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MOTOR SPEECH ADAPTATION: AN ACOUSTIC STUDY OF TEMPORAL AND SPECTRAL RESPONSE PATTERNS IN SUBJECTS WITH FOCAL, CORTICAL LESIONS

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MOTOR SPEECH ADAPTATION: AN ACOUSTIC STUDY OF TEMPORAL AND SPECTRAL RESPONSE PATTERNS IN SUBJECTS WITH FOCAL, CORTICAL LESIONS

by

EMILY A. TOBEY

A dissertation submitted to the Graduate Faculty in
Speech and Hearing Sciences in partial fulfillment
of the requirements for the degree of Doctor of
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1981

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The City University of New York

Abstract

MOTOR SPEECH ADAPTATION: AN ACOUSTIC STUDY OF TEMPORAL AND SPECTRAL RESPONSE PATTERNS IN SUBJECTS WITH FOCAL, CORTICAL LESIONS

by

Emily A. Tobey

Adviser: Professor Katherine S. Harris

Studies reported here explore the speech-production skills of a group of American veterans who sustained focal, cortical lesions to the right or left hemisphere during the Vietnam confrontation. Temporal and spectral characteristics of speech production were examined under two speaking conditions: a normal, or control, condition and an experimental condition which used an appliance to restrict mandibular participation during speech. The purpose of the study was twofold: first, to provide a quantitative analysis of the similarities and differences in temporal and spectral characteristics of speech following a circumscribed lesion to either the right or left hemisphere; and second, to investigate the strategies available to speakers with cortical lesions to adjust, or accomodate, to changes in peripheral, oral-structure relationships. Analyses of temporal and spectral characteristics of speech in these two conditions provided quantitative information related to structure-function questions commonly addressed in the clinical literature regarding speech disorders in cortically injured patients.

Comparable formant frequency and duration values are not produced by Control subjects in normal and restricted-jaw speaking. Control subjects produce slightly higher F_1 and significantly lower F_2-F_3 frequencies during restricted-jaw conditions. Moreover, Control subjects use a temporal strategy of generalized slowing of articulation to assist in optomizing their response to abnormal peripheral conditions. Data from Control subjects suggest the motor speech system uses a range of articulator positions to produce contextual speech under normal and abnormal peripheral conditions. Temporal relationships of gestures are retained by Control subjects during abnormal peripheral conditions suggesting gesture timing may be inherent to phonological representations.

Cortically injured subjects use a slightly different set or range of articulator positions to adjust area/length relationships in the vocal tract than Control subjects, regardless if speaking is under normal or restricted-jaw conditions. Frequency and duration response patterns during restricted-jaw speaking suggest motor-speech systems of cortically injured speakers are less flexible and more heavily influenced by contextual frameworks. Taken overall, frequency- and duration-response patterns indicate cortically injured speakers have difficulty integrating spatio-temporal information underlying articulatory maneuvers during normal- and abnormal-peripheral conditions.

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And, to Shawn Kilcrest-Norris who said it all two years ago, "...I want you to know I don't do windows."

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CHAPTER I

INTRODUCTION

Studies reported here explore the speech-production characteristics of a group of American veterans who sustained focal cortical lesions to the right or left hemisphere during the Vietnam confrontation. Temporal and spectral characteristics of speech production were examined in two speaking conditions: a normal, or control, condition and an experimental condition which used an appliance to restrict mandibular participation during speech. The purpose of the study was twofold: first, to provide a quantitative analysis of the similarities and differences in temporal and spectral characteristics of speech following a lesion to the right or left hemisphere; and second, to investigate the strategies used by speakers with cortical lesions to adjust (or accommodate) to changes in peripheral, oral-structure relationships. Analyses of the temporal and spectral characteristics of speech in these two conditions provide quantitative information related to structure-function questions regarding speech disorders in cortically injured patients.

Typically, structure-function questions are addressed by techniques which analyze the speech errors produced by cortically injured subjects. Normal structure-function relationships are determined from erroneous productions by correlating the site-of-lesion to the presumed abberant function creating the errors. Often these studies are limited to examining phonological or phonetic errors without examining the possible abberant functions underlying the errors. Similarly, patients with cortical lesions produce many error-free utterances, however, these error-free utterances are usually judged by casual perceptual methods and are not studied in acoustic detail. It is not clear if functional limitations of the motor-speech system produced by cortical lesions also are reflected in these error-free productions.

As a first step, it seems reasonable to hypothesize speech-production errors following cortical lesions may reflect restrictions, or limitations, to the characteristic flexibility and adaptability used by the motor-speech system to generate error-free productions. One method of exploring the adaptability of the motor-speech system is to introduce a peripheral disturbance and examine strategies used to circumvent (or adapt to) the experimentally induced disturbance. Speakers without cortical lesions quickly adjust articulatory strategies to produce error-free productions during experimentally induced disruptions to peripheral structures. Careful acoustic measurements of the speech patterns generated under these conditions provide qualitative information about the strategies used by the system to adapt the shape of the vocal tract and the positioning of the jaw and tongue to accommodate the peripheral disruption. Examination of acoustic patterns generated by subjects with lesions in response to peripheral disturbances may provide an estimate of the limitations of the motor-speech system resulting from cortical damage.

Some Approaches to the Assessment of Normal Speech-Motor Function

Investigations of motor-speech capabilities in normal speakers often examine the time frames imposed upon normal gesture control, the temporal organization of articulatory patterns, and the coordination of the series of movements occurring in different parts of the vocal tract. Many studies [see, for example, MacNeilage (1970)] suggest the complex sensori-motor system of normal speakers apparently recognizes where a structure in the vocal tract is at a given point in time and where the structure must move to appropriately complete the articulatory gesture. For example, the velocity of jaw closure for bilabial-consonant production varies directly with the distance needed to acquire closure (Kozhevnikov and Chistovich, 1965; Ohala, Hiki, Hubler, and Harshman, 1968; Sussman, MacNeilage, and Hanson, 1973); velocities are greater if the jaw is in a more open position as contrasted to a closed consonant prior to consonant production than one closely approximating consonant production. Acoustic analyses of such productions reveal transition durations associated with jaw closure are comparable whether the jaw is required to travel a long or short distance. Relatively stable transition times noted acoustically suggest the normal motor-speech system allocates a particular time-frame in which to execute a gesture, regardless of the distance-of-travel involved in completing the gesture.

Several experimental techniques are used to tax the capabilities of the motor-speech system in normal speakers to determine how organization and coordination of articulatory gestures occur. In a general form, these techniques disturb the speaking act by interrupting the normal course of gesture execution or restricting the participation of a particular articulator. Examination of the articulatory patterns generated by the system in response to this type of disruption assists in determining the factors which contribute to the coordination of spatial and temporal control in speech acts.

Interruption to normal speaking is one approach used to determine the dimensions of control contributing to speech production and is accomplished via a number of tactics (some more pleasant than others). One of the earliest tactics used to interrupt normal speaking consists of delivering unexpected blows to the abdominal area (Stetson, 1951); fortunately, less violent techniques are currently used. In more recent studies, a tooth splint is sometimes used to deliver resistive loads to the jaw and, thus, interrupts normal closing gestures associated with consonant production (Folkins and Abbs, 1975, 1976). In this paradigm, subjects complete consonant closing gestures by adjusting upper and lower lip movements in direct proportion to the load-induced resistance applied by the tooth splint to the jaw. An alternative approach is represented by electrical stimulation of the lower lip. Significant changes in displacement of the jaw and upper lip occur during closure gestures under such stimulus conditions (Folkins and Zimmerman, 1979); that is, larger compensatory movements of the jaw and upper lip are observed when electrical stimulation is applied to the lower lip during utterances requiring relatively large jaw excursions.

Alterations to jaw, upper, and lower lip movement suggest neurological control of articulation involves a set of strategies to complete a particular anatomic positioning of articulators in order to produce a phonetically acceptable production. Moreover, these alternative strategies are rapidly implemented to compensate for disturbances to the normal speech act. On the surface, these two observations appear contradictory; on the one hand, the system must organize, store, and set priorities for particular articulatory strategies and, on the other, the system must be capable of readjusting almost instantaneously. Contradictions of this nature lead many authors to suggest motor-system control is composed of two parts: a central pre-planning process and a more peripheral on-line monitoring of vocal-tract activities.

Experimental techniques which focus on delineating the role played by more central pre-planning processes impose a static, constant disruption to the system by restricting the participation of structure (usually the jaw) or increasing the distance between structures participating in the speech act. For example, blocks of wood are often used to separate and restrict the jaws from participating normally in speech. Constant, static disruptions require the system to reorganize dynamic gestures to meet the unusual conditions at the periphery; that is, gestures which normally involve movement of the experimentally restricted articulator must be readjusted or subsumed by an alternative articulator. In part, this technique is based upon anectodal reports of how well pipe smokers modify lingual and labial movements to accommodate the immobility of the jaw (MacNeilage, 1970).

In a manner similar to the "pipe smoker with clenched teeth," subjects appear able to produce vowel formant patterns which closely approximate the vowel frequencies produced with a free-moving jaw, regardless of the size of wood blocks used to restrict and separate the jaws (Lindblom and Sundberg, 1971a). Even large bite-blocks, separating the jaws by 23 mm, do not prevent subjects from achieving formant-frequency patterns similar to those in normal speech. Examination of lateral x-rays taken of restricted-jaw vowel productions indicates tongue shape is preserved and appears independent of the low jaw position created by the bite-block (Lindblom and Sundberg, 1971b). However, a similar acoustic study which extends measures to include isolated vowels and vowels in various phonetic contexts (Garrison, Kent, and Netsell, 1977) disputes the observations of Lindblom and Sundberg (1971a). In this study, subjects do not produce formant patterns similar to free-moving-jaw formant patterns; rather, results indicate a significant decrease in formant-frequency two (F_2) and an increase in formant-frequency one (F_1). Lower F_2 values and higher F_1 values suggest a slightly more posterior tongue position is used to produce the vowels in the restricted-jaw condition. The fact that a slightly more posterior tongue position during restricted-jaw conditions is capable of producing vowels which are perceptually similar to free-jaw productions suggests a range of tongue positions and vocal tract shapes are available and used by the motor system.

Cineradiographic analysis of jaw-restricted utterances also provides evidence for a range of articulatory positions capable of producing perceptually acceptable vowels. A preliminary study by Netsell, Kent, and Abbs (1978) indicates speakers are able to reshape the vocal tract area-length relationships to closely resemble normal speaking conditions. Tongue adjustments are observed to change not only in vertical position (height) but also in horizonal (anterior/posterior) directions. Velocity adjustments to the upper and lower lips appear responsible for maintaining comparable durations of consonant-vowel segments produced in the free-moving and restricted-jaw speaking conditions.

Alternative vocal-tract shapes capable of producing perceptually acceptable acoustic patterns suggest the central "pre-planning" operations of the system are capable of translating a vowel target (or its sensory goal) into spatio-temporal patterns of motor events. In addition, several studies (Lindblom and Sundberg, 1971a, 1971b; Netsell et al., 1978) propose central pre-planning operations of the system are capable of further shaping spatio-temporal patterns to meet contextual conditions of the peripheral-oral structures. However, it is not entirely clear how central planning operations adjust the patterns to meet the conditions of the periphery. Lindblom and Sundberg (1971b) suggest the patterns are adjusted by a central "simulation strategy" which maps and simulates articulatory maneuvers; such mapping and simulation strategies allow the system to predict and correct maneuvers, thus preventing errors prior to the actual positioning of articulators. On the other hand, Netsell and his colleagues (Netsell et al., 1978) hypothesize the control system utilizes an "internal comparator" to adjust the state of the periphery to the intended gesture in order to preserve the temporal and spatial precision of articulatory gestures. Under the latter hypothesis, adjustments or modifications based on the internal comparisons apparently allow the execution of the desired articulation to occur reflexively by peripheral structures.

Central simulation or comparative hypotheses assume the system is aware of modifications to peripheral-oral structures prior to gesture execution. One might predict that a system operating in either of these contexts uses strategies to modify the incidence, timing, and magnitude of jaw-closing muscles when jaw participation is restricted. However, no consistent differences in the timing or magnitude of peak EMG activity are found between muscle activities measured in normal and restricted-jaw-speaking conditions (Folkins and Zimmerman, 1981). It is difficult to determine in the Folkins and Zimmerman (1981) study if alterations to the vocal-tract shape and resultant acoustic patterns occur in conjunction with a lack of change in electromyographic activity in the jaw-closing muscles, as simultaneously obtained acoustic and cineradiographic data are unavailable. However, the electromyographic data suggest at least some peripheral neuromotor processes are not greatly influenced by central simulation or error-correcting procedures. It is possible that central simulation and error-correcting strategies are not used to directly modify jaw-closing activities but, rather, act to modify tongue position and configuration to accommodate the restricted-jaw participation. Modifications to tongue position and vocal-tract configuration may reflect interactions of central "pre-planning" and peripheral neuromotor processes, such as coordinative structures, to accommodate restricted-jaw participation.

The concept of responsive peripheral neuromotor processes, such as coordinative structures, proposes the system does not exclusively use a central pre-planning operation to respond to experimental disturbances. Coordinative structures represent groups of relatively independent muscles functionally linked in a manner which determines their movement relative to one another in a speech context (Fowler, 1980; Fowler, Ruben, Remez, and Turvey, 1981; Fowler and Turvey, 1978). For example, vowel production is achieved by organizing the articulators into a single system operating under a particular set of constraints. Perturbation to the system (such as restricting-jaw participation) may be readily accommodated by coordinative structures which, by virtue of the constraint set, automatically assume values accounting for the restricted participation of a particular articulator.

A coordinative-structure hypothesis assumes the speech-production system relies on the inherent responses of the constraint set as a means (at least in part) of providing instantaneous flexibility and adaptability to peripheral disruptions. However, it is possible disruptions to peripheral-oral structures may exceed the range of response available in the constraint set, thus resulting in a deterioration of speech performance. Comparisons of a single perturbation condition (such as jaw restriction) to multiple perturbation conditions (such as jaw restriction and oral anesthesia), indicate multiple disturbances create greater speech disruptions (Gay and Turvey, 1979). Although this study suggests active peripheral neuromotor processes, such as coordinative structures, may underlie (or contribute to) some adaptive functions of the motor-speech system, it is not clear how these processes may interact with more central-planning operations.

Disrupted Speech-Motor Function Inferred from the Study of Persons with Cortical Lesions

Disrupted central control following cortical damage.

Several studies suggest anterior left-hemisphere cortical lesions limit or restrict central control operations used to organize and execute speech. This is reflected in the analysis of production errors for patients with left-hemisphere damage where phoneme selection, as well as articulation implementation, is disrupted (Blumstein, Cooper, Goodglass, Staltender, and Gottlieb, 1980). Production errors are often misarticulations (Fry, 1959; Shankweiler and Harris, 1966; Johns and Darley, 1970; Deal and Darley, 1972; Trost and Canter, 1974) and frequently represent the substitution of one phoneme for another (Shankweiler and Harris, 1966; Blumstein, 1973; Martin, 1974b; Klich, Ireland, and Weidner, 1979). Examination of these substitutions reveals the anticipation of later portions of the utterance (Blumstein, 1973; Blumstein et al., 1980) and suggests inappropriate serial organization prior to the execution (or implementation) of sequentially ordered neuromuscular representations (Blumstein et al., 1980).

In contrast, serial organization may remain intact while processes encoding phonological units are disrupted (Shankweiler and Harris, 1966). In this type of disruption, there appears to be a reduced capacity to program both the positioning of speech musculture for phoneme production and proper muscle sequencing for the reproduction of words (Darley, Aronson, and Brown, 1975). Poor execution of complex motor sequences (including speech) is often observed to occur in patients who do not demonstrate concominant weakness (Darley et al., 1975), deficiencies in understanding (Darley et al., 1975; Geschwind, 1975); incoordination (Geschwind, 1975; Carpenter, 1976), sensory loss (Carpenter, 1976), or ataxia (Chusid, 1976). These observations suggest cortical lesions may impair motor encoding without affecting perceptual processes (Aten, Johns, and Darley, 1971).

Mateer and Kimura (1977) propose that two systems are used to coordinate and execute speech acts. Disturbances to one system produce execution difficulties of a relatively discrete nature effecting single patterns of articulator movement, whereas disturbances to the second system impair the smooth and orderly transition from one pattern to another. Luria and his colleagues (Luria, 1970; Luria and Hutton, 1977) suggest a similar division of impairment occurs in the encoding of neuromuscular representations by kinetic (producing or causing movement) and kinesthetic (loss of motor sensation) disruptions. Disruptions to kinetic and kinesthetic systems (or to systems controlling isolated and sequential movement) may be related to previous reports suggesting patients with cortical lesions are unable to recall or remember the motor skills needed in articulation (Russell and Espir, 1961; Wepman and Jones, 1964).

Patients with left-hemisphere lesions demonstrate some intact, residual function by producing error-free utterances in combination with errors of serial organization and neuromuscular/articulatory representations, as indicated above. The presence of correct and erroneous productions suggests total disruptions to the motor-speech system rarely occur--rather, the system is reduced in such a way that it produces intermittent errors. Evidence for such a "residual" system is varied and, generally speaking, is based on three classes of observations: (a) the type and frequency of errors (Shankweiler and Harris, 1966; Burns and Canter, 1977); (b) linguistic variables, such as grammatical class and sentence length (Deal and Darley, 1972; Martin, 1974a; Aten et al., 1971; Hardison, Marquardt, and Peterson, 1977); and (c) the characteristics of the intended phoneme which are retained in incorrect productions (Blumstein, 1973; Klich et al., 1979).

Numerous error analyses of the productions of patients with left-hemisphere damage indicate: (a) more errors occur on initial than on final segments (Bay, 1966; Shankweiler and Harris, 1966; Aten et al., 1971; Burns and Canter, 1977); (b) consonant clusters, fricatives, and affricatives requiring precise control of the articulators are usually poorly produced (Bay, 1966; Shankweiler and Harris, 1966; Trost and Canter, 1974) and (c) vowels are more accurately produced than consonants (Shankweiler and Harris, 1966; Trost and Canter, 1974); (d) misarticulations constitute the majority of errors (Shankweiler and Harris, 1966; Blumstein, 1973; Klich et al., 1979). Furthermore, errors are usually within the speaker's native phonetic inventory (Blumstein, 1973) and within two distinctive features of the intended phone (Blumstein, 1973; Klich et al., 1979).

Early reports of articulatory behavior following cortical lesions suggest misarticulations represent a phonetic "disintegration" (Alajouanine, Ombredane, and Durand, 1939; Lecours and Lhermitte, 1969); that is, the speaker errs by simplifying his productions. Partial support for the phonetic disintegration hypothesis is found in reports which observed substitutions of unmarked for marked features (Klich et al., 1979). Although place appears to be the least stable feature retained for vowel (Keller, 1978) and consonant (Klich et al., 1979) productions, alveolar-place features are usually retained in correct productions and are frequently substituted in error productions (Klich et al., 1979). The relative accuracy of alveolar production in correct productions (and its high incidence of occurrence in incorrect productions) may relate to its relatively high frequency of occurrence in normal speech (McCroskey, Corley, and Jackson, 1959). In general, phonemes with high frequency of occurrence are misarticulated less often in patients with cortical lesions (Blumstein, 1973; Trost and Canter, 1974).

Spatial representations following cortical lesions. Most of the information regarding disrupted speech-motor function arises from the study of patients with left-hemisphere lesions. Only a few anecdotal reports are available on the speech-motor function of patients with anterior and posterior right-hemisphere lesions, and virtually no systematic description of their speech patterns is available. Most of the literature available on right-hemisphere lesions focuses on agnosias (Critchley, 1953), cognitive processing (Black, 1973a, 1973b; Black and Strub, 1976), and disruptions to somesthetic tasks (Nebes, 1974; Corkin, 1978). Somesthetic tasks, such as spatial orientation and part/whole (Gestalt) relationships often are disrupted following right-hemisphere lesions whereas lesions to the left-hemisphere region disrupt language-related skills (Critchley, 1953). It is not clear if spatial representations of the vocal tract are encompassed under more generalized orientation functions used to determine body position and direction by the right hemisphere, or if they are subsumed by more generalized language-related functions by the left hemisphere.

Patients with left-hemisphere lesions appear less facile in producing phones in novel phonetic environments, as indicated by dramatic increases in errors when producing meaningless syllables (Alajouanine et al., 1939; Martin, 1974a) or the frequent substitutions of a relatively, less novel alveolar position for other place features (Klich et al., 1979). Frequent place errors in the speech of patients with left-hemisphere lesions suggest the patients may centrally misrepresent speech events or, possibly, the spatial correlates of these events. Faced with misrepresentations, the patient may be forced to rely on more "stable," well-practiced alveolar positions.

Additional evidence, indicating cortically injured patients may misrepresent the spatial characteristics of speech events, is suggested by reports of speech errors produced by some of the subjects participating in this study. The majority of the reported misarticulations are substitutions of one phoneme for another; however, the substitutions extend only across place contrasts, not manner or voicing contrasts. Notations in the medical records of these individuals are particularly interesting since the place- (or "spatial") production errors are produced by subjects with *right*-hemisphere lesions and occur in conjunction with reports of more general spatial difficulty (i.e., right-left confusions, etc.).

Temporal disruptions following cortical damage. Several studies suggest left-hemisphere cortical lesions disrupt motor programs which synchronize different articulators and impair mechanisms which organize the temporal coordination of articulators. These errors apparently do not stem from selection or serial organization disruptions but, rather, from a "... common defect, that is poor temporal coordination of air-flow, phonation, and articulation" (Sands, Freeman, and Harris, 1978, pg. 106). Poor temporal coordination suggests cortical lesions impair motor association functions (Burns and Canter, 1977) or integrative control (Freeman, Sands, and Harris, 1978) involved in encoding speech acts.

For example, many authors (Freeman et al., 1978; Blumstein et al., 1980) report the discrete temporal categories for voiced and voiceless initial stop consonants are not well preserved in patients with left hemisphere lesions. Itoh and his colleagues (Itoh, Sasanuma, and Ushijima, 1979) report poor temporal coordination between the upper articulators associated with velar lowering and tongue-tip movement. When the intended nasal target, /n/, is replaced by /d/, the velum lowers in an inappropriate time frame, thus, preserving a movement pattern specific to a nasal target rather than one associated with a stop-consonant target.

Alternatively, less efficient temporal coordination may be indicated by reports which show the overall rate of speech (measured in words and syllables/second) is often slower than normal, while rate of articulator movement between syllables is more rapid than normal (DiSimoni and Darley, 1977). In many instances, articulatory mechanisms appear driven to the limit of articulatory speed, even in short utterances such as monosyllabic words. When production stress is increased in these patients (e.g., by requiring more complex responses), errors also increase (Deal and Darley, 1972).

DiSimoni and Darley (1977) report a loss of segment-duration control in one cortically injured patient who decreased phoneme duration associated with /p/ when sentences increased from one to three words. However, the patient increased phoneme durations for /p/ when the utterances increased from three to five words. In normal speakers, phoneme duration for both consonants and vowels decreases as a direct function of additional words in the utterance (Swartz, 1972). Apparently, the motor-speech system of this particular patient is capable of estimating and planning the durational control of three-word utterances, but is limited in its control of longer utterances.

Although DiSimoni and Darley's (1977) study suggests a limited capability for estimating and planning duration control of long utterances, Collins and his colleagues (Collins, Shaughnessy, and Becher, 1979) propose some patients are capable of implementing durational strategies to compensate for system limitations in planning long utterances. Duration of phonetic segments composing a stem word (such as in the word 'but') systematically decreases as a word increases (as in 'butter' or 'butterfly') in normal speakers. Patients with left-hemisphere lesions reduce duration of word segments as the word increases in length; however, total word duration is significantly longer. These data indicate some patients preserve the ratio of segment-duration/total-word length by effectively slowing articulation to accommodate segmental duration changes for longer words.

Data from these two studies suggest the intricate and tightly constrained timing relationships implemented in speech production are influenced by cortical lesions in one of two ways. On the one hand, it is possible cortical lesions effect only the time frame in which speech gestures are produced (i.e., longer time frames are imposed upon normal gesture patterns), or, on the other hand, it is possible cortical lesions effect the temporal organization of the gesture patterns themselves. Moreover, it is not clear if lesions to the right versus left hemisphere differentially effect the temporal control of speech.

Central Disruptions following War Injuries

Documentation of brain injuries and recovery of various disrupted functions following cortical damage sustained in major wars often occurs (MacPherson, 1922; Credner, 1930; Russell, 1951; Russell and Espir, 1961; Newcombe, 1969). For example, disruptions of major behavioral deficits in American soldiers following World War I, World War II, and Korea are reported in accounts by Frazier and Ingram (1927), Walker and Jabon (1961), and Caveness (1965). Descriptive and experimental methods have been applied to areas incorporating visual defects (Teuber, 1960), aphasia (Russell and Espir, 1961; Caveness et al., 1979), problems in motor coordination and cognitive deficits [see, for a review, Newcombe, 1969)]. Studies tracking cortical injuries and related performance deficits following the Vietnam confrontation, however, are rare. Neurosurgery and morbidity data are available (Hammon, 1971; Carey, 1972), as well as preliminary reports of neurological- and speech-disorders (Carey, 1972b, 1974).

