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v										2							0	0	0	0
θ											2						0	0	0	0
ð				1								1					1	0	0	1
s													2				0	0	0	0
z														2			0	0	0	0
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1

Figure 25. Confusion matrix of responses on 16 consonants by subject B.M. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		0				1											1	1	0	2
t			2														0	0	0	0
d				1								1					1	0	0	1
k					2												0	0	0	0
g					1	0											1	1	0	2
tʃ							0										0	0	2	2
dʒ							1	0									1	0	1	2
f									0								0	2	0	2
v		1								0							1	1	0	2
θ											2						0	0	0	0
ð											1	1					1	0	0	1
s													2				0	0	0	0
z													2	0			2	0	0	2
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	1	0	0	1	1	1	0	0	0	1	1	2	0	0	0	8	5	3	16

Figure 26. Confusion matrix of responses on 16 consonants by subject B.M. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	1				1												1	0	0	1
b		2															0	0	0	0
t			2														0	0	0	0
d				1													0	0	1	1
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ							1	1									1	0	0	1
f									1		1						1	0	0	1
v										2							0	0	0	0
θ											1						0	1	0	1
ð												2					0	0	0	0
s													2				0	0	0	0
z														2			0	0	0	0
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	3	1	1	5

Figure 27. Confusion matrix of responses on 16 consonants by subject V.M. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	1				1												1	0	0	1
b		1				1											1	0	0	1
t			1														0	1	0	1
d				1									1				1	0	0	1
k					2												0	0	0	0
g				1		1											1	0	0	1
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v										2							0	0	0	0
θ			1								1						1	0	0	1
ð				1						1		0					2	0	0	2
s													2				0	0	0	0
z													2	0			2	0	0	2
m															1	1	1	0	0	1
n																2	0	0	0	0
Total	0	0	1	2	1	1	0	0	0	1	0	0	3	0	0	1	10	1	0	11

Figure 28. Confusion matrix of responses on 16 consonants by subject V.M. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		2															0	0	0	0
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									1				1				1	0	0	1
v										2							0	0	0	0
θ											2						0	0	0	0
ð											2	0					2	0	0	2
s													2				0	0	0	0
z														2			0	0	0	0
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	3	0	0	3

Figure 29. Confusion matrix of responses on 16 consonants by subject S.L. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	0																0	2	0	2
b	1	1															1	0	0	1
t			0														0	2	0	2
d				1													0	1	0	1
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v										2							0	0	0	0
θ											1	1					1	0	0	1
ð										1		1					1	0	0	1
s													2				0	0	0	0
z													1	1			1	0	0	1
m															2		0	0	0	0
n																2	0	0	0	0
Total	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	4	5	0	9

Figure 30. Confusion matrix of responses on 16 consonants by subject S.L. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	0	1			1												2	0	0	2
b		2															0	0	0	0
t			2														0	0	0	0
d		2		0													2	0	0	2
k					1	1											1	0	0	1
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v										2							0	0	0	0
θ											1						0	0	1	1
ð												2					0	0	0	0
s													2				0	0	0	0
z														2			0	0	0	0
m															1	1	1	0	0	1
n																2	0	0	0	0
Total	0	3	0	0	1	1	0	0	0	0	0	0	0	0	0	1	6	0	1	7

Figure 31. Confusion matrix of responses on 16 consonants by subject J.J. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	1				1												1	0	0	1
b		2															0	0	0	0
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ							1	1									1	0	0	1
f									2								0	0	0	0
v										2							0	0	0	0
θ											2						0	0	0	0
ð											1	1					1	0	0	1
s													2				0	0	0	0
z														2			0	0	0	0
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	3	0	0	3

Figure 32. Confusion matrix of responses on 16 consonants by subject J.J. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		2															0	0	0	0
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g						2											0	0	0	0
tʃ			1				1										1	0	0	1
dʒ								2									0	0	0	0
f	1								1								1	0	0	1
v										2							0	0	0	0
θ											2						0	0	0	0
ð				1								1					1	0	0	1
s													2				0	0	0	0
z														1			0	0	1	1
m															2		0	0	0	0
n																2	0	0	0	0
Total	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	4

Figure 33. Confusion matrix of responses on 16 consonants by subject E.P. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	1				1												1	0	0	1
b		1				1											1	0	0	1
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v		1								1							1	0	0	1
θ			1								1						1	0	0	1
ð				1							1	0					2	0	0	2
s													2				0	0	0	0
z														2			0	0	0	0
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	1	1	1	1	1	0	0	0	0	1	0	0	0	0	0	6	0	0	6