Black and his colleagues report extensively on the neuropsychological performance of American veterans wounded in Vietnam. Deficits are noted in memory and abilities to learn new tasks (Black, 1973b, 1974), cognition (Black, 1974a, 1974b; Black and Strub, 1976), constructional problems linked to quadrant localized lesions (Black, 1976), and personality differences (Black, 1974c; 1975). Newcombe (1969) concluded left-hemisphere lesioned British veterans of World War

II showed diminished verbal performance, as well as, verbal learning problems. Patients with right temporoparietal wounds were specifically handicapped in visual and spatial tasks, however, there were no significant linguistic impairments in patients with right-hemisphere lesions following World War II. Sporadic reports of speech and language difficulties appear following right-hemisphere lesions (Newcombe, 1969; Zangwill, 1979). In Carey's (1973) Vietnam veteran populations, 11 of 43 men with right-hemisphere lesions and 55 of 68 men with left-hemisphere lesions were reported to have speech and language difficulties. The high incidence of speech and language difficulties following left- and right-hemisphere damage sustained in Vietnam deserves further examination because detailed investigations may reveal additional information regarding the roles of dominant (usually left) and non-dominant (usually right) hemispheres in speech production.

Objectives of the Study

While there is some indication the motor speech system in normal speakers "adjusts" for perturbations to the peripheral oral structures, it is not clear exactly how much of the adjustment is contributed by more central versus more peripheral operations. However, the motor speech system of a normal speaker appears capable of: (a) generating a range of tongue positions and vocal tract shapes which produce perceptually acceptable utterances; (b) shaping spatio-temporal patterns to meet contextual conditions of the periphery; and (c) using a strategy such as coordinative structures to increase the efficiency of its response to peripheral perturbations.

Articulation and temporal disruptions to speech production often occur following cortical lesions. It is possible cortical lesions may impose limitations on the motor system in a number of ways including: (a) restricting the spatial framework needed to provide a range of tongue positions and vocal-tract shapes; (b) altering spatio-temporal patterns by effecting the time frame in which speech gestures are produced or the temporal organization of the patterns themselves; or (c) decreasing the responsiveness of peripheral neuromotor processes by limiting the amount of information available to the processes. Peripheral disturbances are readily adjusted to by speakers without cortical damage; however, introduction of a peripheral disturbance (such as restricting-jaw participation) may provide additional stress to the motor-system capabilities of cortically injured individuals. Careful examination of the acoustic response patterns generated in response to perturbations of peripheral-oral structures by subjects with focal, left- and right-hemisphere lesions sustained during the Vietnam Conflict may assist in delineating organizational and executional limitations of the motor-speech system which contribute to speech production errors commonly found in the literature.

CHAPTER II

METHODS AND MATERIALS

A group of men who received focal, cortical lesions to either the right or left hemisphere in Vietnam participated in three studies. Two descriptive studies were executed concurrently, with the experimental study examining forced adaptation to restricted mandibular movement. The first descriptive study examined the ability of the subjects to perform isolated gestures with the oral mechanism and with the arm homolateral to their lesion (Descriptive Study I--Oral- and Limb-Apraxia Assessment). The second descriptive study examined the ability of the subjects to repeat isolated, monosyllabic words (Descriptive Study II--Articulation Assessment). The third study examined their speech under two conditions: a normal-speaking condition and a condition requiring them to speak with an appliance which restricted-mandibular movement (Experimental Study--Forced Adaptation.

Subjects were selected from a population of American veterans who received neurosurgical treatment for discrete, low-velocity missile wounds to the brain. These veterans with discrete brain lesions provided an excellent population to study, as all were examined medically in conjunction with their military service and were determined to be free of gross neurological or sensory abnormalities prior to their injuries in Vietnam. In addition, low-velocity missile wounds produced specific deficits in performance on tasks involving verbal learning (Newcombe, 1969), memory (Newcombe, 1969; Black, 1973a, 1973b; 1974), and constructional abilities (Black and Strub, 1976) rather than generalized poor performance due to closed head injuries, tumors, or vascular accidents (Newcombe, 1969). The men selected to participate in this study were unique in that they recieved neurosurgical treatment by a single team of neurosurgeons in Chu Lai, Republic of Vietnam, which performed the neurosurgery in a uniform manner, including diagramming the area of brain injury and estimating the quantity of brain resectioned during surgery (Carey, Young, and Mathis, 1972a, 1972b). Access to the previous medical histories of the men following their surgery was arranged by Dr. Michael E. Carey (Department of Neurosurgery, Louisiana State University Medical Center, New Orleans, Louisiana) who commanded the neurosurgical unit in Vietnam and has maintained periodic contact with them over the past ten years. In addition to serving as subjects for this study, they also participated in an extensive study of speech perception and neurobehavior coordinated by the Kresge Hearing Research Laboratory of the South, Department of Otorhinolaryngology, Louisiana State University Medical Center, New Orleans, Louisiana.

Two time periods for preparation and two time periods for execution of these studies were scheduled during the week the subjects were in New Orleans. Preparation time periods were devoted to the manufacturing and fitting of the dental appliance used in the Experimental Study--Forced Adaptation. The initial preparation period served two purposes (1) to insure severe dental abnormalities did not preclude building the appliance, and (2) to make impressions of the maxillary and mandibular dental arches. The second preparation period was scheduled following fabrication of the appliance for any adjustments necessary to ensure the appliance fit snugly and comfortably.

The third period during the week served as the experimental session for collecting speech-production measures. The initial portion of the third period was devoted to collecting data assessing non-speech movement (Descripive Study I--Oral- and Limb-Apraxia Assessment) and articulation (Descriptive Study II--Articulation Assessment). Examination of normal speaking and forced adaptation to a restricted-jaw position (Experimental Study--Forced Adaptation) was carried out in the second portion of the session.

The fourth time period was scheduled following the experimental session in order to assess the ability of subjects to discriminate (auditorily) the articulation assessment materials. This session was scheduled as a means of determining if articulation errors obtained in Descriptive Study II--Articulation Assessment actually represented production errors, rather than perceptual discrimination errors which might be associated with their cortical injuries.

Subject Selection

Selecting subjects from the original pool of 101 men followed by Dr. Carey involved two considerations. The first consideration was the need to select subjects who could primarily participate in the speech perception and neurobehavioral studies funded by the National Institutes of Health in a grant awarded to Kresge Hearing Research

Laboratory of the South, Louisiana State University Medical Center, New Orleans, Louisiana. The second consideration was to select a subgroup from the men participating in the speech perception studies to participate in the speech studies described in this document. In order to select 15 men to participate in the speech perception studies from the original pool of 101 men, the following inclusion and exclusion criteria were followed (Table II-1 illustrates the number of men excluded or included from the study using these criteria).

Exclusion Criteria for Speech Perception Studies

1. Capacity to perform

> No amputations, severe abnormal
> psychological problems, nor total
> total blindness.

This criterion was set for a number of practical reasons. Amputation of limbs (either arm or leg) or total blindness prohibited the subjects from participating in other aspects of the speech-perception and neurobehavioral studies held in facilities poorly equipped for testing physically handicapped subjects. In addition, a number of the perception and neurobehavioral tasks required good visual acuity, typing on computer terminals, or responding to printed scoreforms. Exclusion of patients with severe, abnormal psychological problems was minimal insurance that the subjects would be cooperative and able to withstand the rigor of an arduous testing schedule.

TABLE II-1

NUMBER OF LEFT- AND RIGHT-HEMISPHERE-LESIONED PERSONS ELIMINATED FROM PARTICIPATING IN THE SPEECH PERCEPTION STUDIES

Criteria	Number of Left-hemisphere	Number of right-hemisphere
Exclusion		
1. Capacity to perform	15	7
2. Audiological performance	10	6
Inclusion		
1. Hemispheric involvement	30	19

2. Audiological performance
    a. No hearing asymmetry of more than 40dB (average) for frequencies of 500, 1000, 2000, and 4000 Hz. The poorest ear to not have thresholds greater than 50dB hearing threshold level (HTL) in these frequencies.
    b. Abnormal discrimination for phonetically balanced words presented at 40dB relative to the speech reception thresholds in at least one ear.

In part, these criteria were imposed as the subjects would participate in a number of speech-perception studies which required normal hearing thresholds (at least in the ranges generally associated with perceiving speech). A second consideration involved in setting these criteria was to eliminate subjects who received hearing losses in Vietnam which were severe enough to affect their speech production.

Inclusion Criteria for Speech Perception Studies

1. Hemispheric involvement
    a. Circumscribed lesion of a single hemisphere (right or left), with minimal bilateral involvement of the upper and lower extremeties.
    b. Neurological examination indicating intact Cranial Nerves II-XII.

These criteria were set to ensure minimal contra coup and no involvement of deep cortical structures. Intact Cranial Nerves II-XII ensured the musculature involved in speech production and the sensory structures involved in vision and audition were relatively free of damage.

Additional inclusion and exclusion criteria were developed to select a subgroup from the men participating in the speech perception studies to participate in the speech production studies described in this document. These criterion are listed below.

Exclusion Criteria for Speech Production Studies

1. Speech production

    a. Proficiency in two languages; exposure to foreign languages in secondary school or college did not exclude a subject.

    b. Notations of severe expressive language difficulties (i.e., jargon or echolalia).

Bilingual individuals were excluded as a means of eliminating production characteristics of a second language upon English. Individuals with severe expressive language difficulties were excluded because of difficulties in separating the contributions of language disabilities from speech-production execution.

Inclusion Criteria for Speech Production Studies

1. Speech production

    Notations in post-trauma histories of deviant articulations (i.e., misarticulations) or rate (i.e., slow or hesitant).

Medical records of the RTP group were particularly interesting because the men had difficulty with spatial relations (i.e., right versus left confusions) which apparently extended to their speech production in terms of misarticulations. Misarticulations of these subjects were primarily substitutions of one phoneme for another;

however, the substitutions extended only across place contrasts, not manner or voicing contrasts. It was possible these place (or "spatial") articulation errors were linked to their general spatial difficulty.

Medical records of the LTP group indicated a fairly even distribution of misarticulation types and substitutions which included manner, place, and voicing cues. In addition, several of this group's medical records indicated alterations in rate, such as slowing or hesitancies.

Experimental Subjects

Eight American veterans who sustained cortical lesions served as subjects for the forced-adaptation, oral- and limb-apraxia-assessment, and articulation-assessment investigations. Two experimental groups (four males in each group) were investigated and designated by side-of-lesion, right or left hemisphere (i.e., RTP or LTP, respectively). Mean age of the RTP group at the time of injury was 21 years 4 months, with a range of 20 years 7 months to 22 years 7 months (see Table II-2). Cortical injuries for the RTP group occurred within a time frame of 8 months 8 days (December 15, 1968 to August 7, 1969). Average age of the LTP group when injured was 24 years 9 months and ranged from 20 years 4 months to 36 years 2 months (see Table II-2). Injuries were inflicted in the LTP group within a time course of 11 months 23 days (February 28, 1969 to February 25, 1970).

Surgical notes and diagrams documenting the side-of-lesion at the time of neurosurgery in Vietnam were available for all subjects. The

TABLE II-2

BIRTH AND WOUNDED-IN-ACTION DATES FOR RTP AND LTP SUBJECTS

Subjects	Birthdate	Date Age Wounded	Age at Wounded	Testing
RTP1	07/22/47	03/18/69	21	30
RTP2	12/01/46	07/16/69	22	32
RTP3	08/01/48	08/07/69	21	31
RTP4	05/19/48	12/15/68	20	30
LTP1	10/18/48	04/13/69	20	31
LTP2	10/17/48	06/08/69	20	30
LTP3	05/25/33	02/25/70	36	45
LTP4	06/21/46	02/28/69	22	32

extent- and site-of-lesion at the time of this study were updated by computer-enhanced tomography (CT) scans (see Figure II-1 and II-2), electroencephalograms (EEG's), and standard neurological and neuropsychological evaluations provided through the cooperation of Baptist Hospital, Oschner Hospital, and the Louisiana State University Medical Center. A summary of recent neurological and speech performance is shown in Tables II-3 and II-4 for the RTP and LTP subjects, respectively. Detailed data acquired during this joint neurobehavioral study for the individual subjects, including surgical diagrams and notes, CT scans, EEG reports, speech and language evaluations, audiological evaluations, and neuropsychological performances, are included in Appendix A.

Control

A control group of eight men also participated in the *Experimental Study--Forced Adaptation*. Subjects were selected from personnel and students associated with Kresge Hearing Research Laboratory of the South. Control subjects were required to meet similar inclusion and exclusion criteria to that previously described for the experimental groups. An attempt was made to try to match Control and experimental subjects from similar regions in order to control for possible dialect influences. As shown in Table II-5, we were not entirely successful. In addition, Control subjects were required to have no history of head trauma, neurological disease, or neuromuscular disorders. Average age of the Control group was 30 years 7 months, with a range of 20 years 9 months to 44 years 7 months. Control subjects were not required to

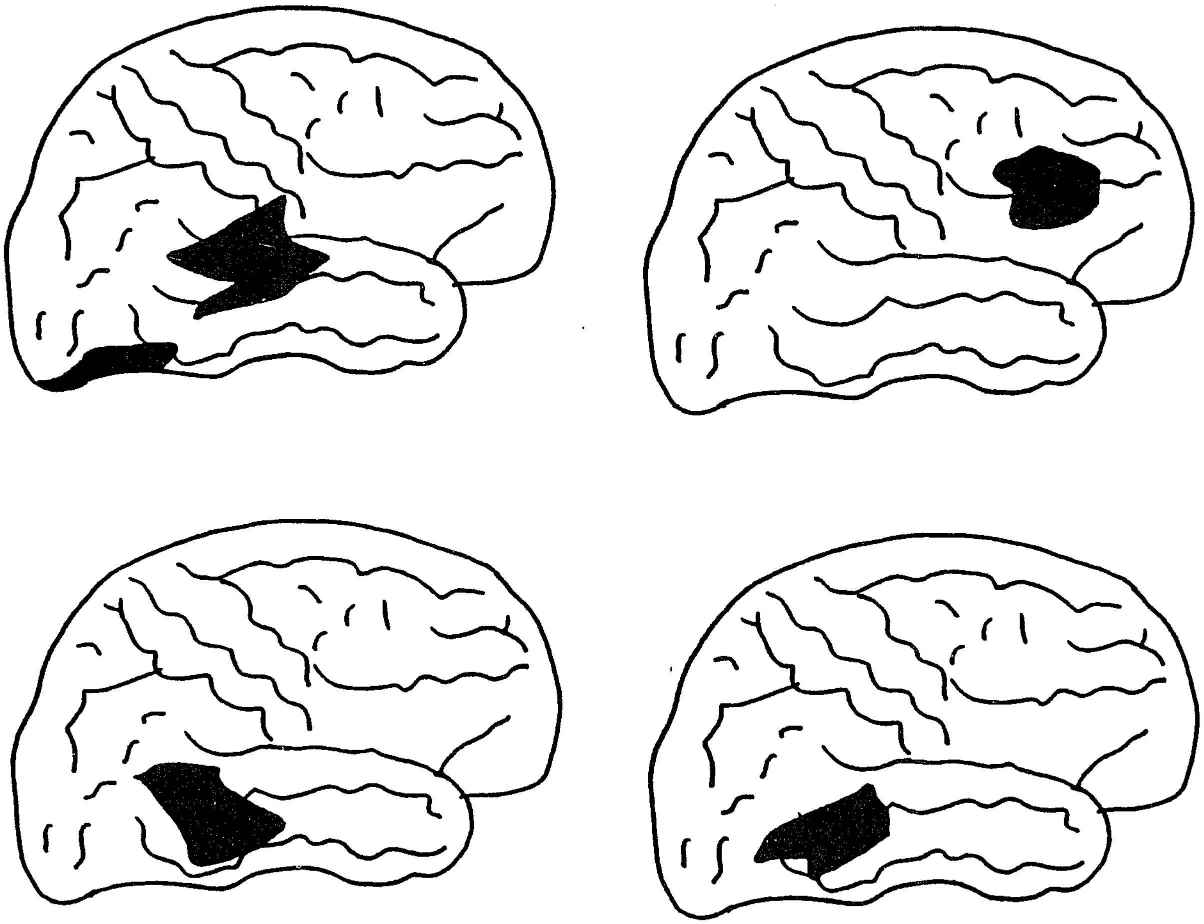

Figure II-1. Sketches acquired from CT scans of right-hemisphered lesioned subjects.

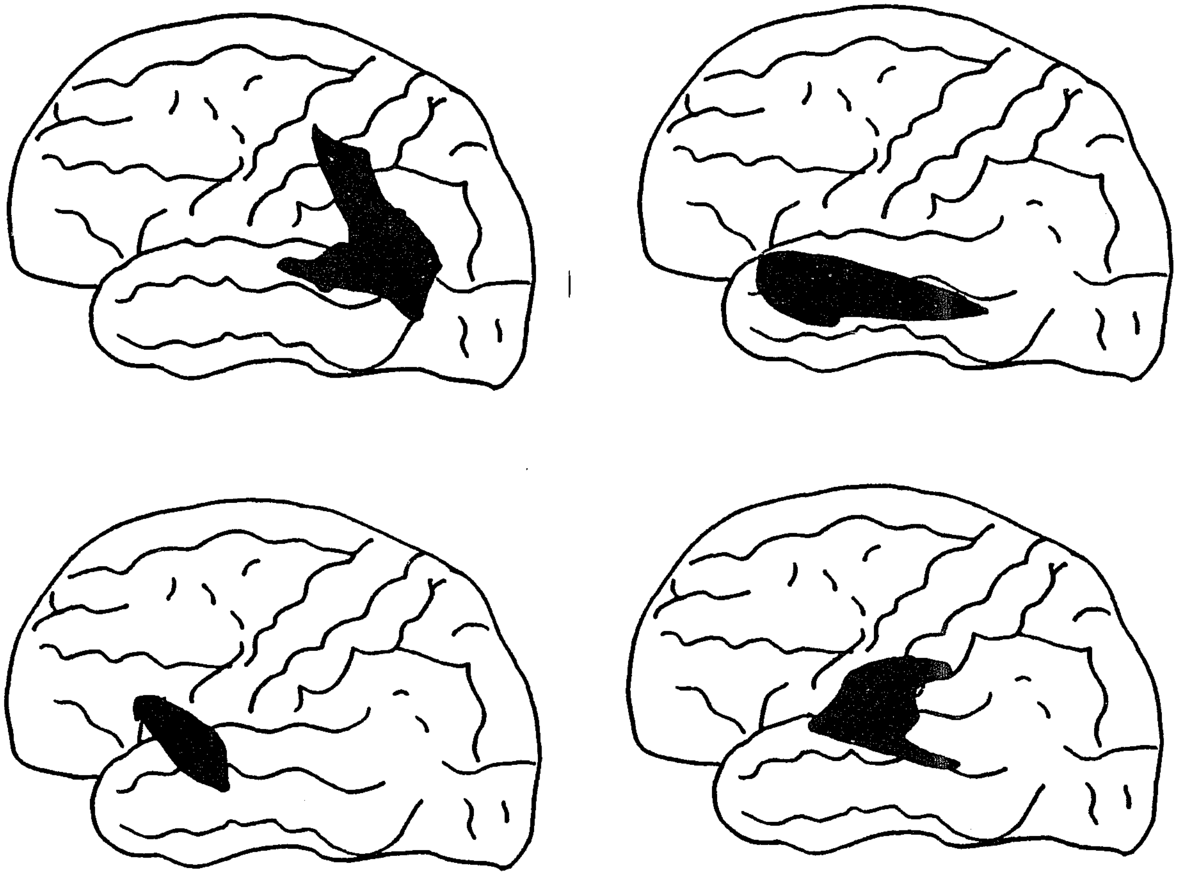

Figure II-2. Sketches of the lesions from the CT scans for the left-hemisphered lesioned subjects.

TABLE II-3

PERFORMANCE AND LESION-LOCATION SUMMARY FOR RTP SUBJECTS

Subjects	Lesion Location	Neurological	Full-Scale I.Q.	Language
RTP1	Right parieto-temporo, with a congenital density in the occipital lobe	Right-left orientation difficulties	122	Some word searching and misarticulations
RTP2	Right frontal	Normal examination	122	Normal examination
RTP3	Right temporal	Normal examination	97	Reading difficulty; unable to produce rapid speech
RTP4	Right temporal	Slight increase in reflexes in left arm and leg	94	Fluent language with misarticulations

TABLE III-4

PERFORMANCE AND LESION-LOCATION SUMMARY FOR LTP SUBJECTS

Subjects	Lesion Location	Neurological	Full-Scale I.Q.	Language
LTP1	Left parieto-temporal	Unsteady tandem walking; five trials required for double stimulation of face and arm	78	Halting speech; oral agility decreased;
LTP2	Left fronto-temporal	Slight drift of right arm; decreased sensation of maxillary division of Trigeminal nerve	113	Mild hesitancy; verbal deliberatness
LTP3	Left temporal	Decreased sensation in left muscles of mastication	86	Mild anomia
LTP4	Left parieto-temporal	Slight decrease in sensation around right mouth corner; subtle facial droop	133	Slight articulation and word-choice problems

participate in Descriptive Study I--Oral- and Limb-Apraxia Assessment or Descriptive Study II--Articulation Assessment.

TABLE II-5

RESIDENCE OF INDIVIDUAL SUBJECTS AS IT MAY RELATE TO DIALECT SPOKEN

Subject	State
Control	
1	Louisiana
2	Louisiana
3	Louisiana
4	Louisiana
5	Maryland
6	Illinois
7	Washington
8	New York
RTP	
1	Massachusetts
2	Maine
3	Illinois
4	California
LTP	
1	New York
2	Oklahoma
3	Virginia
4	Maryland

Descriptive Study I--

Oral- and Limb-Apraxia Assessment

Materials

Oral apraxia was assessed using the following 10-item test designed by De Renzi, Pieczuro, and Vignolo (1966):

1. Stick out your tongue.
2. Whistle.
3. Yawn.
4. Try to touch the tip of your nose with your tongue.
5. Give a "Bronx cheer" or "raspberry."
6. Show how your teeth chatter when you are cold.
7. Show how you would kiss someone.
8. Click your tongue, imitating the sound of a horse galloping.
9. Puff or blow.
10. Clear your throat.

In addition to these items, the following two practice items were included to ensure subjects understood the task and could follow the directions:

1. Show me how you smile.
2. Show me how you frown.

Limb apraxia was examined using a 10-item test adapted from De Renzi and his colleagues (De Renzi et al., 1966) with Item 8 altered for this study. De Renzi and his colleagues requested subjects to demonstrate the sign of a cuckold; however, informal survey using members of the laboratory revealed most people were unfamiliar with the appropriate gesture indicating cuckolds. Wording of the item was adjusted to ask subjects to demonstrate the sign designating a Texas Longhorn, which was formed in a similar fashion to the Italian sign for a cuckold. Items which were tested are listed below:

1. Make the sign of the cross.
2. Salute.
3. Wave goodbye.
4. Threaten somebody with your hand.
5. Show that you are hungry.
6. Thumb your nose.
7. Snap your fingers.
8. Make the sign designating a Texas Longhorn.
9. Indicate someone is crazy.
10. Make the letter "O" with your fingers.

In addition, the following two practice items were designed to ensure subjects understood the task and directions.

1. Make a fist.
2. Make a muscle.

Equipment

The experimental session was video recorded using a Panasonic black and white portable camera connected to a Panasonic video cassette tape recorder. A high-quality Realistic microphone was used to record the various speech samples directly onto the video cassette tapes. Video recordings were monitored via a Panasonic video monitor. Limb-apraxia assessment was recorded with the video camera focused on the upper torso allowing the arm and hand to be viewed. A zoom lens was used for "close-up" recordings of the face during oral-apraxia assessment and the remainder of the experimental session.

Procedure

Items were given as verbal commands and, if necessary, demonstrated by the examiner. Subjects were asked to produce oral and limb gestures following the verbal or imitative prompts of the examiner. Limb-apraxia items were produced with the subjects' arm or hand homolateral to the side of their lesion (i.e., LTP subjects used their left arm and hand). Homolateral limbs were used rather than contralateral limbs in order to rule out (assuredly, in a gross sense) bilateral hemispheric involvement.

The following instructions were given to subjects prior to oral apraxia items:

> "I am going to ask you to do some things with your mouth or tongue, such as 'Show me a smile,' or 'Show me how you frown.' Do you understand? Show me how you smile. Show me how you frown."

If subjects were unable to complete the gesture when given verbal commands, the experimenter demonstrated the action and said:

> "I want you to do what I do. Do this."

Immediately following oral-apraxia assessment, the camera was readjusted to focus on the upper torso of the subject. Instructions for the limb-apraxia items were similar to the oral-apraxia items:

> "I am going to ask you to do a number of things with your arm and hand; for example, 'Make a fist' or 'Make a muscle.' I would like you to use your right/left arm and hand to do them. Do you understand? Good. Show me how you make a fist. Show me how you make a muscle."

If the subjects were unable to complete the gestures, the experimenter demonstrated the action using the same instructions used for imitative prompts in the oral-apraxia assessment.

Analysis

Video recordings of the subjects' responses were rated on a 3-point scale following the system proposed by De Renzi and his colleagues (De Renzi et al., 1966). Subjects failing to initiate a gesture following verbal command were scored only on imitative responses. Scoring guidelines are shown in Table II-6.

Composite scores were tabulated for each subject by adding the total number of points (maximum = 20) granted on the oral- and limb-apraxia materials. Subjects scoring less than 16 points on the oral-apraxia items were classified orally apractic. A cut-off score of 17, identical to that used by De Renzi and his colleagues (De Renzi et al., 1966), was used to classify subjects with limb apraxia. In addition to examining total-score performance, the relative difficulty of the oral- and limb-apraxia items was examined and expressed as the mean score obtained on each item by the RTP and LTP groups.

TABLE II-6

SCORING GUIDELINES FOR ORAL- AND LIMB-ASSESSMENT ITEMS[1]

Definition of Response	Observed Behavior	Score
Correct	a) accurate performance immediately follows oral command (or demonstration)	2
	b) accurate performance is preceded by pauses, during which unsuccessful movements may be present	1
Raw	overall pattern of gesture is acceptable though, movements are defective in terms amplitude, accuracy, force and/or speed	1
Partial	some important part of gesture is lacking, though the rest is performed correctly	0
Perserveration	gestures elicited by preceding items are performed	0
Irrevelant	some other incorrect oral performance (including speech sounds) is produced	0
Nil	no oral performance is produced	0

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[1] Table taken from De Renzi, E., Pieczuro, A., and Vignolo, L. A. Oral Apraxia and Aphasia. Cortex, 2:50-73, 1966.

Descriptive Study II--
Articulation Assessment

Materials

Articulation skills were assessed using 200 monosyllabic real-words (Shankweiler and Harris, 1966). The list sampled most singleton consonants, frequently occurring consonant clusters, and vowels which were not generally characterized by glides. Twenty-five consonants and consonant clusters occurred eight times in initial and final position. Eight vowel nuclei appeared approximately 25 times within the list. Words used to assess articulation are shown in Table II-7.

Stimuli were recorded by a professional male speaker of North Central States dialect using a high-quality, Shure microphone (Model 459, Unidyne IV) and Tandberg tape recorder (Model 1200AX). All recordings of the professional speaker were made in a sound-proof room (Model 1204). Tokens were entered into an 8/32 Interdata computer via a 12-bit analog-to-digital (A/D) converter at a 20-kHz rate. Prior to processing, tokens were passed through a low-pass, 5000-Hz, Ithaca filter (Model 4251). Subsequent to filtering, tokens were edited and equated for intensity. The test tape, with the articulation-assessment items, was assembled under computer control with an 8-sec interstimulus interval between items to allow subjects time to repeat the items.

Equipment

Stimuli were presented free-field to subjects from a Magnecord tape recorder (Model 1022) through an Altec speaker. Prior to

TABLE II-7

MONOSYLLABIC ARTICULATION ASSESSMENT ITEMS
FROM SHANKWEILER AND HARRIS[1]

help
pledge
weave
lips
wreath
felt
zest
crisp
touch
palp
stash
niece
soothe
ding
that's
mesh
deep
badge
belk
gulp
stilt
zag
reach
stock
thief
coop
theme
cult
stood
these
vat
hoof
clog
move
talc
shoes
smooch
hook
took
teethe
stoops
bilk
hulk
jog
shook
plume
thatch
zig
teeth
moot
foot's
jeeps
leave
van
cheese
vets
loops
pooch
mash
scalp
thud
booth
wreathe
gasp
smoothe
feast
jest
chief
dune
wasp
heath
tooth
lodge
jam
roof
gap
shove
plebe
than
dab
choose
thong
puts
hood
fun
sting
knelt
please
this
that
dub
vast
clash
soot
sheath
stop
cob
zen
push
cleave
mops
hasp
fuzz
smith
tots
such
veldt
culp
wisp
guest
bulk
silk
moose
smut
soup
fez
bing
jots
shoots
with
noose
chin
rob
plot
book
milk
vest
give
then
plug
knob
cook
love
posh
lisp
nest
would
tube
chap
put
rook
loom
judge
breathe
whelp
smash
zing
could
mob
clasp
smudge
kilt
thing
fog
death
goose
thus
smelt
nudge
welt
chops
vim
vet
sip
plop
smug
foot
chest
should
clots
pulp
wedge
hatch
says
watch
kelp
sheathe
bush
juice
thieve
chaff
stuff
seethe
gin
zoom
cliff
plod
rough
nook
dodge
thug
cling
news
look
doom
puss
god
clang
them
good
sulk
zips
rasp
shops

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[1] Taken from Shankweiler, D. and Harris, K. An Experimental Approach to the Problem of Articulation in Aphasia. *Cortex*, 2:277-292, 1966.

presentation, audio signals were passed through a Hewlett-Packard attenuator (Model 3501). Microphone placement was adjusted at a 0° incidence, six inches from the subjects' lips. Speech samples were monitored by the examiner via a Tektronix oscilloscope (Model 5000). As mentioned in the Oral- and Limb-Apraxia Assessment section, all responses to the articulation-assessment materials were video recorded.

A second session was scheduled with subjects after completion of the experimental session to assess discrimination. Subjects were seated in an Industrial Acoustics Corporation sound-proof room (Model 1204). Stimuli were presented via an Ampex tape recorder (Model AG440) through TDH-49 earphones. Prior to presentation, audio signals were passed through a Daven power attenuator and a Hewlett-Packard attenuator (Model 350D) in order to adjust the intensity levels. Signals were presented binaurally at 75dB sound pressure level (SPL).

Procedure

A two-step procedure was used to assess articulation. In the first, subjects were instructed to listen and repeat the monosyllabic words. Articulation trials were monitored and transcribed using broad transcription notation [International Phonetic Alphabet (IPA)] by the examiner. Subjects were given the following instructions:

> "You will hear a number of different words. I would like you to listen carefully and repeat them. Do you understand? Let's practice a few. Say desk. Say lamp. Good. Here are the real words. Listen carefully and say them as soon as you hear them."

Subjects were given a 5-min break after the articulation assessment recordings. During a second session, subjects were placed in a sound-proof room and asked to listen to the words presented via the headphones. Subjects were given the following instructions:

> "Now you are going to hear the same words that you heard earlier. This time I want you to write the words down on paper. Don't worry about your spelling or handwriting. Just do the best you can."

Analysis

Utterances were transcribed using IPA by two speech clinicians. Articulation errors were determined by examining the transcriptions and determining which verbal responses were incorrectly produced. These items were compared to the written responses obtained during the discrimination trials. For instance, if /git/ was produced for /bit/ and written as 'beet' in the discrimination trials, it was considered an articulation error. Discrimination errors included two types of incorrect verbal and written responses (1) a similar incorrect verbal and written response (e. g., /git/ for /bit/ production and 'geet' as the written response), and (2) dissimilar but incorrect verbal and written responses (e. g., /git/ for /bit/ verbal production and 'seat' for written response). An additional notation, dialect, was recorded and represented similar incorrect verbal and written responses which were appropriate for the dialect of the subject; for instance, two subjects from the New England area responded to the target word 'large' as 'lodge'.

Articulation errors were tabulated in confusion matrices indicating the frequency each phoneme was "correctly" produced, "distorted," or replaced by another phoneme. Each row in the matrix referred to the phonemes occurring in the target stimuli, and each column referred to the subjects' verbal productions. Confusion matrices were made for each individual subject and collapsed across the subjects to provide a matrix representing the performance of each group on the articulation-assessment items. Percentages were calculated to determine the total number of errors for initial and final phonemes for each group.

Experimental Study--Forced Adaptation

Materials

Speech. Speech materials were contained within the carrier phrase, "Here is a _____ now," in order to maintain uniform stress across replications. Target stimuli consisted of monosyllabic words and nonsense syllables of the form consonant-vowel-consonant (CVC). Initial consonants or clusters consisted of /t, d, s, r, tr, str/ and were chosen for a number of reasons. The set consisted of homorganic consonants which required varying degrees of tongue height and coordination in relationship to the alveolar ridge. Inclusion of the alveolar stop-consonant cognates, /t, d/, contrasted any effects related to voicing. The consonant clusters, /tr, str/, were included because they required the tongue to execute coordinated, carefully timed gestures within the same spatial area and were reported to be difficult to produce by patients with cortical lesions [see, for example, Shankweiler and Harris (1966)].

Medial vowels, /i, ae, u/, were selected to examine tongue positioning in relatively extreme points of the vowel space. In addition, these vowels are characterized acoustically by distinct formant patterns which relate, to a first approximation, to their place-of-articulation in the oral cavity [see, for example, Stevens and House (1955) and Fant (1962; 1973)].

The bilabial voiceless stop-consonant, /p/, was the final consonant. Selection of the voiceless bilabial stop-consonant as the final consonant was predicated on a number of factors. A voiceless stop-consonant is partially characterized by a period of silence containing no glottal pulsing, which aided in determining the offset of the vowel nuclei. In final position, transitions of the bilabial stop-consonant fell and assisted in determining vowel steady-state (operationally defined as the peak of vowel-formant frequency prior to the downward moving transitions of /p/). All possible combinations of initial consonants and vowels rendered a total of 18 stimuli listed below.

/rip/	/raep/	/rup/
/sip/	/saep/	/sup/
/tip/	/taep/	/tup/
/dip/	/daep/	/dup/
/trip/	/traep/	/trup/
/strip/	/straep/	/strup/

Sentences containing the target stimuli were recorded by the same professional male speaker used to generate the articulation assessment materials. Tokens were edited under similar conditions to the earlier-described articulation-assessment items. Four randomizations of the 18 stimuli in block were assembled under computer control with an interstimulus interval of 10 sec. Prior to the first randomization of the stimuli, three practice items, consisting of one real word and two nonsense target stimuli, were recorded on the test tape. These additional practice items were included to ensure the subjects understood the task and could repeat the sentences which contained either a real or nonsense word.

Dental appliance construction. Impressions were made of the subjects' maxillary and mandibular dental arches. Impressions were poured into dental stone and the stone casts mounted on a hinge articulator. As shown in Figure II-3, the articulator was opened and the casts were separated a distance of 10 mm, as measured from the mesiobuccal cusp of the maxillary and mandibular first molars. Autopolymerising resin occlusal splints were constructed on the stone casts, as pictured in Figure II-4. Four pieces of .036" orthodontic wire were attached to the mandibular splint in positions which allowed them to occlude against the maxillary splint. Splints were fitted onto the subjects' dental arches and the orthodontic wires attached to the mandibular splint, as illustrated in Figure II-5. Orthodontic wires were permanently secured to both splints with autopolymerising resin, while the subjects occluded in the centric relation position. The finished appliances (shown in Figure II-6) were polished to remove rough spots and stored in water until the experimental session.

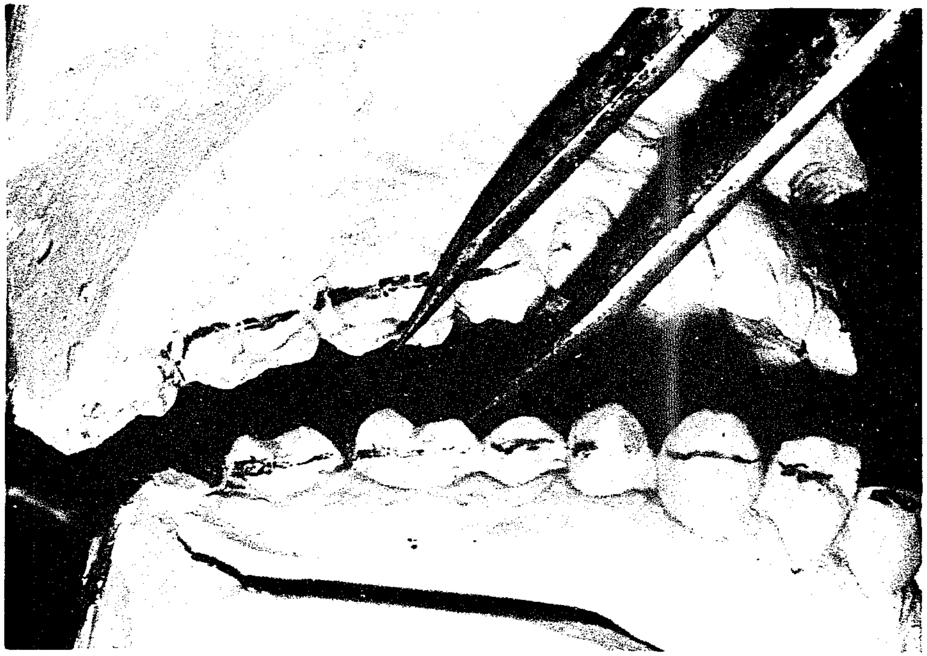


Figure II-3. Separation distances for appliance were determined by opening articulator 10 mm, as measured from mesiobuccal cusp of first molars.

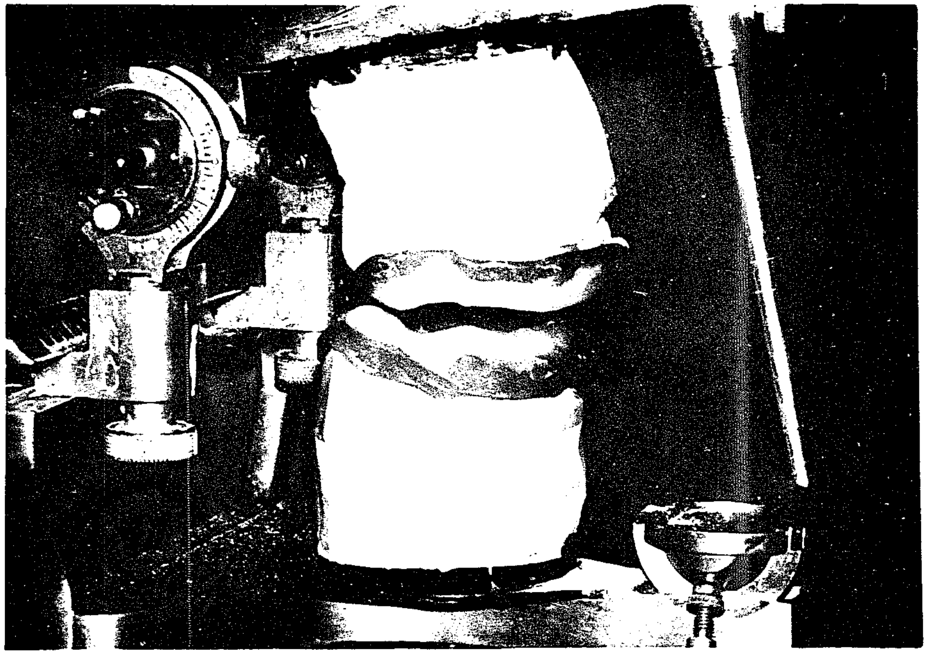


Figure II-4. Autopolymerising resin occlusal splints were constructed on stone casts.

Figure II-5. Mandibular and maxillary splints were attached while subject was in a centric resting position.

Figure II-6. An example of a completed appliance is shown. Finished appliances were stored in water until experiment.

The experimental appliance was designed and constructed by Dr. Israel M. Finger, Department of Removable Prosthodontics, Louisiana State University School of Dentistry, New Orleans, Louisiana. The occlusal splint design for the appliance was used for a number of reasons. First, although several previous studies [see, for example, Gay and Turvey (1979) and Lindblom, Lubker and Gay (1979)] used blocks of wood calibrated to separate the mandible from the maxillary dental arches by a variety of distances, we were hesitant to use this method in the event one of the subjects might have a seizure and aspirate the block of wood. Secondly, we needed an appliance which could be easily replicated across a variety of oral cavities. This was particularly important because we had no _a apriori_ information about the subjects' dental structures or their condition. Third, the appliance had to be constructed within the time period the subjects would be in New Orleans for testing. The occlusal splint appliance was adapted from similar splints used for bruxing (grinding of one's teeth). In order to separate the mandible from the maxilla, a 10-mm separation was used as it represented a value in which the mandible was moving in a downward direction prior to condyle rotation as shown by Posselt's space (Posselt, 1968).

Two sets of orthodontic braces were placed on the mandibular splint. The first set was positioned at the first molars and the second at the first bicuspids in order to reduce anterior movement of the mandible.

Equipment

Stimuli for the normal- and restricted-jaw-speaking conditions were presented free-field from a Magnecord tape recorder (Model 1022) via an Altec speaker. Prior to presentation, audio signals were passed through a Hewlett-Packard attenuator (Model 350D) in order to adjust the presentation intensity levels.

Recordings of subjects' responses to the target stimuli were made using a Shure microphone (Model 459, Unidyne IV) which was recorded on one channel of a second Magnecord tape recorder (Model 1022). Microphone placement was adjusted at a 0° incidence, six inches from the subjects' lips. Speech samples were monitored by the examiner via Tektronix oscilloscope (Model 5000).

All recording and playback equipment was located in an adjoining room as a means of reducing the noise level in the recordings. The two rooms were separated by a two-way window which allowed visual contact with the subjects.

Procedure

Forced adaptation consisted of two conditions: a normal-speaking condition (no appliance) and a restricted-jaw-speaking condition (with appliance). Subjects were instructed to listen and repeat the entire experimental sentence. Following are instructions given for the normal-speaking condition:

> "This time you will hear a number of sentences. The sentences are of the form, 'Here is a ___ now.' The blank will be filled in with a number of real words, like 'deep' or 'sap' and with nonsense words like '/strup/' and '/trip/.' I want you to repeat the entire sentence after you hear it. Do you understand? Let's try a few for practice. Ready for the test sentences? Good."

Upon completion of repeating the sentences in the normal-speaking condition, subjects were given a 5-minute break. Following the break, the dental appliance was placed in the subjects' mouths. During the adaptive-speaking condition, subjects listened to the experimental tape again; however, the practice items were not included in the adaptive-speaking condition. The following directions were given:

> "I have inserted a 'bite-block' in your mouth. It is there to prevent your lower jaw from moving very much. You will hear the same sentences as before. Repeat them the best you can. Do you understand? Ok, let's begin."

Duration Analysis

A three-step procedure was used to prepare data for measurement. In the first procedure, audio recordings were analyzed by spectrographic techniques. Boundaries of acoustic segments associated with initial consonants and vowel nuclei of target stimuli were located on spectrograms in the second procedure in order to obtain duration of various segments.

In the third procedure, stimuli were edited under computer control to extract four pitch periods from the steady-state portion of the vowel nuclei. These pitch periods subsequently were spectrally analyzed under computer control to obtain frequency values associated with F_1, F_2, and F_3. In addition, fundamental frequency was obtained for each of the vowel nuclei.

Detailed descriptions of the three-step procedures follow.

Spectrographic Procedure. Speech samples were played back on a Tandberg tape recorder (Model 1200AX) at a speed of 7.5 ips into a Kay Sonagraph (Model 6061A). Broadband spectrograms were generated using a 300-Hz bandpass filter and logarithmic scale. A 500-Hz tone was recorded on each spectrogram to serve as a frequency calibration.

Spectrograms were placed on a drawing board for segmentation. A triangle and t-square were used to align the sonagrams and to mark the acoustic boundaries associated with the various target phonemes.

Segmentation Procedure. One of the major difficulties encountered in measuring the duration of acoustic segments associated with consonants and vowels was determining the boundaries encompassing the segments. In many situations, the cues signalling the beginning or ending of a particular segment were relatively unambiguous, but in many cases it was difficult to define a boundary. The following guidelines were used for demarcating the various segments associated with the initial consonants and vowel nuclei.

1. Alveolar stop-consonants, /t/ and /d/. Three major acoustic segments were associated with stop-consonants. These segments were designated as: (a) silence, representing the occlusion of air flow in the vocal tract; (b) burst, representing the release of occlusion in

the vocal tract; and (c) transition, representing the movements of the articulators to positions used for vowel production (Halle, Hughes, and Radley, 1956). Although Fant (1962) suggested the burst may be further differentiated into an explosive transient and short-frication period, for the purposes of this study, a burst comprised both segments.

As shown in Figure II-7, Boundary One was established following the systematic formant structure of the schwa vowel and represented the onset of silence which was characterized by a lack of energy in all frequencies above the voicing component of 300 Hz. Boundary Two was drawn at the point reflecting burst onset. Bursts were represented in the spectrographic displays by short periods of noise in the form of either a flat spectrum of energy or a fairly concentrated area of energy in the frequencies above 4000 Hz. On several occasions, the bursts for the voiceless-alveolar cognate, /t/, included transitions without voicing striations in the 300-Hz region. Boundary Three was located at the onset of the first glottal pulse established by finding the first voicing striation in the 300- to 500-Hz frequency region. Establishing these boundaries provided duration measures for silence or occlusal period and voice-onset-time (Lisker and Abramson, 1964).

2. Lateral /r/. Three acoustic segments were located for measurement following the detailed method discussed by Russell (1977). Figure II-8 depicts the four boundaries used to delineate the segments. Boundary One was established at the offset of the steady-state portion of the schwa vowel at a point where the formant frequencies began to

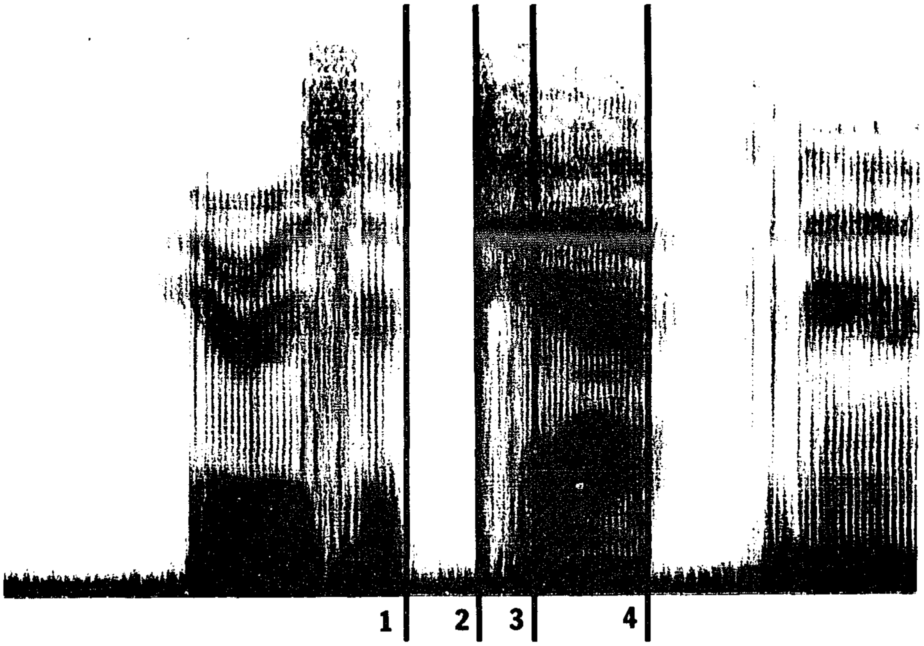


Figure II-7. Boundaries used to determine segment durations in target words containing initial stop-consonants, /t, d/.

decrease in frequency. Boundary Two was located at a position following the formant-frequency decreases at a point where F_2 and F_3 were a lower intensity than in the preceding or following transitions. Boundary Three was determined by a rise in frequency of F_2, accompanied with a sharp increase in intensity for the entire formant structure (F_1, F_2, F_3). Two other cues were associated with this boundary (a) F_3 was visible and increased in frequency in a manner paralleling the F_2 frequency rise, and (b) F_1 appeared to have its greatest bandwidth at the boundary. Boundary Four was drawn at the point where the transitions ceased increasing in frequency and remained in a steady-state position for the vowel nuclei.

These boundaries established three segments: transition one (TR1), steady-state portion (SS), and transition two (TR2). Onset of TR1 was determined by Boundary One, Boundary Two determined the offset of TR1 and the onset of SS. In addition to appearing as low-intensity, parallel formant frequencies, SS segments also were depicted by a lack of energy (or extremely low-intensity energy) in all frequencies above the voicing component of 300 Hz. Offset of SS and onset of TR2 were determined by Boundary Three. Offset of TR2 was determined by Boundary Four.