Figure 34. Confusion matrix of responses on 16 consonants by subject E.P. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		2															0	0	0	0
t			2														0	0	0	0
d				1													0	0	1	1
k					1	1											1	0	0	1
g						1											0	0	1	1
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									1		1						1	0	0	1
v										2							0	0	0	0
θ											2						0	0	0	0
ð												2					0	0	0	0
s													2				0	0	0	0
z														2			0	0	0	0
m															2		0	0	0	0
n															1	1	1	0	0	1
Total	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	3	0	2	5

Figure 35. Confusion matrix of responses on 16 consonants by subject J.E. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	1				1												1	0	0	1
b		1													1		1	0	0	1
t			2														0	0	0	0
d				1									1				1	0	0	1
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v										2							0	0	0	0
θ											1	1					1	0	0	1
ð											1	1					1	0	0	1
s													2				0	0	0	0
z														2			0	0	0	0
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	0	0	0	1	0	0	0	0	0	1	1	1	0	1	0	5	0	0	5

Figure 36. Confusion matrix of responses on 16 consonants by subject J.E. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		2															0	0	0	0
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v		1								1							1	0	0	1
θ											2						0	0	0	0
ð												2					0	0	0	0
s													2				0	0	0	0
z				1										1			1	0	0	1
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2

Figure 37. Confusion matrix of responses on 16 consonants by subject D.H. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b	1	1															1	0	0	1
t			2														0	0	0	0
d			1	1													1	0	0	1
k	1				1												1	0	0	1
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v										2							0	0	0	0
θ											2						0	0	0	0
ð												2					0	0	0	0
s													2				0	0	0	0
z													2	0			2	0	0	2
m															2		0	0	0	0
n																2	0	0	0	0
Total	2	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	5	0	0	5

Figure 38. Confusion matrix of responses on 16 consonants by subject D.H. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		2															0	0	0	0
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v										2							0	0	0	0
θ											1		1				1	0	0	1
ð												2					0	0	0	0
s													2				0	0	0	0
z													1	1			1	0	0	1
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	0	2

Figure 39. Confusion matrix of responses on 16 consonants by subject P.G. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		2															0	0	0	0
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v										2							0	0	0	0
θ											2						0	0	0	0
ð				1								1					1	0	0	1
s													2				0	0	0	0
z													2	0			2	0	0	2
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	3	0	0	3

Figure 40. Confusion matrix of responses on 16 consonants by subject P.G. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		2															0	0	0	0
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g				1		1											1	0	0	1
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v		1								1							1	0	0	1
θ											2						0	0	0	0
ð												2					0	0	0	0
s													2				0	0	0	0
z														2			0	0	0	0
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2

Figure 41. Confusion matrix of responses on 16 consonants by subject C.M. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b	1	1															1	0	0	1
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v										1					1		1	0	0	1
θ											2						0	0	0	0
ð											1	1					1	0	0	1
s													2				0	0	0	0
z														2			0	0	0	0
m															2		0	0	0	0
n																2	0	0	0	0
Total	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	3	0	0	3

Figure 42. Confusion matrix of responses on 16 consonants by subject C.M. (Final Position Only).

Initial Consonants Produced

Initial Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	1				1												1	0	0	1
b		2															0	0	0	0
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v		1								1							1	0	0	1
θ											2						0	0	0	0
ð				1								1					1	0	0	1
s													2				0	0	0	0
z														2			0	0	0	0
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3

Figure 43. Confusion matrix of responses on 16 consonants by subject C.B. (Initial Position Only).

Final Consonants Produced

Final Consonants Presented

	p	b	t	d	k	g	tʃ	dʒ	f	v	θ	ð	s	z	m	n	Sub.	Omis.	Other Sub.	Total
p	2																0	0	0	0
b		2															0	0	0	0
t			2														0	0	0	0
d				2													0	0	0	0
k					2												0	0	0	0
g						2											0	0	0	0
tʃ							2										0	0	0	0
dʒ								2									0	0	0	0
f									2								0	0	0	0
v										2							0	0	0	0
θ			1								1						1	0	0	1
ð												2					0	0	0	0
s													2				0	0	0	0
z														2			0	0	0	0
m															2		0	0	0	0
n																2	0	0	0	0
Total	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1

Figure 44. Confusion matrix of responses on 16 consonants by subject C.B. (Final Position Only).