3. Fricative /s/. Onset of the fricative /s/ was located by looking for the presence of a period of noise which did not contain vertical striations around the frequency of 300 Hz. As shown in Figure II-9, Boundary One was determined by the presence of low-intensity, high-frequency noise which followed the systematic steady-state formant pattern of the preceding schwa vowel. Offset of friction was located

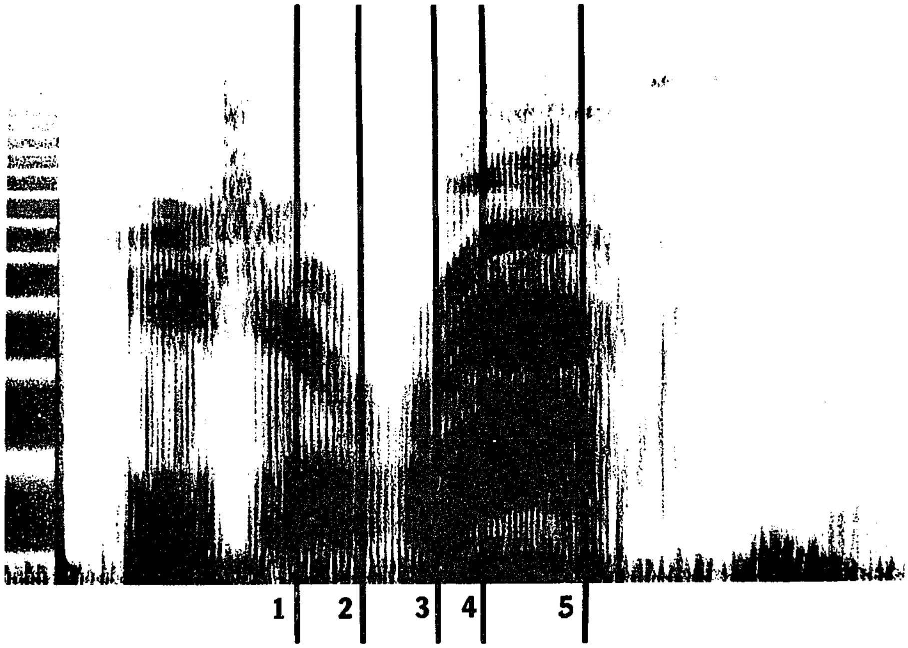


Figure II-8. Boundaries used to determine segment durations in target words containing initial consonant, /r/.

at the first vertical striation in the regions of 300 Hz, and the rising formant patterns signaling the presence of vowel nuclei were used to establish Boundary Two. In some instances, formant patterns were present in the higher frequencies of the segment, however, low-level-intensity noise was always found throughout the spectrum.

4. Cluster /tr/. Four boundaries were established to obtain the durations of the silence and voice-onset-times associated with the voiceless stop-consonant, /t/, and TR2 of the consonant, /r/, (see Figure II-10). Location of the boundaries associated with segments of the voiceless, alveolar stop-consonant, /t/, was determined in a similar manner to the method described earlier for stop-consonants. Three boundaries were associated with the durations of the segments for /t/. Boundary One was established following the systematic formant pattern associated with the schwa vowel and designated the onset of silence; Boundary Two was established at the onset of the burst; and Boundary Three was located at the first vertical striation in the frequency region of 300 Hz. Boundary Two marked the onset and Boundary Three marked the offset of the voice-onset-time measure. Boundary Three also marked the onset of the TR2 measure. A fourth boundary was placed at the point in which the transitions no longer increased in frequency and were characterized by steady-state, parallel-formant patterns associated with vertical striations in the 300-Hz region. Boundary Four represented the offset of TR2.

5. Cluster /str/. Onset of the fricative, /s/, (Boundary One) was located in exactly the same manner as previously described for the

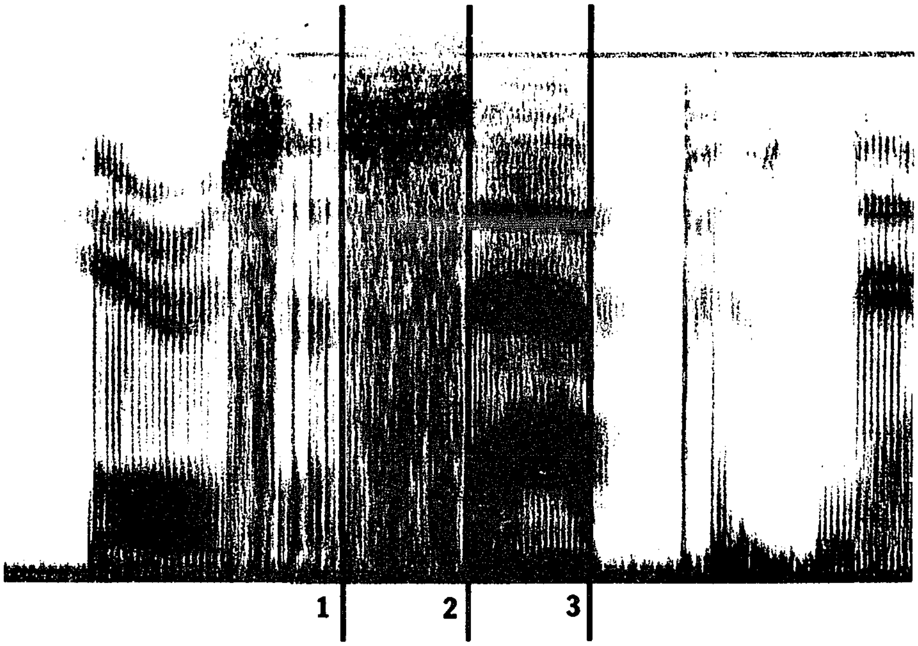


Figure II-9. Boundaries used to determine segment durations in target words containing initial consonant, /s/.

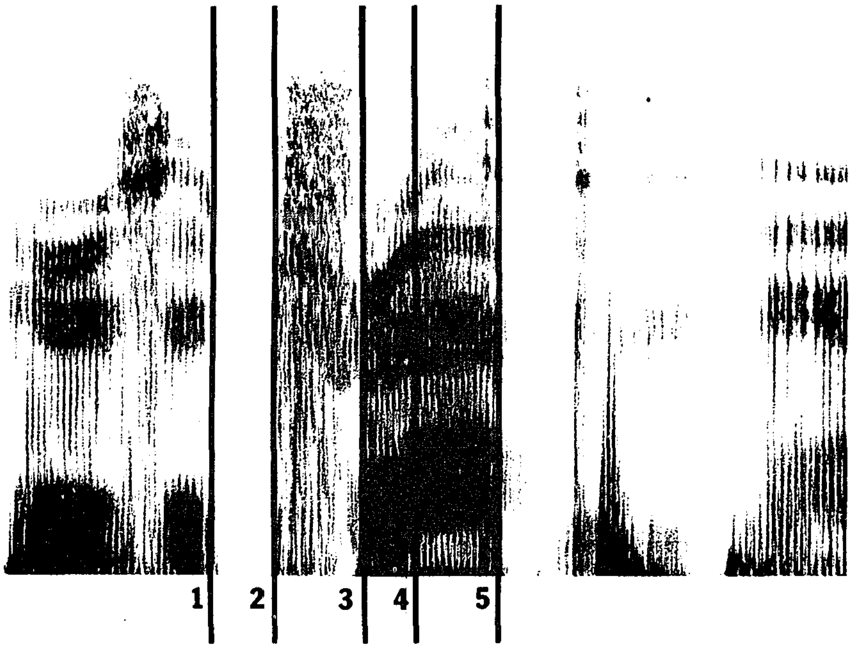


Figure II-10. Boundaries used to determine segment durations in target words containing initial consonant cluster, /tr/.

initial singleton consonant, /s/. Offset for /s/ was determined by the lack of energy around 3500 Hz, with no other energy present in the other frequency regions (see Figure II-11)--this was particularly true for utterances obtained with the appliance. Thus, Boundary Two, offset of the frication, was set following the disappearance of the flat spectrum at all frequencies. Boundary Three was set at the onset of the burst associated with the stop-consonant, /t/, and Boundary Four was set at the first vertical striation located in the voicing ranges of 300 Hz. Boundaries Three and Four were used to determine the voice-onset-time durations. Boundary Five was located at a point where the formant frequencies appeared constant and parallel to one another. Boundaries Four and Five established the duration intervals associated with TR2.

6. Vowel nuclei. Onset of the various vowel nuclei shared a common boundary with the offset of TR2 of /r/ and the first vertical voicing striation boundary of /s/, /t/, and /d/. Offset of the vowel nuclei was located at the final vertical striation of the formant patterns. Vowel nuclei included the transitions representing the initial consonants of /t, d, s/; however, selection of the final vertical striation as the determination of the final position of the vowel nuclei excluded the frictionized transitions associated with the final consonant, /p/.

7. Total-word duration. Calculations of total-word durations were acquired by adding the acoustic segments of a given target word. Onset of a target word was considered the first visible acoustic

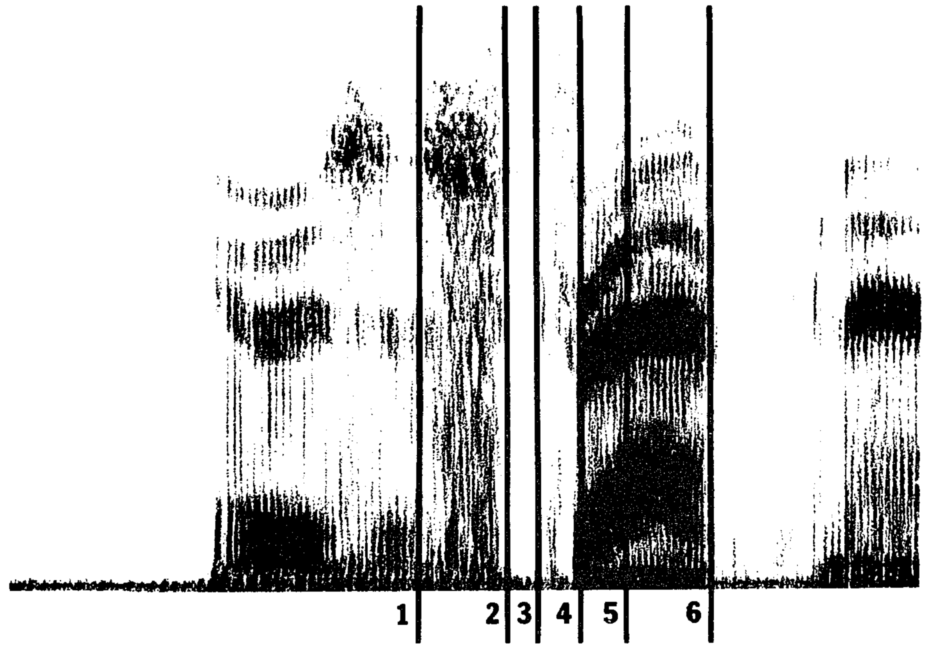


Figure II-11. Boundaries used to determine segment duration in target words containing initial consonant cluster, /str/.

segment (i.e., the burst segments in /t/ and /d/). Two segments, closure-period one and TR1, were not included in the total-word durations. Although closure-period one (silence, representing the occlusion of air flow in the vocal tract during stop-consonant production) was considered a major acoustic segment associated with stop-consonant production, it was eliminated from total-word analysis in order to avoid difficulties in separating between-word pauses and occlusal periods. TR1 segments represented the transition period of change from the schwa vowel to the following consonant and were excluded from the analysis of total-word duration. Transitions from the schwa vowel into the following initial consonants were not included for any of the target stimuli.

Total-word durations for the target words containing the initial stop-consonants, /t/ and /d/, were obtained by adding segmental durations of voice-onset-time and vowel nucleus. Acoustic segments, friction and vowel nucleus, were added to acquire total-word durations of target stimuli containing the initial singleton consonant, /s/. Similarly, the segments, voice-onset-time, TR2, and vowel nucleus, were summed to provide total-word durations for target words containing the initial two-element cluster, /tr/. Total duration of target stimuli containing the three-element consonant cluster, /str/, were acquired by adding durations of friction, closure period two, voice-onset-time, TR2, and vowel nucleus segments. Acoustic segments, SS, TR2, and vowel nucleus, were summed to provide a total-word duration of target stimuli containing /r/.

Spectral Analysis

A four-step procedure was employed for spectrally analyzing the steady-state portion of vowel nuclei. These steps included: (1) initally locating the steady-state portion of the vowel nuclei on the spectrograms used for duration measures; (2) editing four pitch periods from the steady-state portion of the vowel via computer control; (3) analyzing the four pitch periods via a Discrete Fourier Transform (DFT) program; and (4) locating the frequencies of the formants associated with the three vowels. A detailed description of each of these steps follows.

Steady-State Location. Three acoustic segments easily located in the spectrographic and waveform displays were selected as reference points: (1) the onset of burst associated with the stop consonants for the target phonemes, /t, d, tr, str/; (2) the offset of the friction for the singleton consonant, /s/; and (3) the offset of the friction for /z/ in the carrier phrase for the consonant, /r/. Duration was measured from the reference points to the steady-state portions of the vowel nuclei using the spectrographic displays. Steady-state portions of the vowel nuclei were operationally defined as the point in which the formant frequencies of F_1, F_2, and F_3 were parallel and not moving in an upward or downward direction. Duration from the reference points to the onset of the vowel steady-state were consequently converted to sample index numbers to facilitate location of the steady-state portion in the computer programs.

Extraction of steady-state periods. Sentences were played on an Ampex (Model 440G) tape recorder through an amplifier. Tokens were entered into an 8/32 Interdata computer via a 12-bit A/D converter at a 30-kHz rate. Prior to processing, tokens were passed through two, low-pass, 5000-Hz Ithico filters (Model 4251). Waveforms were displayed on a Tektronix scope (Model 4010) and edited using interactive computer programs. Signals were monitored auditorially via an amplifier and speaker.

Samples were edited by locating the reference points in the waveforms. Onset of the reference points was set at the beginning buffer address. The first 200 msec of the samples were displayed and a cursor was used to determine the first zero crossing associated with the first pitch period of the steady-state portion. The sample was shifted until the first zero crossing was the beginning buffer address. Offset of the pitch periods was determined by displaying the waveform and determining the last zero crossing associated with the four pitch periods. Samples were labeled and stored on magnetic tape for later analysis.

Spectral analysis. Tokens were analyzed using a DFT which specified the spectrum using a Cooley-Tukey algorithm (Cooley and Tukey, 1965). A data record length of 512 points and a Kaiser data window of 510 points were employed in the program (Reimer and Cullen, 1979). Spectra were pre-emphasized, linearly displayed, and normalized to the highest point. Output of the DFT program rendered a pictorial display of the spectrum, as well as amplitude and frequency values of the sampled points.

CHAPTER III

RESULTS

Results obtained from RTP and LTP subjects for oral- and limb-apraxia assessment (Descriptive Study I--Oral- and Limb-Apraxia Assessment) are presented first. A description of the articulation characteristics of the RTP and LTP groups is presented in the discussion of the results obtained in Descriptive Study II--Articulation Assessment. The final portion of this chapter is devoted to the presentation of the results obtained in the Experimental Study--Forced Adaptation.

Descriptive Study I-- Oral- and Limb-Apraxia Assessment

Mean score of the oral-apraxia items is 18.5 and 18.1 for the RTP and LTP groups, respectively. Scores for the RTP subjects range between 20 to 17. Slightly lower scores, ranging from 19 to 16.5, are noted for the LTP group. Average scores of 16.4 and 12.1 are achieved by the RTP and LTP groups, respectively, for the items assessing limb apraxia. Scores on the limb-apraxia items range from 18 to 15.5 for the RTP subjects and 16 to 6.0 for the LTP subjects.

De Renzi and his colleagues (De Renzi et al., 1966) used a score of 16 as the cut-off point for classifying a subject orally apraxic; however, no subject in either the LTP or RTP groups scored lower than 16.5. Table III-1 shows the oral-apraxia items for the RTP group ranked in terms of relative difficulty. Items requesting subjects to

TABLE III-1

RELATIVE DIFFICULTY OF ORAL-APRAXIA ITEMS FOR RTP GROUP

Item	Mean Score	Rank
10. Clear your throat.	20.0	1
1. Stick out your tongue.	19.0	2
2. Yawn.	19.0	2
5. Give a Bronx Cheer.	19.0	2
6. Show how you would kiss someone.	19.0	2
8. Click your tongue, imitating the sound of a horse galloping.	19.0	2
9. Puff or blow.	19.0	2
3. Whistle.	17.5	3
4. Try to touch the tip of your nose with your tongue.	17.5	3
7. Show how your teeth chatter when you are cold.	17.5	3

'whistle,' 'chatter the teeth as if one is cold,' and 'touch the tip of the nose with the tongue' appear more difficult to execute relative to the other items for the RTP group. Table III-2 illustrates the relative difficulty of the oral-apraxia assessment items for the LTP group. Two of the oral-apraxia assessment items which appeared difficult for the RTP group, 'whistle' and 'chatter the teeth as if it is cold,' present no difficulty for LTP subjects as designated by perfect scores of 20. Two items which appear to create the most difficulty for the LTP group are requests to 'show how you would kiss someone' and 'click your tongue imitating the sound of a horse galloping.' Scores on oral-apraxia assessment items fall in a tighter range for the RTP group (20 to 17.5) than for the LTP group (20 to 15).

A cut-off score of 17 was used by De Renzi and his colleagues (De Renzi et al., 1966) to establish the presence of limb apraxia, while a cut-off score of 11 distinguished mild from severe limb apraxia. All subjects in the RTP and LTP groups, with the exception of one RTP subject, achieved scores which were below the cut-off score of 17 suggesting subjects in this study performed poorer than the De Renzi et al. (1966) subjects on the limb-apraxia items. Only one LTP subject scored below the cut-off score of 11 used to distinguish between mild and severe limb apraxia.

Table III-3 indicates the relative difficulty of the limb-apraxia items for the RTP group. Three items received a perfect score for all the RTP subjects--'salute,' 'wave goodbye,' and 'indicate someone is crazy.' The most difficult item to execute for the RTP subjects was

TABLE III-2

RELATIVE DIFFICULTY OF ORAL-APRAXIA ITEMS FOR LTP GROUP

Item	Mean Score	Rank
3. Whistle.	20.0	1
7. Show how your teeth chatter when you are cold.	20.0	1
9. Puff or blow.	20.0	1
10. Clear your throat.	20.0	1
1. Stick out your tongue.	19.0	2
2. Yawn.	17.5	3
4. Try to touch the tip of your nose with your tongue.	17.5	3
5. Give a "bronx cheer."	17.5	3
6. Show how you would kiss someone.	15.0	4
8. Click your tongue, imitating the sound of a horse galloping.	15.0	4

TABLE III-3

RELATIVE DIFFICULTY OF LIMB-APRAXIA ITEMS FOR RTP GROUP

Item	Mean Score	Rank
2. Salute.	20.0	1
3. Wave goodbye.	20.0	1
9. Indicate someone is crazy.	20.0	1
6. Thumb your nose.	19.0	2
7. Snap your fingers.	18.0	3
4. Threaten someone with your hand.	17.5	4
1. Make the sign of the cross.	15.0	5
8. Make the sign of the Texas longhorn.	15.0	5
10. Make the letter "O" with your fingers.	15.0	5
5. Show you are hungry.	6.3	6

'show your are hungry.' Examination of Table III-4 shows overall performance of the LTP group is lower than limb apraxia performance of the RTP group. Although the LTP group also had little difficulty executing the command to 'wave goodbye,' overall mean score for this item by LTP subjects was 5 points lower than the RTP group. The most difficult item, 'show you are hungry', for the RTP group (mean score 6.25) appears to be an easier item to execute for the LTP group, as indicated by the mean score of 15. The most difficult items for LTP subjects to execute were requests to 'make the sign of the cross' and to 'thumb the nose' (mean scores of 6.3) which fall in the mid-range of difficulty for the RTP group (mean scores 15 and 19, respectively).

Descriptive Study II--
Articulation Assessment

A greater number of discrimination errors are found for the LTP subjects (37 errors) than for the RTP subjects (16 errors). A greater number of articulation errors are found in the RTP group (a total of 40) than in the LTP group (a total of 34); however, 23 of the articulation errors in the RTP group are contributed by one subject.

The majority of discrimination errors for the two groups occur on initial consonants, 10 errors for the RTP group and 19 errors for the LTP group. Discrimination of final-position consonants produce 2 errors in the RTP group compared to 14 errors for the LTP group. Both groups failed to correctly discriminate four vowel contexts.

The majority of misarticulations for RTP and LTP groups occur on the initial consonants--RTP subjects produced 26 errors and LTP subjects produced 22 errors. These results agree with previous reports

TABLE III-4

RELATIVE DIFFICULTY OF LIMB-APRAXIA ITEMS FOR LTP GROUP

Item	Mean Score	Rank
3. Wave goodbye.	15.0	1
5. Show you are hungry.	15.0	1
7. Snap your fingers.	15.0	1
4. Threaten someone with your hand.	13.8	2
8. Make the sign of the Texas Longhorns.	13.8	2
10. Make the letter 'O' with with your fingers.	12.5	3
2. Salute.	10.0	4
9. Indicate someone is crazy.	8.8	5
1. Make the sign of the cross.	6.3	6
6. Thumb your nose.	6.3	6

indicating the majority of articulation errors in subjects with cortical lesions occur in the initial position of target assessment words [see, for example, Shankweiler and Harris (1966)]. RTP subjects produced 14 errors and LTP subjects produced 12 errors on final position consonants.

The RTP group produced twice as many place substitutions as the LTP group. Sixteen place substitutions in initial consonant positions, and four place substitutions in final consonant positions were produced by the RTP group. LTP subjects produce seven initial-consonant and three final-consonant place substitutions.

Experimental Study--
Forced Adaptation

Speech production measures acquired during normal (free-moving jaw) and restricted-jaw speaking are organized and presented around four central questions. First, do frequency and duration measures of speech segments produced by the Control subjects during free-moving jaw conditions parallel previous reports? Second, are frequency and duration measures acquired from the cortically injured groups during free-moving-jaw conditions similar to the Control group values? Third, what are the response patterns (as represented by temporal and spectral measures) generated by Control subjects during restricted-jaw speaking? Fourth, are response patterns generated in the restricted-jaw condition by the cortically injured groups similar to the response patterns generated by the Control group? Speech production in normal and restricted-jaw speaking is examined in two respects--the patterns associated with formant and fundamental frequencies of the vowel nuclei and the duration patterns of total-word and individual segments.

Statistical analysis was accomplished in the following manner. Control subjects were arbitrarily partitioned into two groups of four subjects each in order to make direct comparisons to the two pathological groups. Analysis-of-variance procedures were used to examine similarities and differences in speech production of the four groups, Controls 1 and 2, and RTP and LTP. Three additional orthogonal breakdowns were used to examine group interactions found in the analysis of variance contrasting the four groups. The first orthogonal breakdown examined only the Control data to rule out any group effects attributable to the arbitrary partitioning of the subjects. The second orthogonal breakdown evaluated only the RTP and LTP data in order to determine similar and different response patterns produced in the restricted-jaw-speaking condition by the two cortically injured groups. The third orthogonal breakdown collapsed the control data into a single Control group and collapsed the RTP and LTP data into a single Pathological group as a means of evaluating the differences in response patterns produced by Control subjects and cortically injured subjects, regardless of side of lesion, in the restricted-jaw-speaking condition. Summary tables of significant values found in the analysis-of-variance procedures are in Appendix B.

Frequency Measures of Vowel Nuclei in Normal Speaking

Although several approaches are used to assess formant- and fundamental-frequency patterns generally associated with contextual speech production, it seems reasonable to limit the assessment to three considerations. First, do formant and fundamental frequencies reflect vocal tract area/length relationships normally associated with vowel production? Second, do mean formant and fundamental frequencies of the vowel nuclei correspond to previous reports of normal male speakers producing contextual speech? Third, are formant and fundamental frequencies of the vowel nuclei influenced by the initial consonant or cluster contexts?

Formant frequencies in normal speaking. Table III-5 illustrates formant and fundamental frequencies for the Control, RTP, and LTP groups during normal (free-moving-jaw) speaking. (Means representing the Control groups 1 and 2 are collapsed on all tables and figures shown in this section, since the Control subjects are arbitrarily partitioned into two groups only for statistical analysis.) Formant frequencies produced in a sustained hVd context (Peterson and Barney, 1952) and in bisyllabic nonsense syllables (Stevens and House, 1963) are shown for comparison purposes. Control subjects and the male speakers in the two comparison studies produced comparable formant frequencies for /i/ and /ae/. Large formant-frequency differences occurred for the vowel /u/; however, these differences in the case of the Peterson and Barney (1952) study are probably attributable to the inclusion of /u/ in our particular contextual frame and in the case of the Stevens and House (1963) study probably are contributed by the dental contexts (i.e., /s, t, d/) which often result in appreciable shifts (nearly 300 Hz) in F_2 and F_3 frequencies for /u/ [see, for

TABLE III-5

AVERAGE FUNDAMENTAL AND FORMANT FREQUENCIES FOR CONTROL, RTP, AND LTP GROUPS IN NORMAL SPEAKING

Frequencies		Vowels (Hz) /i/	/ae/	/u/
Fundamental				
	Control	142	126	146
	RTP	131	117	138
	LTP	135	121	138
	P & B[1]	136	127	141
Formant				
F_1				
	Control	298	724	351
	RTP	279	700	305
	LTP	308	680	373
	P & B[1]	270	660	300
	S & H[2]	300	730	320
F_2				
	Control	2194	1629	1412
	RTP	2128	1591	1235
	LTP	2126	1570	1279
	P & B[1]	2290	1720	870
	S & H[2]	2260	1650	1110
F_3				
	Control	2682	2402	2185
	RTP	2567	2377	2178
	LTP	2536	2365	2154
	P & B[1]	3010	2410	2240
	S & H[2]	2910	2500	2200

[1] Values taken from Peterson, G. and Barney, H. Control methods used in a study of the vowels. J. Acoust. Soc. Am., 24:175-184 (1951).

[2] Values taken from Stevens, K. and House, A. Perturbations of vowel articulation by consonant context: An acoustical study. J. Speech Hear. Res., 6:111-128 (1963).

example, Stevens and House (1963) and Fant, Stalhammer, and Karlsson (1974)]. Formant patterns of the Control group also paralleled previous studies reporting the shifting of formant frequencies to more central positions during contextual speech [see, for example, Lindblom (1963)].

Formant frequencies of the cortically injured groups resembled formant frequencies produced by the Control group and the two comparative studies. Control subjects produced higher F_1 frequencies for /ae/ nuclei than either the RTP or LTP groups; however, LTP subjects produced higher F_1 frequencies for the vowel nuclei /u/ and /i/ than the RTP or Control groups. Control subjects produced higher F_2 and F_3 frequencies, regardless of vowel identity, than either the RTP or LTP subjects. Mean F_2 frequencies of the RTP group were higher than the LTP group values for the vowels /ae/ and /i/; however, the RTP group produced lower F_2 frequencies for /u/ than the LTP group. RTP subjects produced higher F_3 frequencies than the LTP subjects for /i/ and /u/ but lower F_3 values for /ae/. In general, the formant-frequency patterns indicate Control, RTP, and LTP groups adjusted articulatory dimensions underlying vocal tract area/length relationships during normal (free-moving-jaw) speaking in a manner similar to male speakers in previous studies.

Figure III-1 illustrates the mean formant frequencies of the three groups as a function of initial consonant or cluster context on a logrithmic scale. Minimal shifts are found in F_1 frequencies as a function of the various initial consonants; however, F_2 and F_3

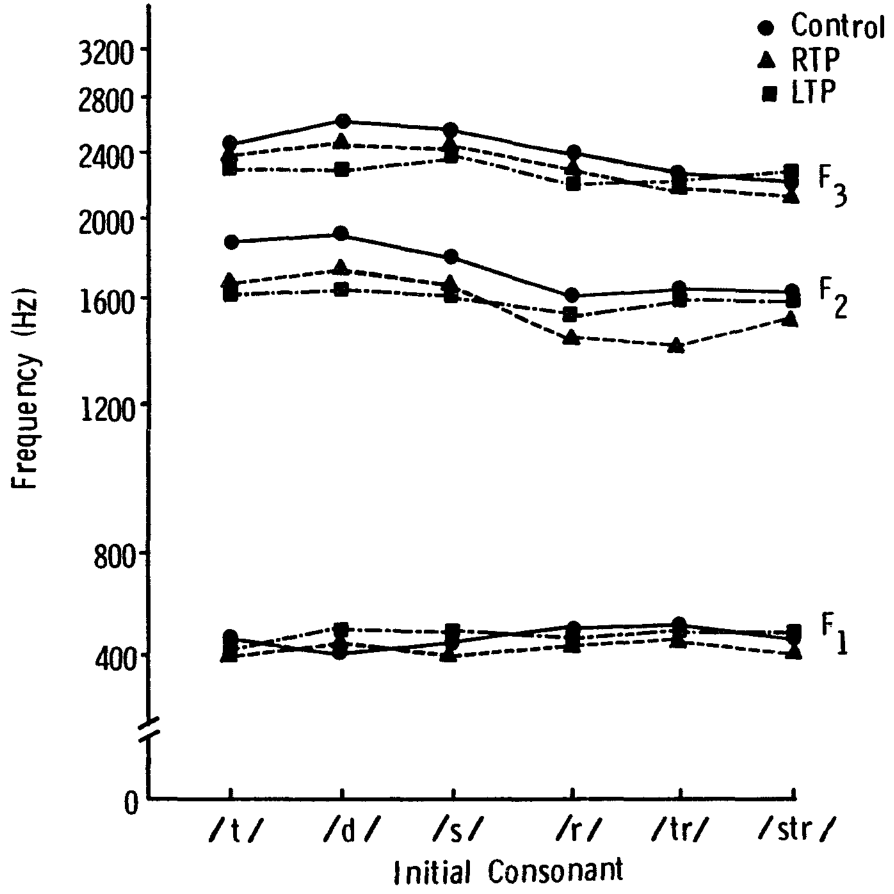


Figure III-1. Formant frequency as a function of initial consonant or cluster produced by Control, RTP, and LTP groups during normal speaking.

frequencies tend to shift in value as a function of initial consonants for each of the three groups.

In Figure III-2, a linear plot of F_2 frequencies produced in the various initial consonant or cluster contexts are shown for the RTP, LTP, and Control groups. (For the sake of keeping this discussion to a managable size, only F_2 measures are examined further--F_3 measures parallel the F_2 frequencies for each group.) Control subjects produced higher F_2 frequencies following the singleton consonants, /t, d, s/, than for the initial consonants containing /r/. A similar frequency pattern also occurred for the two cortically injured groups--F_2 frequencies were higher in /t, d, s/ contexts than contexts containing /r/. As noted earlier, the Control group produced higher F_2 frequencies than either of the cortically injured groups. RTP subjects produced higher F_2 frequencies than the LTP group in initial contexts containing /t, d, s/ and lower F_2 frequencies in the contexts containing /r/. The reliability of these measures and the differences noted between the groups are verified by significant group-by-consonant [$F=2.02$, $df=15,60$ ($p<.01$)] and Control/Pathological-by-vowel-by consonant interaction [$F=2.873$, $df=10,120$ ($p<.01$)].

Fundamental frequencies in normal speaking. Table III-5 also shows fundamental frequencies of the Control, RTP, and LTP groups. In addition, fundamental frequencies obtained from normal male speakers in the Peterson and Barney (1952) study are shown. Fundamental frequencies produced by the Control, RTP, and LTP groups are similar to the frequencies reported in Peterson and Barney (1952). Although the

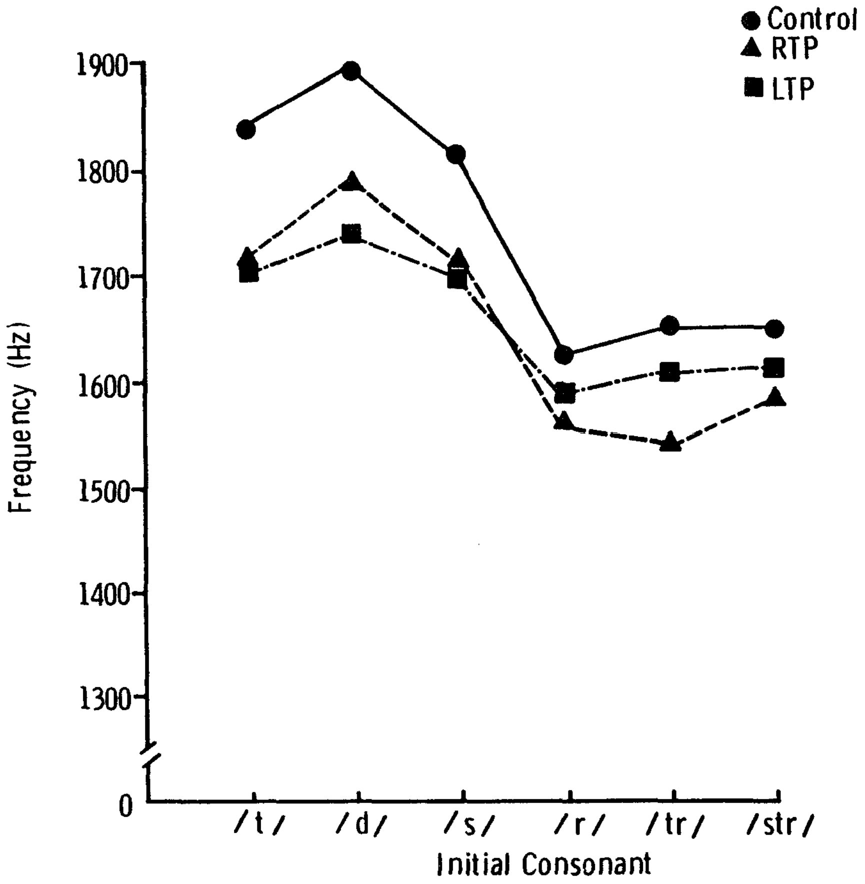


Figure III-2. Mean F_2 frequency as a function of initial consonant or cluster produced by Control, RTP, and LTP groups during normal speaking.

Control group produces higher fundamental frequencies than either the RTP or LTP groups, these differences are small and only on the order of 5 or 6 Hz.

Figure III-3 illustrates the fundamental frequencies of the three groups as a function of the initial consonant or cluster contexts. The pattern of fundamental-frequency relationships is similar for all groups--fundamental frequency is lower for the voiced, singleton consonants, /d/ and /r/, and higher for the voiceless, singleton consonants, /t/ and /s/. The reliability of these measures is verified by significant consonant [F=43.87, df=5,60 (p<.01)] and vowel-by-consonant [F=47.15, df=1,12 (p<.01)] interactions in the analysis of variance.

Frequency Measures of Vowel Nuclei in Restricted-Jaw Speaking

The previous review of formant and fundamental frequencies suggests the Control, RTP, and LTP groups adjusted articulatory dimensions underlying vocal tract area/length relationships in a manner similar to previous reports of male speakers during normal (free-moving-jaw) speaking. In addition, normal-speaking formant and fundamental frequencies of the three groups appeared to be influenced in a systematic fashion generally associated with initial consonants.

A number of questions arise regarding formant and fundamental frequencies generated during restricted-jaw speaking. First, do the acoustic consequences of restricted-jaw speaking in Control subjects, as represented by formant and fundamental frequencies, reflect adjustments to the articulatory dimensions underlying vocal tract

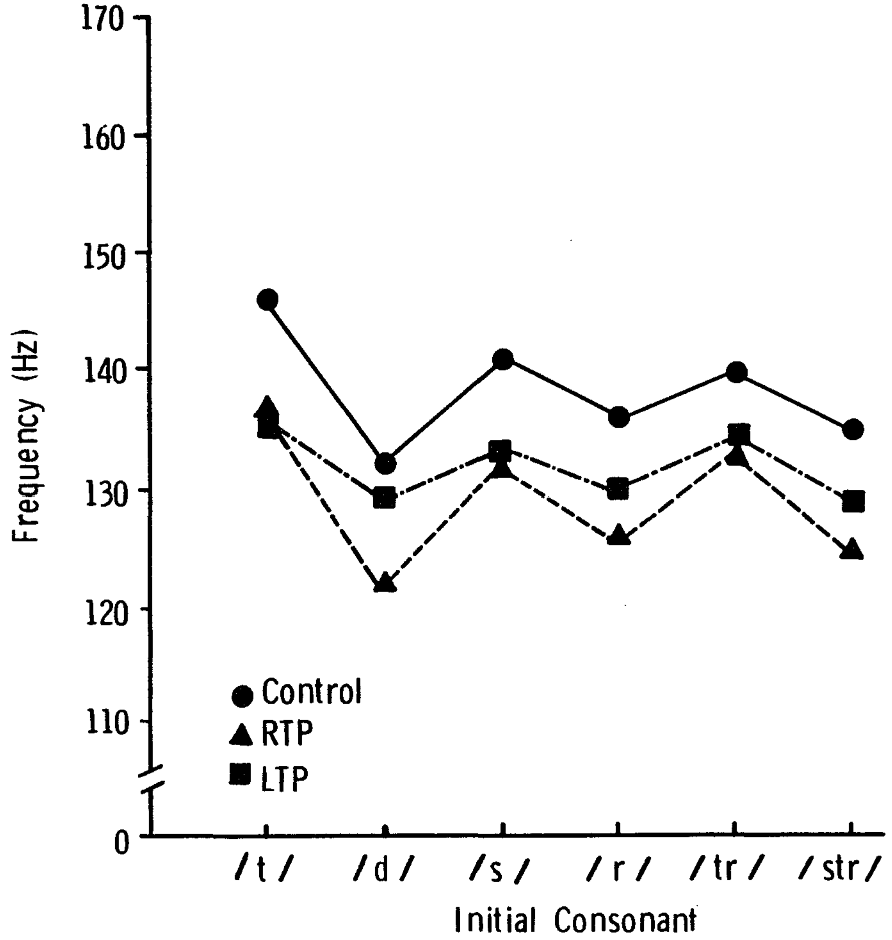


Figure III-3. Mean fundamental frequency as a function of initial consonant or cluster produced by Control, RTP, and LTP groups during normal speaking.

area/length relationships? Adjustments to the articulatory dimensions may appear in two possible response patterns. Response Pattern One hypothesizes the Control formant frequencies will parallel previous reports investigating isolated vowel production during restricted-jaw speaking. That is, subjects may produce rapid, accurate adjustments which result in comparable formant frequency values between normal and restricted-jaw speaking. Response Pattern Two, on the other hand, hypothesizes Control subjects may adjust articulatory dimensions in a manner which does not produce comparable formant frequency values in normal and restricted-jaw speaking, but renders perceptually acceptable productions of the vowel nuclei. That is, subjects may adjust articulatory dimensions within a range of values capable of producing a given vowel but not necessarily resulting in exactly the same output. Second, do cortically injured subjects employ similar articulatory adjustments during restricted-jaw speaking? Third, do response patterns generated during restricted-jaw speaking take into account the initial consonant-to-frequency relationships seen in normal speaking?

Formant frequencies in restricted jaw speaking. Formant-frequency response patterns for the three groups are depicted in Figure III-4. Frequency Response Pattern One, comparable formant values between the two speaking conditions, is evident for the F_1 frequencies of the three groups. Only minimal, non-significant shifts occur for F_1 frequencies produced by the three groups in restricted-jaw speaking.

Frequency Response Pattern Two, different formant frequencies in the two speaking conditions, is found for the F_2 and F_3 measures of the

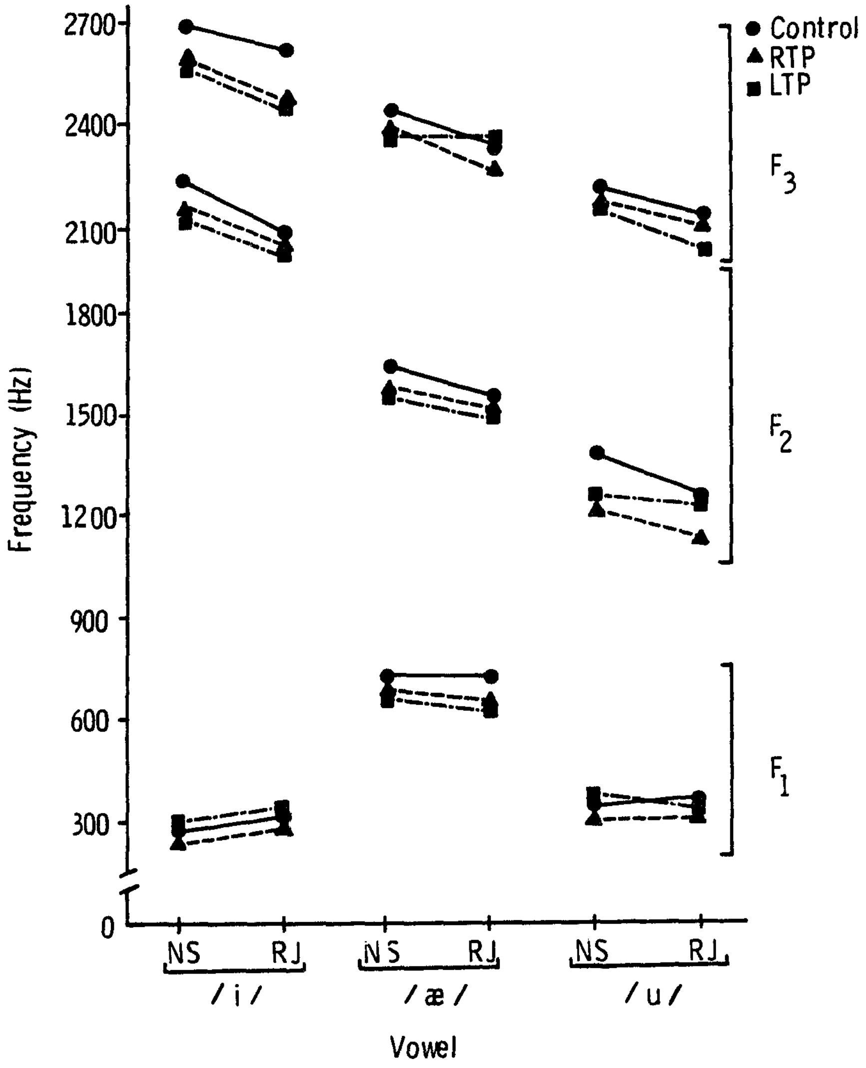


Figure III-4. Mean F_1, F_2 and F_3 frequencies as a function of speaking condition for Control, RTP, and LTP groups.

Control, RTP, and LTP groups. Significantly lower F_2 frequencies are produced by the Control subjects [F=86.88, df=1,6 (p<.01)] and cortically injured groups [F=10.595, df=1,6 (p<.01)]. Similarly, significantly lower F_3 values occur during restricted-jaw speaking for the Control [F=35.067, df=1,6 (p<.01)] and cortically injured groups [F=20.59, df=1,6 (p<.01)].

The F_2 and F_3 response patterns generated during restricted-jaw production are interesting because F_2, and to a lesser extent F_3, reflect the degree and location of tongue constriction in the vocal tract. It is possible the shifts in F_2 represent a change in articulatory dimensions which consequently produce more schwa-like, or centralized, frequencies. If subjects adjust articulatory strategies to produce more schwa-like formant frequencies, one would expect to see F_2 lower for /i/, remain relatively constant for /ae/, and increase for /u/. Examination of Figure III-5, however, reveals this is not the case for any of the groups. Control subjects show minimal F_1 and large F_2 shifts resulting in an overall lowering of the vowel triangle. LTP subjects produce a somewhat narrower vowel triangle (reflecting a smaller range of F_1 frequencies) than Control subjects but LTP subjects lower F_2 in a similar response pattern during restricted-jaw speaking. RTP subjects lower F_2 frequencies during restricted-jaw speaking but, contrary to Control and LTP groups, RTP subjects also increase F_1 slightly.

Figure III-6 shows the mean F_2 values of Control, RTP, and LTP groups as a function of speaking condition. As mentioned earlier,

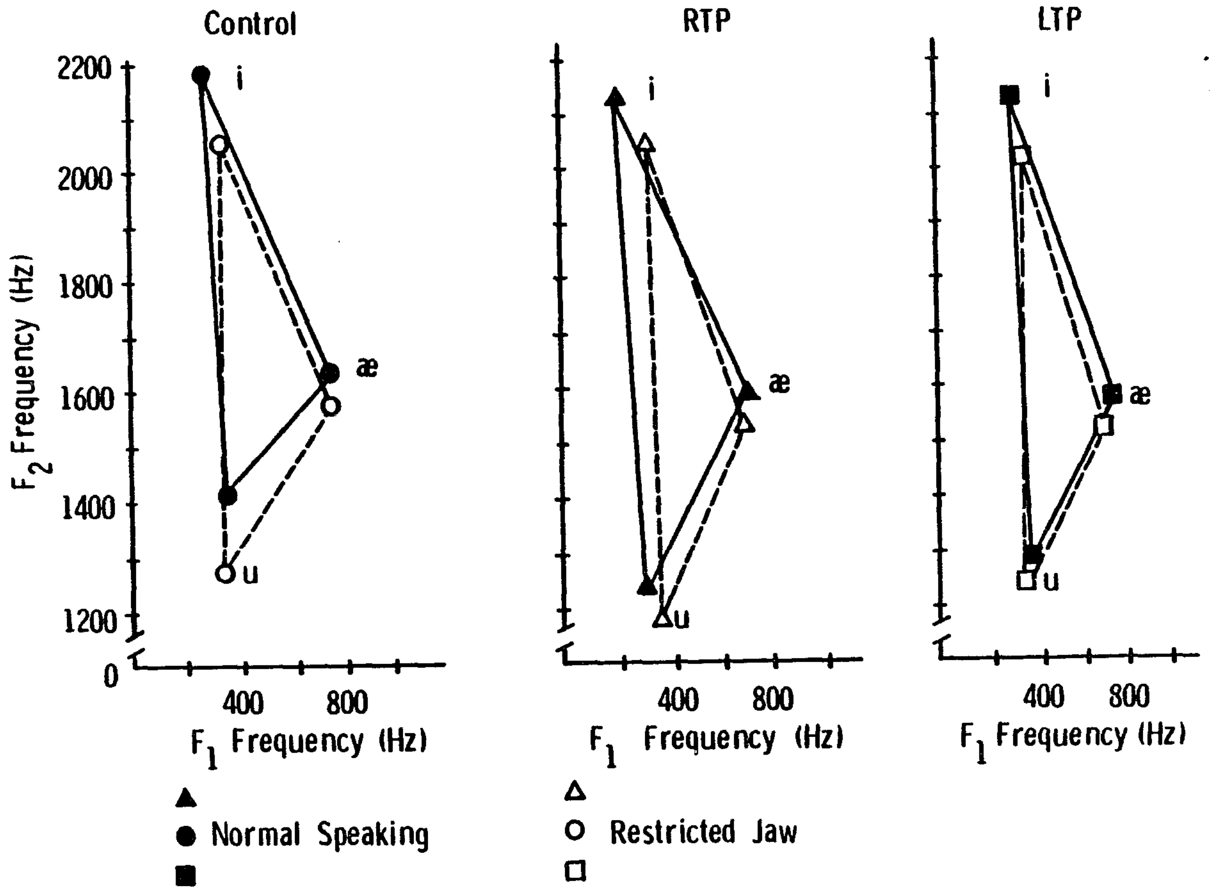


Figure III-5. Mean F_1 and F_2 formant frequency as a function of speaking condition produced by Control, RTP, and LTP groups.

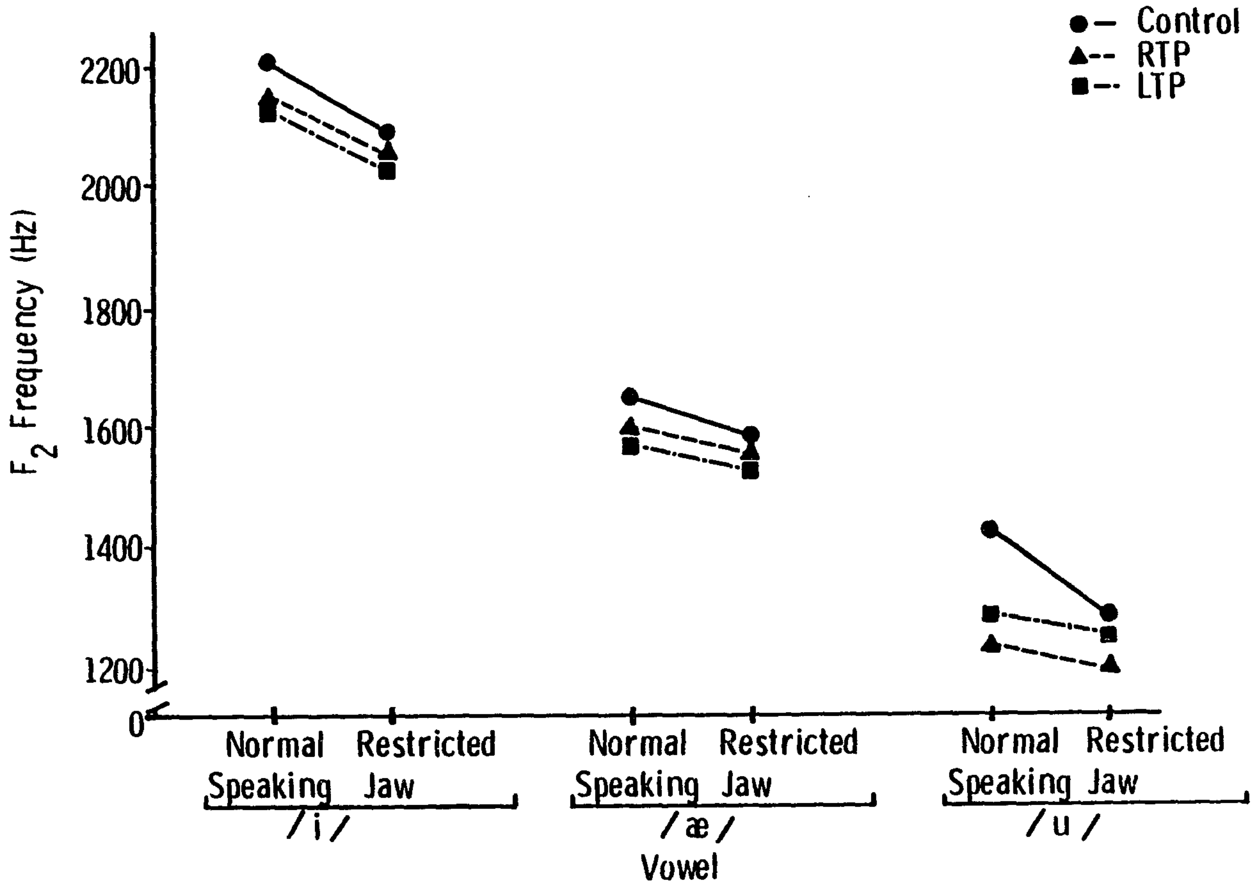


Figure III-6. Mean F_2 frequencies as a function of speaking condition for Control, RTP, and LTP groups.

values for each of the groups are lower during restricted-jaw speaking; however, the greatest change in frequency occurs for the Control group, in the high, front and back vowels, /i/ and /u/. The greatest frequency shifts occur for /i/ in the two cortically injured groups. A significant vowel-by-condition interaction occurs in the orthogonal breakdown examining only the F_2 values of Control subjects [F=7.63, df=2,12 (p<.01)]; however, no significant vowel-by-condition or group-by-vowel-by-condition interactions occurred in the additional analyses contrasting the RTP-LTP data or the Control-Pathological data.

Figure III-7 depicts F_2 as a function of initial consonant and speaking condition for the three groups. In general, the picture is similar for the three groups. Major points include the obvious--lower F_2 frequencies are produced by each group relative to the normal speaking condition and higher F_2 frequencies are produced by the Control group relative to the cortically injured groups. RTP subjects produce higher F_2 frequencies in /t, d, s/ contexts and lower F_2 frequencies in /r/ contexts than the LTP group. No major differences in the pattern of response are noted for the groups and confirmed by the lack of a significant consonant-by-vowel-by-condition interaction.

A response pattern of lower F_2 frequencies for vowels produced in contextual frameworks differs from previously reported response patterns for isolated-vowel production [see, for example, Lindblom et al. (1979)]. However, Control, RTP, and LTP subjects may adjust articulatory dimensions underlying F_2 frequencies with practice. Figure III-8 illustrates the mean F_2 values of the three groups as a

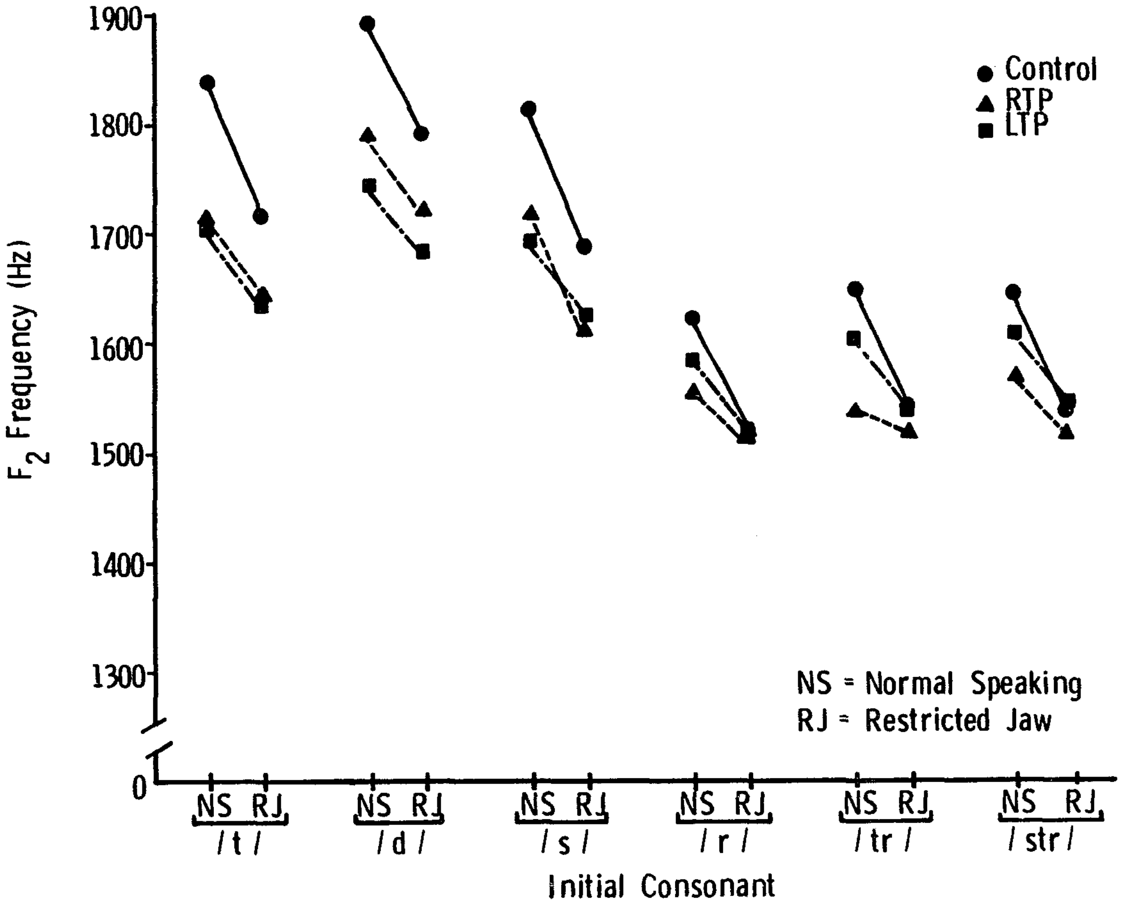


Figure III-7. Mean F_2 frequency as a function of initial consonant or cluster produced by Control, RTP, and LTP groups during normal and restricted-jaw speaking.

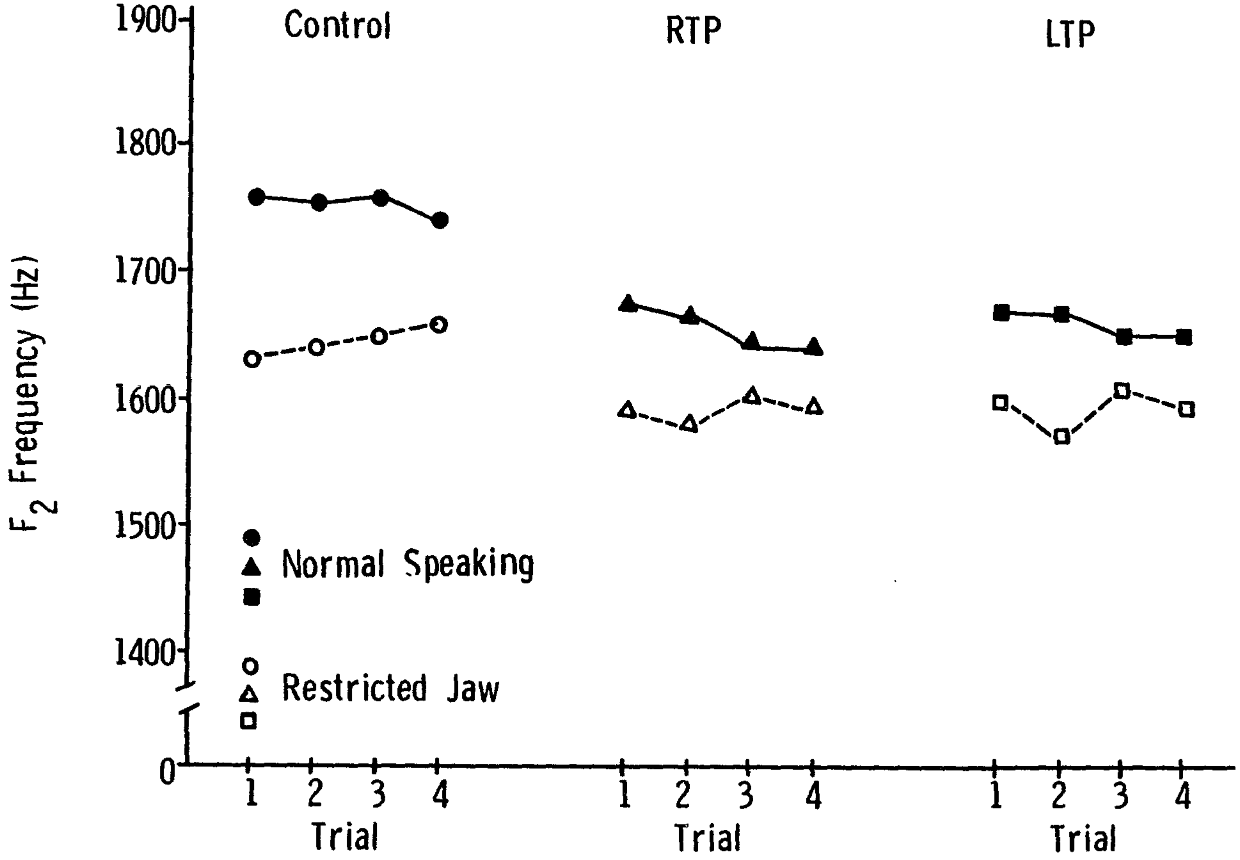


Figure III-8. Mean F_2 frequency as a function of trial and speaking condition for Control, RTP, and LTP groups.

function of trial during normal and restricted-jaw speaking. Control subjects produce fairly consistent F_2 frequencies across normal-speaking trials; however, F_2 frequencies during restricted-jaw speaking appear to increase and approach the frequencies produced during normal speaking. Less consistent F_2 frequencies are produced by RTP and LTP groups during normal speaking and a similar pattern of increasing F_2 frequencies during restricted-jaw speaking is not found for the two cortically injured groups.

Figure III-9 illustrates this observation in a slightly different fashion. Standard deviations of the mean-formant frequencies produced during the two speaking conditions as a function of trial are shown for each of the groups. Standard deviations of the Control group vary minimally as a function of either speaking condition or trial. The two cortically injured groups are more variable in normal speaking than the Control subjects, as indicated by the larger standard deviations. However, the most striking aspect of this figure is the reduced variability (indicated by smaller standard deviations) occurring for each of the three groups during the restricted-jaw condition. These observations are verified by the analysis of variance which indicates a significant condition-by-repetition interaction for F_2 [F=5.104, df=3,86 ($p<.01$)]. Further analysis reveals the significant condition-by-repetition interaction for F_2 measures is contributed primarily by the Control data [F=5.05, df=3,18 ($p<.01$)]--no significant condition-by-repetition effect occurs in the evaluation of the RTP and LTP groups.

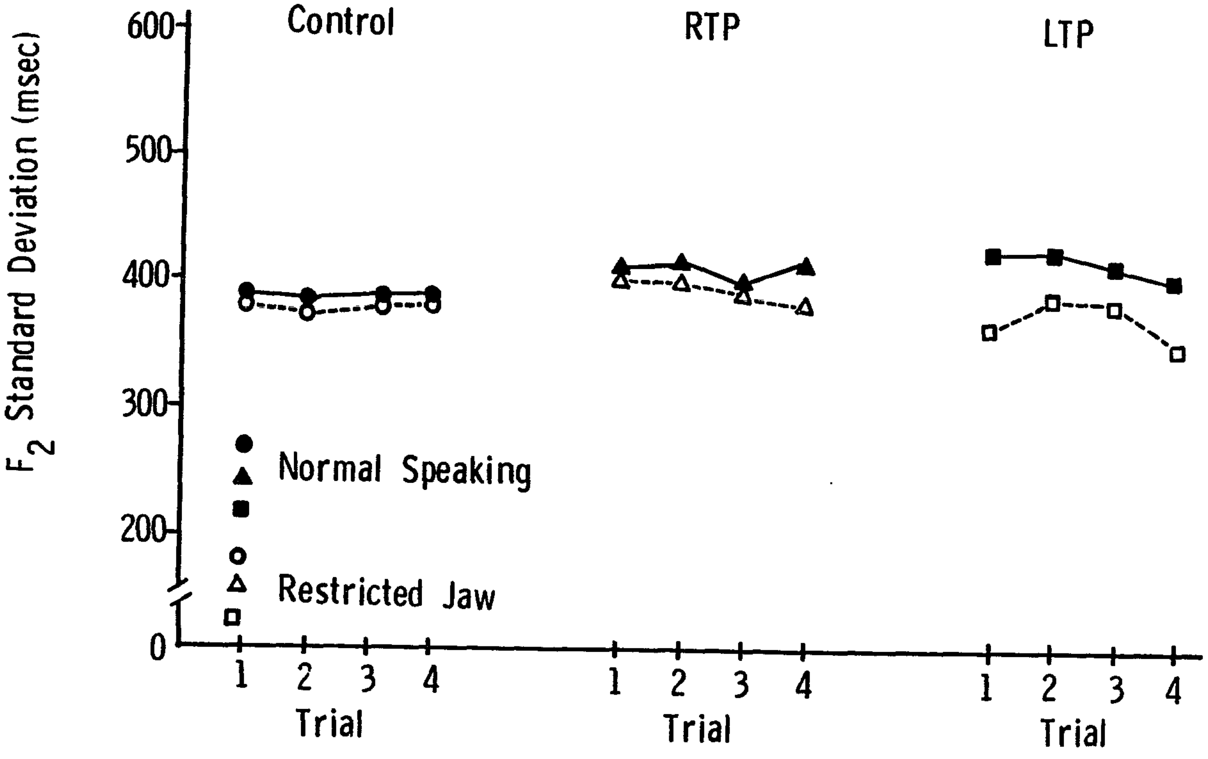


Figure III-9. Mean standard deviation of F_2 as a function of trial and speaking condition produced by Control, RTP, and LTP groups.

Fundamental frequency measures. Fundamental frequency for each of the groups as a function of speaking condition is shown in Figure III-10. Control, RTP, and LTP groups produce a Response Pattern Two for fundamental frequency. Fundamental frequency for each group increases during the restricted-jaw-speaking condition; however, the increases in /ae/ for the RTP group are only on the order of 2 or 3 Hz. These observations are confirmed by a significant main effect for condition [F=47.15, df=1,12 (p<.01)] and a significant vowel-by-condition interaction [F=17.524, df=2,24 (p<.01)].

Fundamental frequency as a function of initial consonant and speaking condition is shown in Figure III-11 for the Control, RTP, and LTP groups. In general, patterns of contextual influence (e.g., higher fundamental frequencies for /t/ and /s/) are retained during restricted-jaw speaking by each of the groups--the major difference between the two conditions is the overall increase in fundamental frequency during restricted-jaw speaking.

Summary of Frequency Measures of Vowel Nuclei

Table III-6 summarizes the frequency-response patterns as a function of initial consonant and vowel nuclei for Control, RTP, and LTP speakers. Frequency increases during restricted-jaw speaking are designated by a plus (+), frequency decreases are designated by a minus (-), and no frequency change is designated by a zero (0). The table provides a rather gross estimate of the average magnitude of frequency shift, as well as summarizing the frequency patterns produced in restricted-jaw speaking. For example, if a given frequency increases

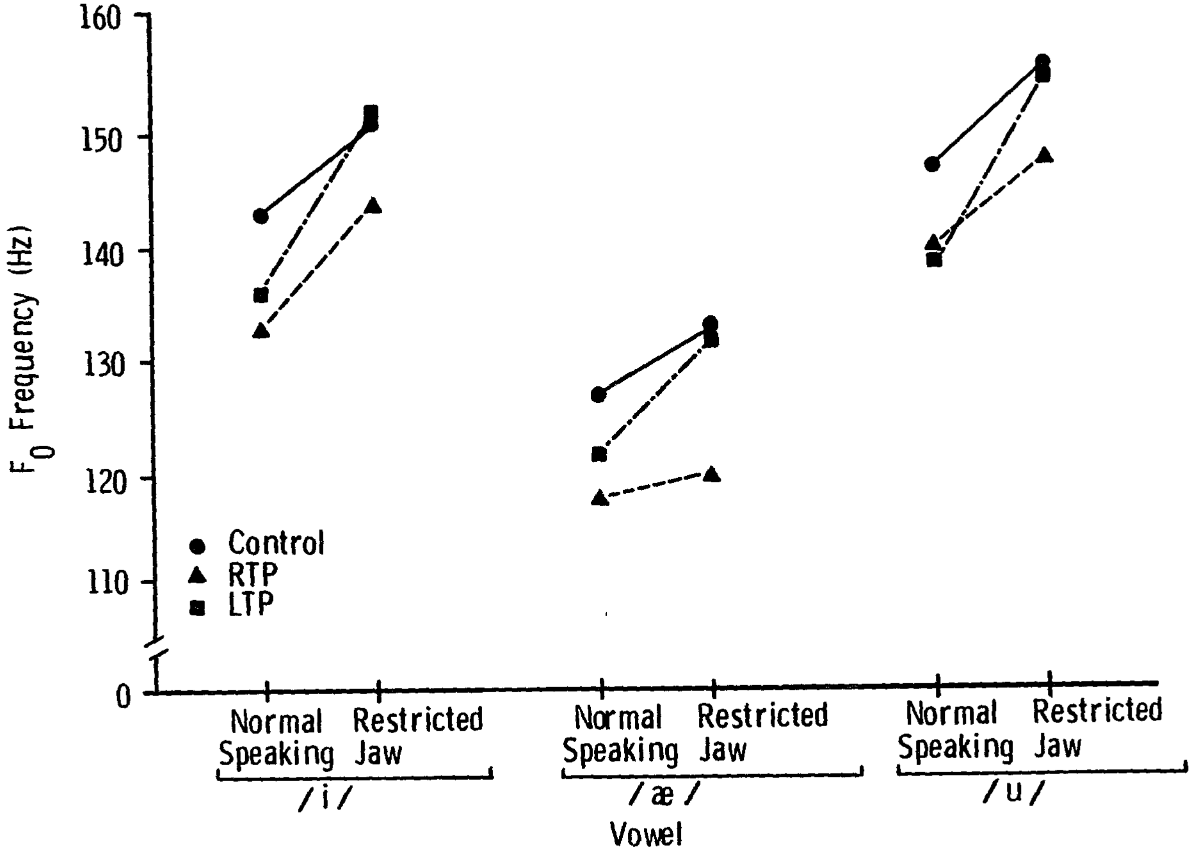


Figure III-10. Mean fundamental frequency produced during normal and restricted-jaw speaking by Control, RTP, and LTP groups.

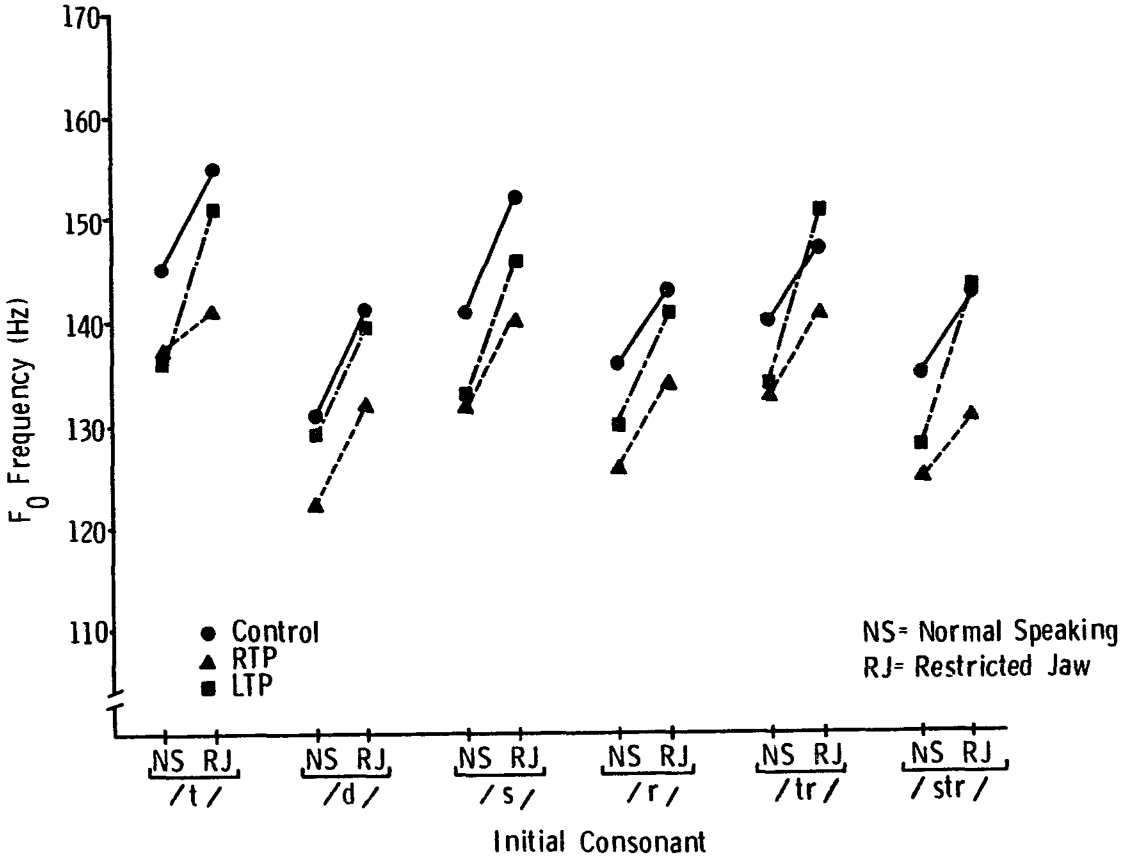


Figure III-11. Mean fundamental frequency as a function of initial consonant or cluster produced by Control, RTP, and LTP groups during normal and restricted-jaw speaking.

Table III-6

SUMMARY OF FREQUENCY-RESPONSE PATTERNS PRODUCED DURING RESTRICTED JAW SPEAKING

	Consonants						Vowels		
Group	/t/	/d/	/s/	/r/	/tr/	/str/	/i/	/ae/	/u/
Control									
F_1	+	+	+	+	+	+	+	0	+
F_2	-	-	-	-	-	-	-	-	-
F_3	-	-	-	-	-	-	-	-	-
F_0	+	+	+	+	+	+	+	+	+
RTP									
F_1	-	+	+	+	+	+	+	-	+
F_2	-	-	-	-	-	-	-	-	-
F_3	-	-	-	-	-	-	-	-	-
F_0	+	+	+	+	+	+	+	+	+
LTP									
F_1	+	-	+	+	-	-	+	-	-
F_2	-	-	-	-	-	-	-	-	-
F_3	-	-	-	-	-	-	-	+	-
F_0	+	+	+	+	+	+	+	+	+

on one trial, stays constant for two trials, and decreases on one trial, the value in the table will reflect the mean frequency shift (i.e., if the increase is far greater than the decrease, the value may be reflected in the table as a +).

Control subjects increase F_1 frequency in all vowel and consonant contexts except for the low-front vowel, /ae/. Decreases in F_2 and F_3 frequencies occur in all contexts for the Control group.

RTP subjects increase F_1 frequencies for the high vowels, /i/ and /u/, and decrease F_1 frequencies for the low, front vowel, /ae/. Increase in F_1 frequencies are produced in restricted-jaw speaking by the RTP speakers for all initial consonant contexts except /t/, which decreases. Decreases in F_2 and F_3 frequencies are produced by the RTP group for all vowels in all consonantal contexts. LTP subjects decrease F_1 frequencies following the voiced stop-consonant, /d/, and the consonant clusters, /tr/ and /str/. In general, F_2 and F_3 frequencies for all vowels following each of the initial consonants decrease during restricted-jaw speaking by the LTP subjects.

Fundamental frequency increases for all vowels in each of the initial consonant or cluster environments during restricted-jaw speaking for the Control group. Similar frequency increases also occur for the two cortically injured groups.

As mentioned earlier, the summary tables provide a rather gross estimate of the average magnitude of frequency shift. A more specific summary table of these changes is provided in Tables III-7, III-8, and III-9. These tables display the mean formant frequency measures

TABLE III-7

SUMMARY TABLE OF F_1 FORMANT FREQUENCIES IN NORMAL AND RESTRICTED JAW SPEAKING FOR CONTROL, RTP, AND LTP GROUPS

					Vowel				
Group	$/i/^N$	$/i/^R$	%	$/ae/^N$	$/ae/^R$	%	$/u/^N$	$/u/^R$	%
Control									
t	307.7	322.4	4.6	710.6	720.9	1.4	327.9	342.6	4.3
d	285.6	302.2	5.5	684.3	690.3	0.9	333.3	338.8	1.6
s	294.8	322.4	8.6	736.1	701.5	-4.9	340.7	338.9	1.6
r	298.5	329.7	9.5	743.2	760.1	2.2	360.7	362.6	0.5
tr	309.5	326.1	5.1	737.9	765.5	3.6	382.7	368.3	- 3.9
str	292.9	322.3	9.1	736.2	725.2	-1.5	362.6	364.5	0.5
Mean	298.2	320.8	7.0	724.6	727.3	0.4	351.3	352.6	0.4
RTP									
t	289.3	300.4	3.7	706.8	685.0	-3.2	315.1	322.5	2.3
d	267.2	307.6	13.1	681.2	681.4	0.0	307.7	336.9	8.7
s	281.9	307.7	8.4	699.7	699.7	0.0	304.0	329.7	7.8
r	270.8	307.6	11.9	714.3	684.9	-2.1	311.4	318.7	2.3
tr	289.3	297.1	2.6	717.8	688.5	-4.3	296.7	351.7	15.6
str	278.3	292.8	4.9	685.0	685.0	0.0	300.4	315.2	4.7
Mean	279.5	303.3	7.5	700.8	687.4	-1.9	305.9	329.1	7.0
LTP									
t	292.8	333.5	12.2	662.9	667.6	0.7	362.7	348.2	- 4.2
d	325.9	333.1	2.2	662.8	626.2	-5.8	366.4	348.1	- 5.3
s	314.9	337.1	6.6	670.1	684.8	2.1	384.6	362.0	- 6.2
r	311.4	359.1	13.3	684.8	714.3	4.1	370.1	309.1	-19.7
tr	296.6	333.5	11.1	695.9	655.6	-6.2	381.0	359.0	- 6.1
str	311.4	351.7	11.4	706.0	670.1	-5.4	373.7	362.7	- 3.0
Mean	308.8	341.5	9.5	680.4	669.8	-1.6	373.1	348.2	-7.2

TABLE III-8

SUMMARY TABLE OF F_2 FORMANT FREQUENCIES IN NORMAL AND RESTRICTED JAW SPEAKING FOR CONTROL, RTP, AND LTP GROUPS

					Vowel				
Group	/i/^{N}	/i/^{R}	%	/ae/^{N}	/ae/^{R}	%	/u/^{N}	/u/^{R}	%
Control									
t	2292	2175	-5.4	1682	1593	-5.6	1545	1382	-11.8
d	2260	2157	-4.8	1729	1666	-3.8	1693	1551	- 9.1
s	2260	2098	-7.7	1660	1577	-5.3	1523	1401	- 8.7
r	2164	1992	-8.8	1588	1546	-2.7	1115	1038	- 7.4
tr	2092	1978	-5.8	1567	1533	-2.2	1292	1130	-14.4
str	2090	1974	-5.9	1549	1499	-3.3	1302	1137	-14.5
Mean	2194	2062	-6.4	1629	1569	3.8	1412	1273	-10.9
RTP									
t	2211	2144	-3.1	1647	1629	-1.1	1298	1173	-10.6
d	2231	2135	-4.5	1706	1633	-4.5	1438	1408	- 2.1
s	2200	2039	-7.9	1617	1569	-3.1	1341	1229	- 9.1
r	2083	2003	-3.9	1573	1508	-4.3	1020	1027	0.7
tr	2016	1973	-2.2	1478	1471	-0.5	1130	1119	- 1.0
str	2025	1965	-3.5	1528	1500	-1.8	1184	1104	- 7.3
Mean	2128	2042	-4.2	1591	1552	-2.6	1235	1177	- 4.9
LTP									
t	2183	2069	-5.5	1594	1569	-1.6	1338	1274	- 4.6
d	2150	2096	-2.6	1676	1534	-9.2	1403	1417	1.0
s	2164	2029	-6.7	1569	1530	-2.5	1365	1320	- 3.4
r	2095	1988	-5.3	1530	1491	-2.6	1137	1086	- 4.7
tr	2102	1940	-8.4	1517	1531	0.9	1207	1167	- 3.4
str	2066	1940	-6.5	1535	1475	-4.1	1229	1224	- 0.4
Mean	2126	2010	-5.7	1570	1522	-3.2	1279	1248	- 2.5

TABLE III-9

SUMMARY TABLE OF F_3 FORMANT FREQUENCIES IN NORMAL AND RESTRICTED JAW SPEAKING FOR CONTROL, RTP, AND LTP GROUPS

					Vowel				
Group	$/i/^N$	$/i/^R$	%	$/ae/^N$	$/ae/^R$	%	$/u/^N$	$/u/^R$	%
Control									
t	2783	2654	-4.4	2443	2426	-0.7	2234	2182	-2.4
d	2804	2740	-2.3	2486	2408	-3.2	2298	2185	-5.2
s	2720	2683	-1.3	2475	2460	-0.6	2318	2236	-3.7
r	2697	2512	-7.4	2355	2245	-4.9	2182	2058	-6.0
tr	2591	2464	-5.2	2319	2261	-2.5	2069	1992	-3.9
str	2504	2430	-3.1	2336	2276	-2.6	2010	1946	-3.3
Mean	2682	2580	-3.9	2402	2341	-2.4	2185	2100	-4.1
RTP									
t	2662	2548	-4.5	2451	2356	-4.0	2223	2158	-3.0
d	2678	2558	-4.7	2468	2297	-7.5	2268	2158	-4.1
s	2616	2511	-4.2	2403	2300	-4.5	2315	2214	-4.5
r	2563	2368	-8.2	2370	2211	-7.2	2191	2124	-3.1
tr	2476	2406	-2.9	2289	2162	-5.9	2095	1985	-5.5
str	2406	2356	-3.5	2181	2143	-1.8	1998	1938	-3.1
Mean	2576	2453	-4.6	2360	2245	-2.7	2178	2096	-3.9
LTP									
t	2593	2406	-7.8	2387	2401	0.6	2195	2139	-2.5
d	2551	2465	-3.5	2414	2406	-0.3	2231	2093	-6.5
s	2598	2477	-4.9	2361	2373	0.5	2257	2102	-7.4
r	2490	2396	-3.9	2328	2347	0.8	2121	2050	-3.4
tr	2499	2405	-3.9	2306	2311	0.2	2065	1945	-6.0
str	2486	2336	-6.4	2394	2393	-0.1	2054	1883	-9.1
Mean	2536	2414	-5.1	2365	2356	-0.4	2145	2035	-5.4

obtained in normal (designated by N) and restricted-jaw speaking (designated by R), as well as, the percent of formant-frequency shift. Percentages of formant-frequency change were obtained by subtracting restricted-jaw from normal speaking formant frequencies, dividing this number by the restricted-jaw values, and multiplying by 100. Thus, a positive percentage represents an increase in formant frequency during restricted-jaw speaking and a negative percentage represents a decrease in formant frequency during restricted-jaw speaking.

The first table (Table III-7) illustrates formant frequency values associated with F_1. Control subjects produce the greatest change for the high, front vowel, /i/ (7.0%) and rather minimal frequency changes for /ae/ (0.4%)) and /u/ (0.3%). In general, Control subjects increase F_1 values during restricted jaw speaking. RTP subjects show a slightly different picture--greatest percent change occurs for the high, front and back vowels, /i/ and /u/ (7.5% and 7.0%, respectively). However, RTP subjects show a minimal negative percent change (-1.9%) for the low, front vowel, /ae/. LTP subjects also show the greatest percent change for the high vowels, /i/ and /u/; however, LTP subjects increase F_1 for /i/ (9.5%) and decrease F_1 for /u/ (-7.2%). As in the case of the RTP subjects, minimal F_1 decreases are noted for the low, front vowel, /ae/ (-1.6%). Table III-8 summarizes the mean F_2 formant frequencies and the percent frequency change across the two speaking conditions. Control subjects show the greatest percent change for the high, front and back vowels, /i/ (-6.4%) and /u/ (-10.9%). RTP subjects also show the greatest percent change for high vowels [/i/

(-4.2%) and /u/ (-4.97%)], although percentage-changes are not as large as Control group percentages. LTP subjects differ from Control and RTP subjects slightly--greatest percent change is found for the front vowels, /i/ (-5.7%) and /ae/ (-3.2%).

Table III-9 is a similar protrayal of mean formant frequency and percent change for F_3 values. Control F_3 data parallel the F_2 data--greatest percent change occurs for high, front and back vowels, /i/ (-3.9%) and /u/ (-4.1%). Similarly, RTP subjects produce the greatest F_3 percent change for /i/ (-4.6%) and /u/ (-3.9%). LTP subjects, however, produce the greatest F_3 percent changes for /i/ (-5.1%) and /u/ (-5.4%) which differs slightly from the greatest percent change seen in F_2 frequencies.

Duration Measures in Normal Speaking

As in the assessment of normal-speaking frequency measures, three questions are interesting regarding total-word and individual segment durations produced during normal (free-moving-jaw) speaking: (1) Are durations produced during normal speaking by Control subjects characteristic of contextual speech produced by male speakers? (2) How do different contextual frameworks effect duration? (3) Are segment durations produced by the two cortically injured groups similar to the Control group? Question 3 is particularly interesting as data from previous studies suggest a differential effect associated with side of lesion (right versus left) may occur. For example, Darley and his colleagues (Darley et al., 1975) suggest many patients with left hemisphere damage produce "slow," "hesitant," and "prolonged" speech.

Anectodal case reports suggest some patients with right hemisphere lesions produce speech which is "rapid" or "fast" (Penfield and Roberts, 1959; Russell and Espir, 1961). Thus, LTP subjects may produce slower speech and RTP subjects may produce faster speech relative to the Control group.

Total-word duration in normal speaking. Table III-10 lists total-word duration as a function of vowel and initial consonant for each of the groups. Control subjects produced the longest total-word durations for target stimuli containing the vowel nucleus, /ae/, and the shortest total-word durations for target stimuli containing /u/ nuclei. A similar duration pattern is apparent for the RTP speakers--total-word duration for stimuli containing /ae/ are longer than stimuli containing /i/ and /u/. Shortest word durations are produced by the RTP subjects for stimuli containing /u/. In addition, RTP subjects produced shorter total durations relative to the Control group productions. LTP subjects also produce the longest total-word durations for stimuli containing /ae/ and the shortest total-durations for stimuli containing /u/. LTP speakers produce longer total-word durations than either the Control or RTP groups. These observations are verified in the analysis of variance by a significant main-vowel effect [F=202.875, df=2,24 ($p<.01$)]. Further analysis reveals a signficant group-by-vowel interaction in the analysis contrasting the RTP-LTP data [F=5.768, df=2,12 ($p<.05$)] and the Control-Pathological data [F=6.400, df=2,24 ($p<.01$)].

TABLE III-10

TOTAL-WORD DURATION PRODUCED BY CONTROL, RTP, AND LTP GROUPS DURING NORMAL SPEAKING

	Vowel (msec)			
Group	/i/	/ae/	/u/	Mean
Control				
/t/	208.8	253.2	196.4	219.5
/d/	161.5	222.6	159.7	181.3
/s/	339.6	373.8	335.2	349.5
/r/	233.5	272.1	237.2	247.6
/tr/	270.6	304.3	258.9	277.9
/str/	419.4	433.0	398.4	416.9
Mean	272.2	309.8	264.3	282.1
RTP				
/t/	189.3	244.4	189.6	207.8
/d/	155.4	213.9	144.3	171.2
/s/	325.1	374.8	311.1	337.0
/r/	230.4	259.6	217.1	235.7
/tr/	241.9	293.4	230.8	255.4
/str/	420.8	444.4	402.3	422.5
Mean	260.5	305.1	249.2	271.6
LTP				
/t/	219.1	243.7	210.2	224.3
/d/	175.1	231.9	178.0	195.0
/s/	350.7	375.3	334.9	353.6
/r/	254.9	291.9	248.4	265.1
/tr/	275.6	303.7	274.4	284.6
/str/	402.6	431.6	417.1	417.1
Mean	279.7	310.0	277.2	289.9

Control subjects produce the longest total-word durations for stimuli containing the three-element consonant cluster, /str/, and the singleton consonant, /s/. Control subjects produce the shortest total-word duration for the stimuli containing the voiced stop consonant, /d/. Similar duration patterns are produced by the RTP and LTP groups. LTP speakers produce longer total-word durations than either the RTP or Control groups. In general, RTP subjects produce shorter total-word durations than the Control group. These finding are verified in the analysis of variance by a significant consonant-main effect [F=607.5, df=5,60 (p<.01)] and a consonant-by-vowel interaction [F=10.109, df=10 (p<.01)].

Vowel nuclei duration in normal speaking. Table III-11 shows the vowel nucleus durations for the Control, RTP, and LTP groups. Control subjects produce longer segments for /ae/ than for either /i/ or /u/. This observation agrees with previous studies indicating low vowels (such as /ae/) are inherently longer in duration presumably because the jaw must assume a lower position (Peterson and Lehiste, 1960). A similar duration pattern occurs for the pathological groups--/ae/ segments are longer relative to the high, front and back vowel segments, /i/ and /u/. Substantial duration differences between the Control and cortically injured groups also are apparent. LTP subjects produce longer vowel segments than the Control group, although these differences are only on the order of 2 msec for /ae/. RTP subjects produce shorter vowel segments than either the Control or LTP groups. These observations are confirmed by a significant main vowel

Table III-11

MEAN VOWEL DURATION PRODUCED DURING NORMAL SPEAKING

BY CONTROL, RTP, AND LTP GROUPS

Group	Vowels (msec) /i/	/ae/	/u/
Control	103.9	154.3	107.3
RTP	96.0	140.9	95.2
LTP	120.0	156.6	119.6

effect [F=273.338, df=2,24 (p<.01)]. Further analysis reveals a significant group-by-vowel effect [F=4.36, df=2,12 (p<.05)] in the analysis contrasting the RTP and LTP data.

Figure III-12 illustrates vowel duration as a function of initial consonants for the three groups. Control subjects produce longer vowel segments following the initial consonants, /t, d, s/, and shorter vowel segments following initial consonant or clusters containing /r/. In part, the large duration differences between these two general classes of consonants (/t, d, s/ versus /r/) may be associated with the segmentation procedure. Measures for /t, d, s/ contexts include the transition, whereas the transition in /r/ is segmented and measured separately as TR2. Control subjects produce shorter vowel segments after initial consonant clusters (even when measurement discrepencies are taken into account). A similar initial consonant influence is evident for RTP and LTP vowel durations. Cortically injured groups differ from the Control group only in actual duration magnitude; i.e., RTP subjects produce shorter segments and LTP subjects generally produce longer segments. Initial consonant or clusters influence vowel nuclei duration, as shown by a significant vowel-by-consonant interaction [F=43.56, df=10,120 (p<.01)]. Differences in the magnitude of duration between the groups are verified by a significant interaction of group-by-vowel-by-consonant in the evaluation of RTP and LTP data [F=3.72, df=10,60 (p<.01)], and a significant group-by-vowel-by-consonant interaction in the additional

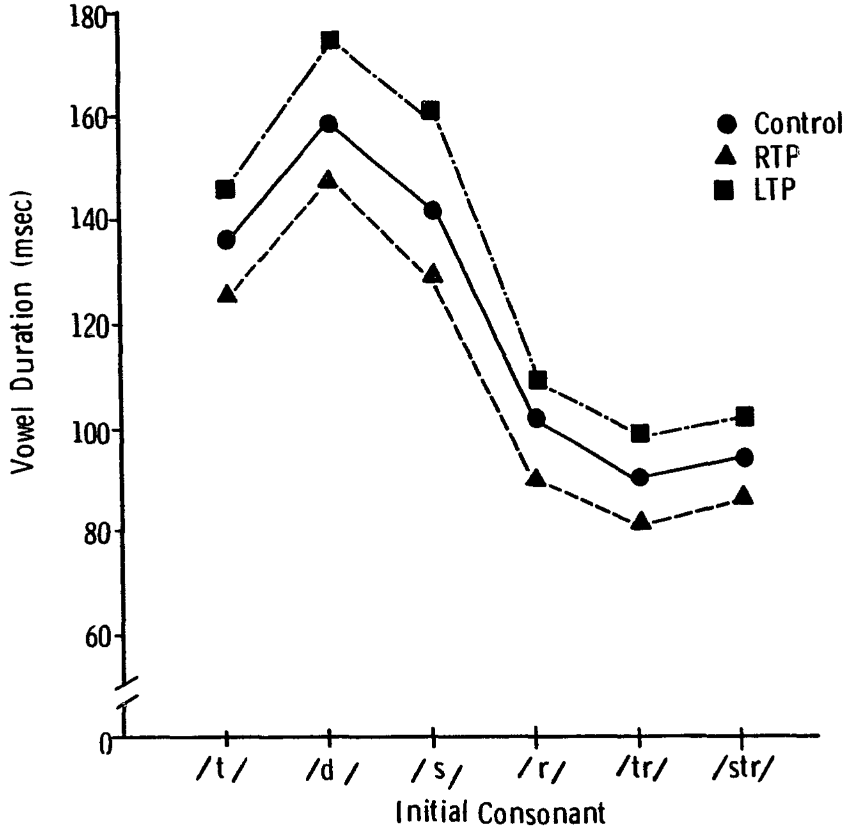


Figure III-12. Mean vowel duration as a function of initial consonant or cluster produced by Control, RTP, and LTP groups analysis comparing Control to Pathological data [F=2.646, df=10,120 (p<.01)].

Voice-onset time in normal speaking. Table III-12 provides the mean voice-onset-times for the three groups, as well as, the range of voice-onset-time for /d/ and /t/ reported previously by Lisker and Abramson (1964). Voice-onset-times for /t/ and /d/ produced by Control, RTP, and LTP groups fall into the ranges found by Lisker and Abramson (1964). Voice-onset-time for /t/ in the initial /str/ cluster is shorter than the duration of /t/ in a singleton context for each of the groups; however, durations also fall in the range of voice-onset-times produced by English speakers (Lisker and Abramson, 1964). Voice-onset-time for /t/ in the two-element cluster (/tr/) is longer than singleton (/t/) and the three-element cluster (/str/) voice-onset-times. In addition, the voice-onset times of /t/ in /tr/ clusters fall outside the upper range of values reported previously [see for example, Lisker and Abramson (1964)]. In general, RTP and LTP subjects produce shorter voice-onset-times than the Control subjects. Differences between voice-onset-times for the various initial consonants is verified in the analysis of variance by a significant main consonant effect [F=293.87, df=3,36 (p<.01)].

Voice-onset-time as a function of vowel nuclei are shown in Figure III-13. Control subjects produced longer voice-onset-times prior to the high-front vowel, /i/, and shorter voice-onset times prior to the low-front vowel, /ae/. Although the voice-onset-time patterns as a function of vowel are similar for the cortically injured groups,

TABLE III-12

MEAN VOICE-ONSET-TIMES PRODUCED DURING NORMAL SPEAKING BY CONTROL, RTP, AND LTP GROUPS

Group	Initial Consonant (msec) /d/	/t/	/tr/	/str/
Control	22.8	83.4	125.0	57.5
RTP	22.8	81.1	114.0	51.2
LTP	20.5	77.9	118.0	60.6
L & A[1]	0-25	30-105		

[1] Range values taken from: Lisker, L. and Abramson, A. A cross-language study of voicing. Word, 21: 120-123 (1964).

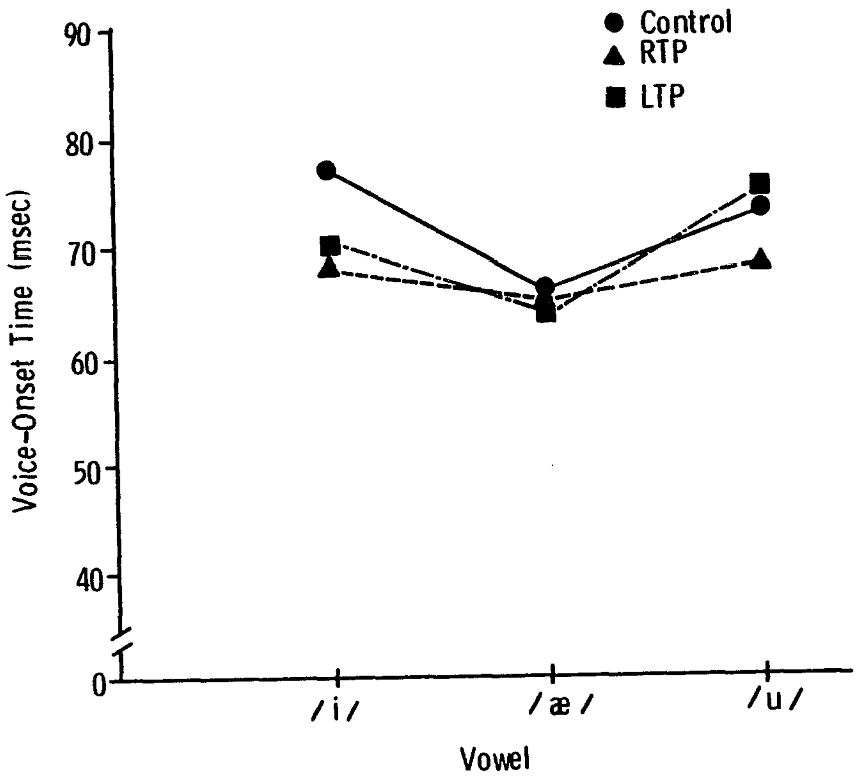


Figure III-13. Mean voice-onset-time as a function of vowel produced by Control, RTP, and LTP groups during normal speaking.

differences in voice-onset-times as a function of vowel are not as great as differences seen in the Control group. Reliability of these observations is confirmed by a signficant vowel-by-consonant interaction [F=3.76, df=1,12 ($p<.01$)]. Further analysis indicates this interaction is primarily contributed by the Control group [F=2.65, df=1,6 ($p<.01$)]--no significant vowel-by-consonant interaction occurs in the orthogonal breakdown comparing RTP and LTP data.

Friction duration in normal speaking. Duration of friction segments generated during /s/ production in initial singleton and cluster consonants for the Control, RTP, and LTP groups is shown in Table III-13. Control subjects produce longer friction segments for singleton /s/ than /str/ consonant clusters. These data are similar to previous reports, indicating friction segments produced during consonant clusters are shorter than friction segments produced in singleton consonants (Klatt, 1974). A similar duration pattern of shorter cluster segments than singleton segments also occurs for the two cortically injured groups; however, in contrast to the vowel nuclei segment durations, LTP subjects produce shorter segments than either the RTP or Control groups. Duration of the acoustic segments associated with the friction of /s/ and /str/ reveals a significant main consonant effect [F=193.56, df=1,12 ($p<.01$)].

Additional contextual effects are shown in Figure III-14 illustrating friction duration as a function of vowel nuclei. Longer friction segments, regardless of singleton or cluster context, are produced prior to the high vowels, /i/ and /u/, than the low vowel,

TABLE III-13

MEAN FRICTION DURATION PRODUCED DURING NORMAL SPEAKING BY CONTROL, RTP, AND LTP GROUPS

Group	Initial Consonant (msec) /s/	 /str/
Control	204.6	135.4
RTP	211.7	147.2
LTP	192.8	132.2

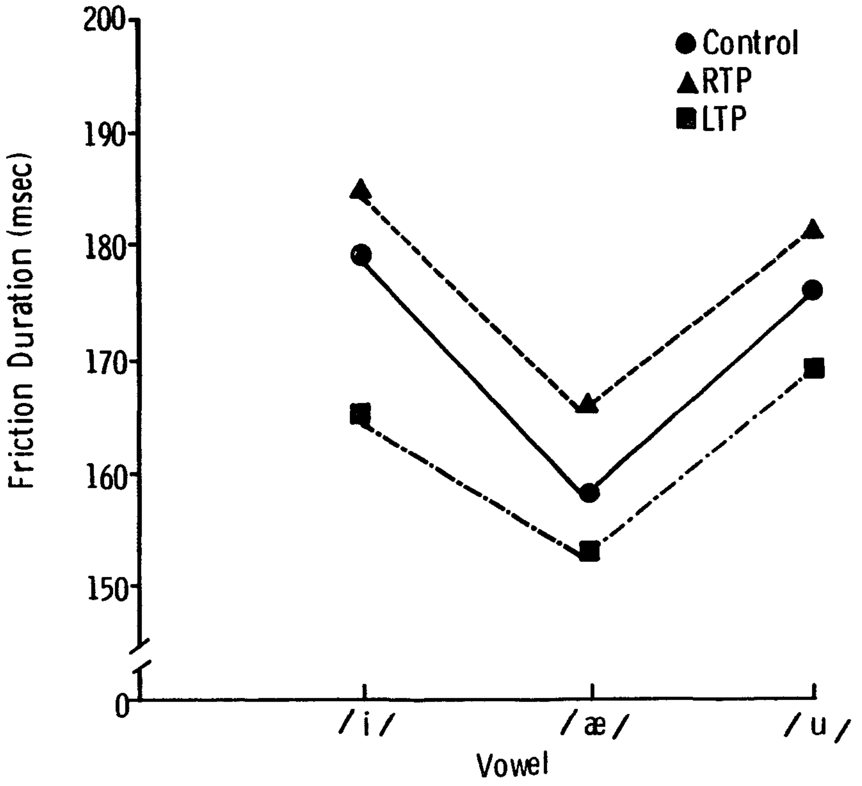


Figure III-14. Mean friction duration as a function of vowel produced by Control, RTP, and LTP groups during normal speaking.

/ae/, for each of the groups. As mentioned earlier, the LTP group produces shorter friction segments and the RTP group produces longer friction segments than the Control group regardless of the vowel following the friction segments.

<u>TR2 duration in normal speaking</u>. Table III-14 contains the mean duration of TR2 segments produced by the Control, RTP, and LTP groups. In addition, mean TR2 durations reported by Russell (1977) are shown for comparison. Control subjects produce comparable TR2 durations in /r/ and /tr/ consonant contexts and slightly increase TR2 duration in /str/ clusters. These data differ somewhat from Russell (1977) who reports speakers systematically shorten TR2 segments as initial consonant contexts increase from singleton to three-element clusters; however, differences may relate to the contextual frameworks used in this particular study. Klatt (1973) indicates /r/ production is longer when its preceding cluster member (e.g., /s/ or /t/) is articulated in approximately the same place of articulation.

A slightly different durational pattern occurs for the two cortically injured groups. Duration of TR2 segments in singleton, /r/, and three-element, /str/, contexts are longer than TR2 segments produced in two-element, /tr/, clusters. LTP subjects produce longer TR2 segments than either RTP or Control groups; however,in general, RTP and Control groups produce similar TR2 durations. Differences in TR2 durations as a function of initial consonant are confirmed by a significant main-consonant effect [$F=27.065$, $df=2,24$ ($p<.01$)] in the analysis of variance.

TABLE III-14

MEAN DURATION OF TR2 SEGMENTS PRODUCED DURING NORMAL SPEAKING BY CONTROL, RTP, AND LTP GROUPS

Group	Initial Consonant (msec)		
	/r/	/tr/	/str/
Control	61.4	62.2	69.3
RTP	64.5	57.5	70.8
LTP	75.6	66.9	73.9
Russell[1]	66.0	62.7	54.4

[1] Mean duration values taken from: Russell, L. An Acoustic Study of Selected Phonetic Types Comprising /r/ in General American Dialect. Unpublished doctoral dissertation. City University of New York: New York, New York (1977).

Further coarticulation influences are shown in the next figure (Figure III-15) illustrating TR2 duration as a function of vowel. Longer TR2 segments are produced prior to the front vowels, /i/ and /ae/, than prior to the back vowel, /u/, for each of the groups. Although the RTP group produces shorter TR2 segments in /i/ and /u/ contexts than the Control group, RTP subjects produce longer TR2 durations for /ae/. LTP subjects produce longer TR2 segments than the RTP or Control subjects for the high vowels, /i/ and /u/. Vowel coarticulatory influences are verified by a significant vowel-by-consonant interaction [F=10.197, df=4,48 (p<.01)].

Duration Values in Restricted-Jaw Speaking

The brief review of normal-speaking duration patterns suggests Control, RTP, and LTP groups adjust the time course of articulatory gestures to take into account contextual frameworks. However, in light of the observations made in the sections dealing with fundamental and formant frequencies produced during restricted-jaw speaking, a number of questions arise regarding how the motor-speech system may alter the time course of articulatory gestures during restricted-jaw speaking.

First, it seems reasonable to ask if the system will change duration patterns during restricted-jaw speaking. Although the formant-frequency measures indicate articulatory strategies may be slightly altered during restricted-jaw speaking, it does not necessary follow that the time course associated with gesture execution will also change. Possibly, however, a response pattern of comparable segment durations between normal and restricted jaw-speaking may cccur.

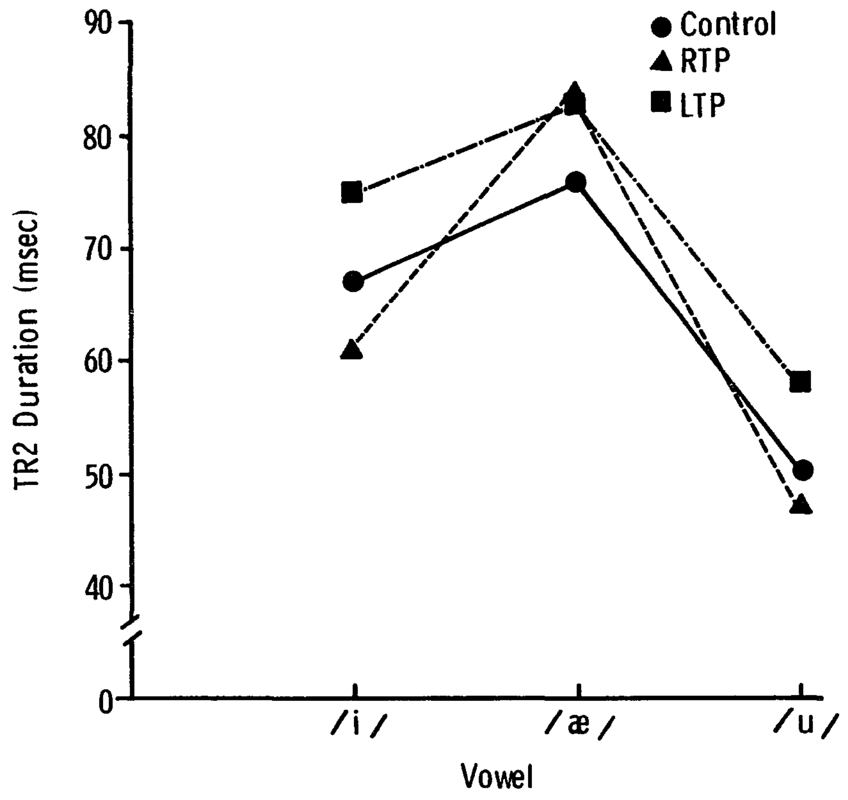


Figure III-15. Mean TR2 duration as a function of vowel produced by Control, RTP, and LTP groups during normal speaking.

On the other hand, it is possible a response pattern composed of different segment durations between normal and restricted-jaw speaking may occur. Duration Response Pattern One hypothesizes the system may elect to selectively reorganize temporal parameters, perhaps in a manner which reflects the relative difficulty of one production versus another; e.g., greater durational changes of a segment contained in a more complex utterance such as a three-element cluster versus a singleton consonant. Alternatively, the system may elect to apply a single temporal strategy during restricted-jaw speaking. Duration Response Pattern Two hypothesizes the system may overlay a longer (or shorter) time frame upon normally planned gestures, rather than reorganizing temporal characteristics of the gestures themselves. That is, the system may respond to limited-jaw participation by simply slowing (or speeding) articulation.

The final question to consider when examining the duration of segments produced during restricted-jaw speaking is, will the Control and cortically injured subjects employ similar temporal adjustments during restricted-jaw speaking?

Total-word duration in restricted-jaw speaking. Duration response patterns of total-word duration as a function of vowel during restricted-jaw speaking by the three groups are shown in Figure III-16. Control subjects produce a Duration Reponse Pattern Two, systematic lengthening, for target stimuli regardless of vowel; however, the greatest increase in overall duration occurs for stimuli containing the front vowels, /ae/ and /i/. A similar Duration Response Pattern Two is

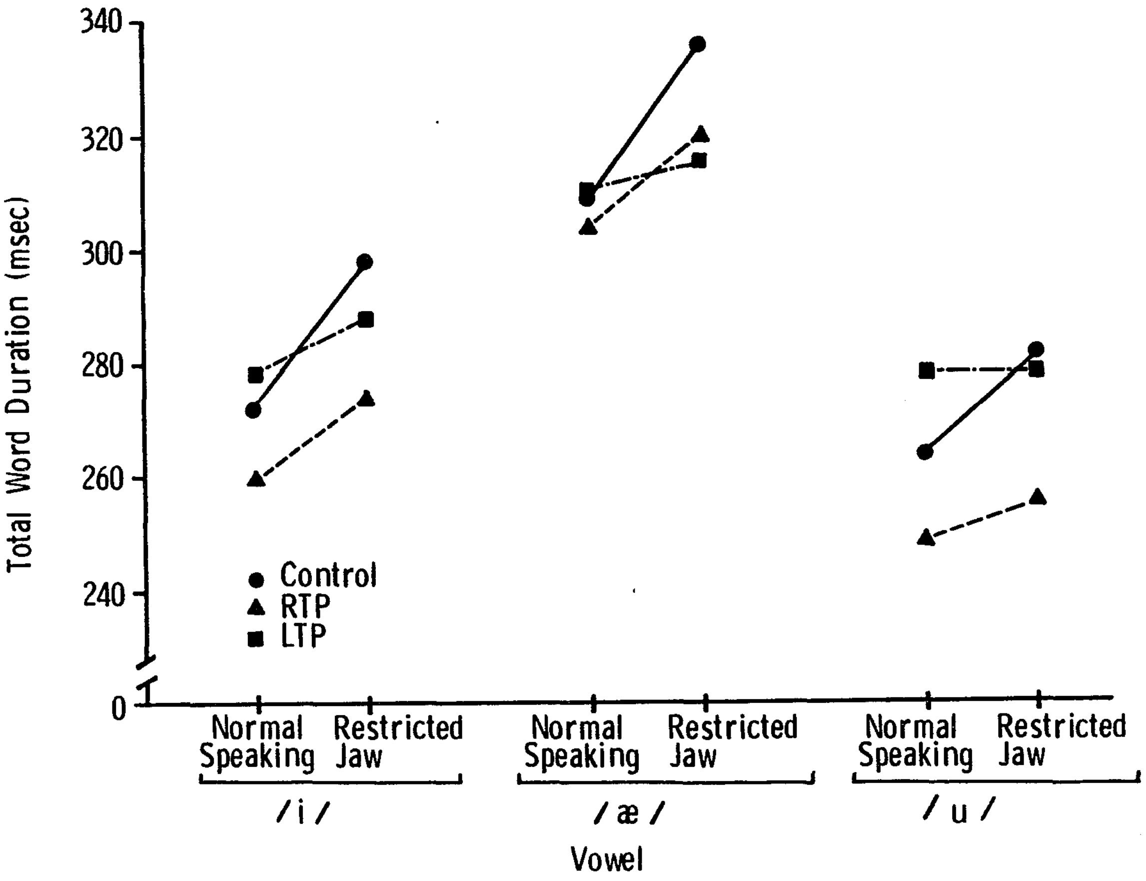


Figure III-16. Mean total-word duration as a function of vowel for Control, RTP, and LTP groups during normal and restricted-jaw speaking.

shown for the RTP group. LTP subjects, however, produce a Duration Response Pattern One, selective lengthening. Although LTP subjects lengthen target stimuli containing /i/, these increases are not as great as the duration increases produced by Control and RTP subjects. Only minimal total word lengthening occurs for target stimuli containing /ae/ and no duration changes are noted for target stimuli containing /u/. These observations are verified by a main condition effect [F=14.650, df=1,12 (p<.01)]. Further analyses reveals this effect is mainly contributed by the Control group [F=26.048, df=1,6 (p<.01)]--no significant condition effect is found in the orthogonal breakdown contrasting only the RTP-LTP data.

Figure III-17 depicts the duration response patterns as a function of initial consonant or cluster for each of the groups. Control subjects produce a Duration Response Pattern Two, systematic lengthening, for all initial consonant target stimuli. Control subjects produce the greatest duration increases for words containing the three-element cluster, /str/, and the least durational increases for target words containing the initial consonant, /t/. Cortically injured groups produce Duration Response Pattern One. RTP subjects lengthen total-word durations during restricted-jaw speaking in all initial contexts except the three-element cluster, /str/, which shows no duration change during restricted-jaw speaking. LTP subjects, on the other hand, show maximum lengthening for words containing /t/, /d/, and /r/ and minimal increases for target stimuli containing /s/ and /tr/. No duration changes are noted for target stimuli containing the

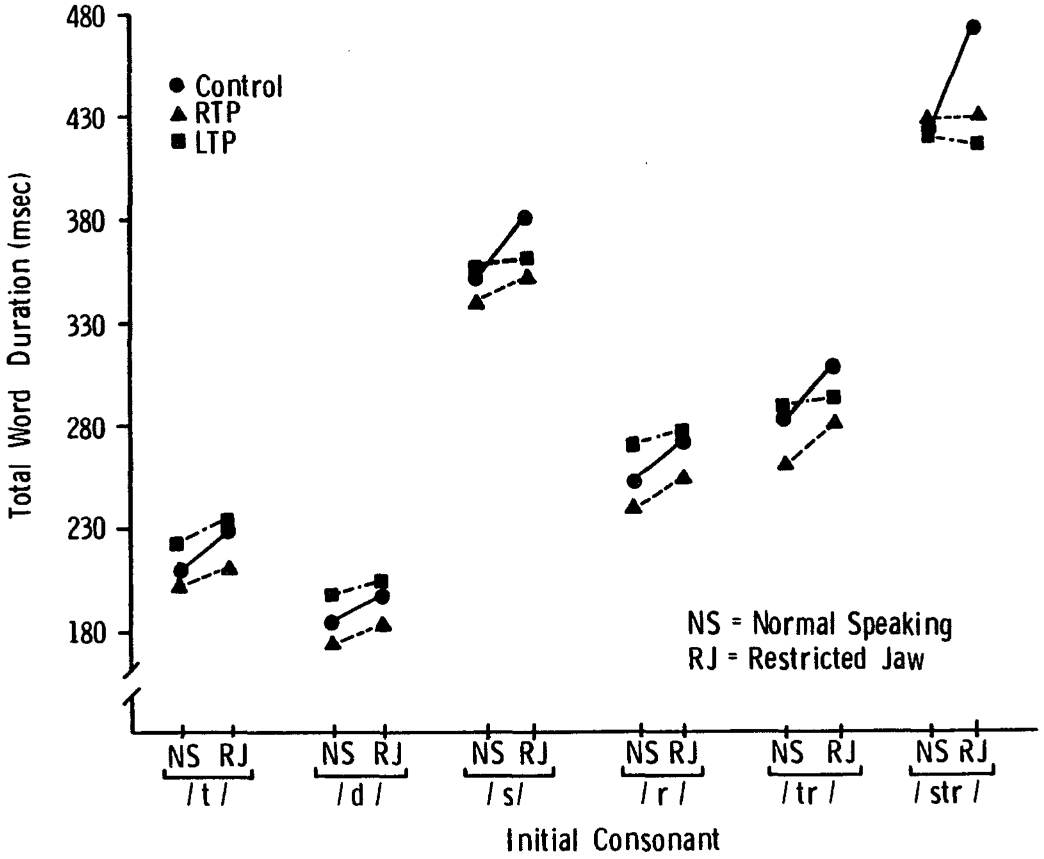


Figure III-17. Mean total-word duration as a function of initial consonant or cluster for Control, RTP, and LTP groups during normal and restricted-jaw speaking.

three-element cluster, /str/. Analysis of variance procedures reveal a significant group-by-consonant-by-condition interaction [F=2.146, df=15,60 (p<.05)]. An additional orthogonal breakdown of the Control-Pathological data reveals a significant Control-by-Pathological by-consonant-by-condition interaction [F=5.728, df=5,60 (p<.05)].

The next figure (Figure III-18) shows the mean total-word duration as a function of speaking condition and trial. Although Control subjects decrease total-word duration between trials one and two, total word duration remains relatively constant across the remainder of trials. A similar pattern is shown for trials of the RTP subjects. Duration increases produced by RTP speakers during restricted jaw speaking approach the durations produced by the Control subjects during normal speaking. LTP subjects appear to systematically decrease total-word duration as a function of speaking trial and condition.

Figure III-19 illustrates the standard deviations of total-word duration as a function of speaking trial and condition. Control subjects are more variable, as indicated by the larger standard deviations, during restricted-jaw speaking than normal speaking. RTP subjects show a similar picture; however, the standard deviations are smaller during trial three and four of restricted-jaw speaking than normal speaking. LTP subjects are less variable during restricted-jaw than normal-speaking conditions. In addition, LTP subjects appear to systematically decrease their variability as a function of speaking trial. These data, in conjunction with the data in the previous figure, suggest the LTP subjects may change total-word duration in a

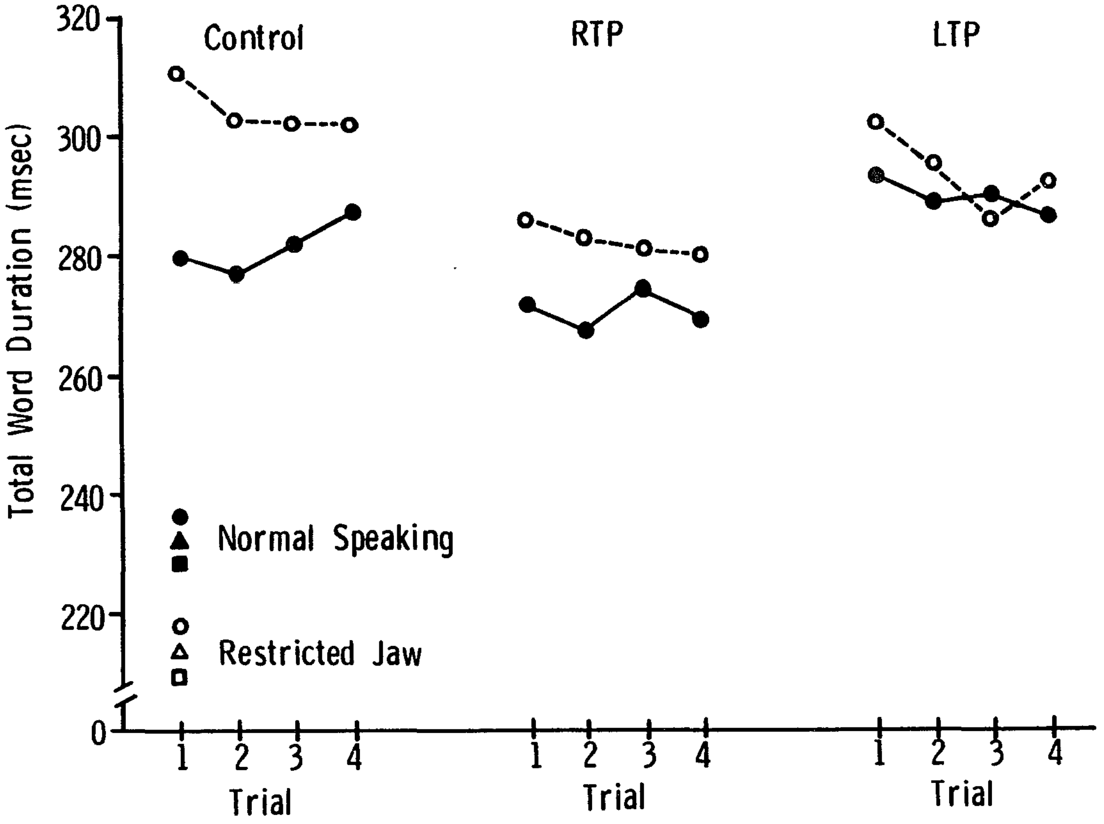


Figure III-18. Mean total-word duration as a function of trial and speaking condition for Control, RTP, and LTP groups.

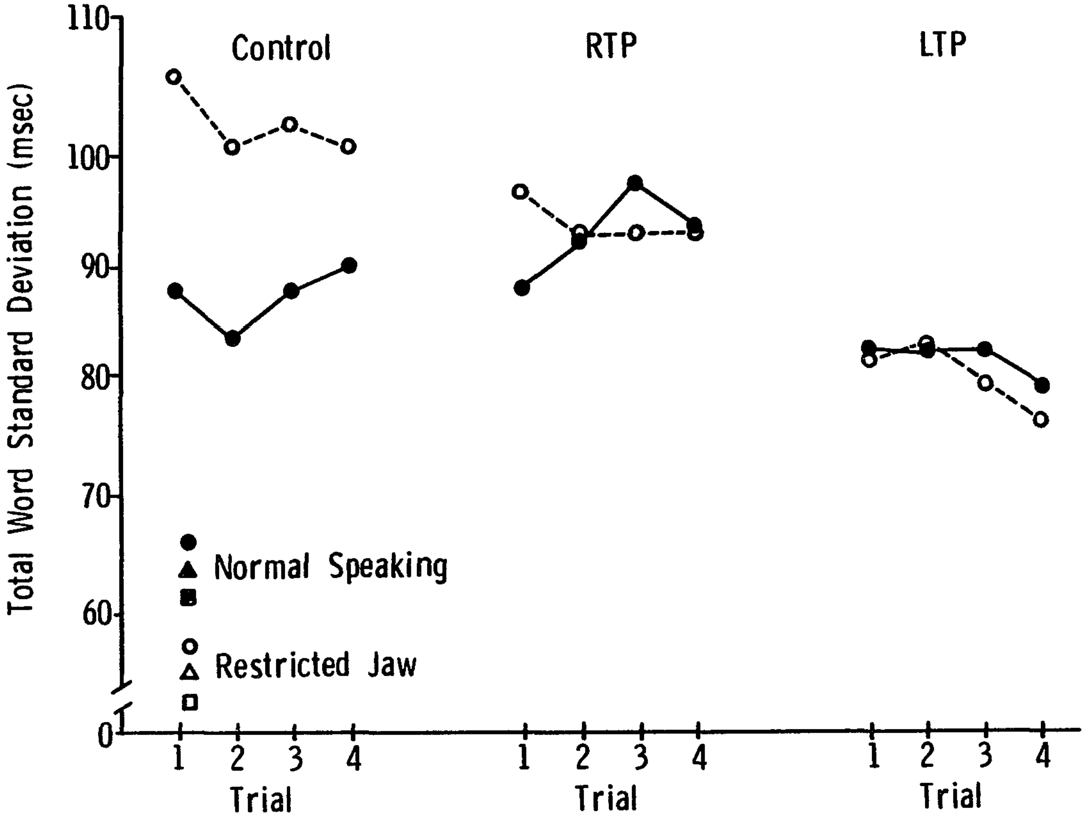


Figure III-19. Mean standard deviation of total-word duration as a as a function of trial and speaking condition for Control, RTP, and LTP groups.

systematic manner during restricted-jaw speaking; however a similar trend is not found for the Control or RTP groups. The analysis of variance indicates a significant main trial effect [F=3.627, df=3,36 (p<.05)]. Additional procedures reveal the effect is contributed by the cortically-injured groups [F=3.627, df=3,18 (p<.05)]--no significant trial effect is found in the orthogonal trial contrasting only the Control data.

Vowel nuclei duration in restricted-jaw speaking. Duration Response Patterns for the vowel nuclei are depicted in Figure III-20 for the Control, RTP, and LTP groups. Duration Response Pattern Two, lengthening of all vowel segments in restricted-jaw speaking, is shown for the Control subjects. Duration Response Pattern One, selective lengthening of segments during restricted-jaw speaking, occurs for the two cortically injured groups; however, RTP and LTP subjects selectively lengthen different vowel segments. RTP subjects produce longer durations for the front vowels, /i/ and /ae/, and slightly shorter durations for the back vowel, /u/. LTP subjects, on the other hand, lengthen the high, front vowel segments of /i/ and show virtually no change in duration for the low, front and high, back vowels, /ae/ and /u/. In general, LTP subjects produce longer durations and RTP subjects produce shorter durations relative to the Control group, regardless of speaking condition. Comparisons of the vowel nuclei durations obtained in the normal and restricted-jaw speaking conditions reveal a significant main effect [F=8.54, df=1,12 (p<.01)]. Further analysis reveals the significant main effect for speaking condition is

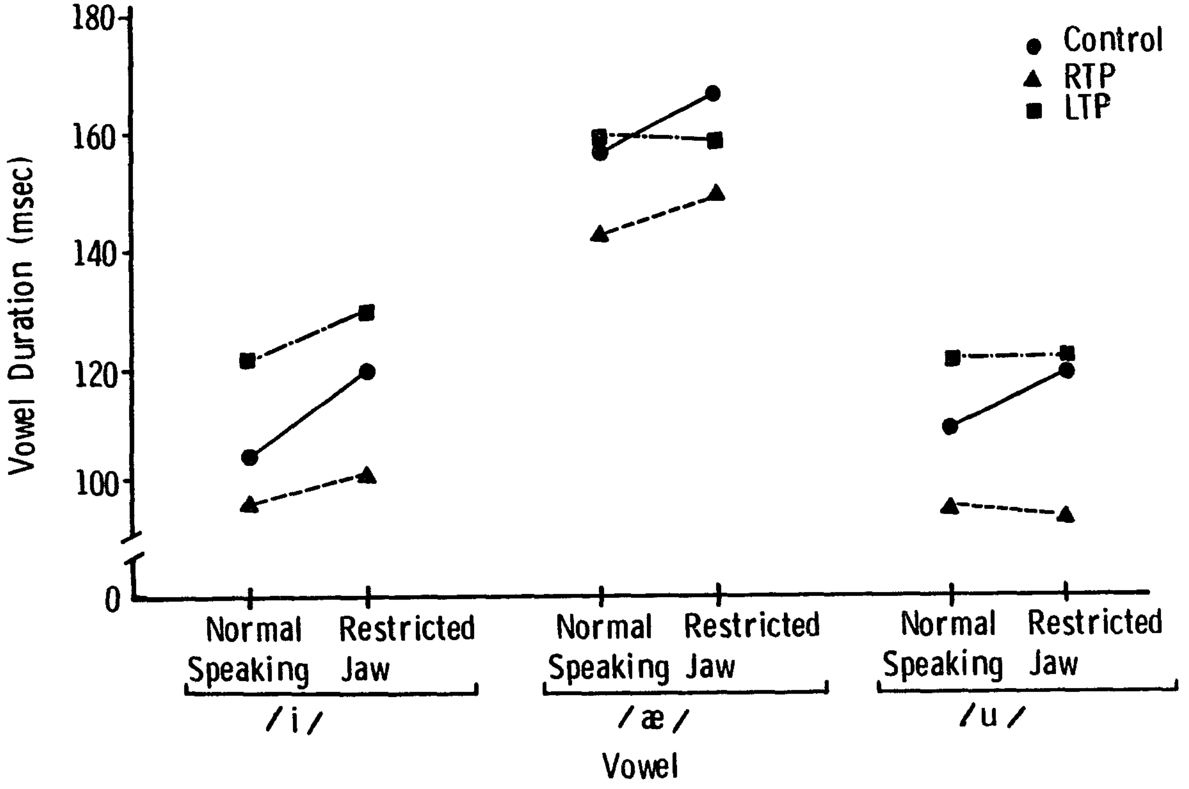


Figure III-20. Vowel duration produced by Control, RTP, and LTP groups during normal and restricted-jaw speaking.

contributed only by the Control group [F=15.68, df=1,6 (p<.01)]--no significant condition main effect is noted in detailed analysis examining the RTP and LTP data.

Different duration response patterns also are evident in Figure III-21 illustrating vowel duration as function of initial consonant and speaking condition. Control subjects lengthen vowel segments in all initial consonant or cluster environments during restricted-jaw speaking. Duration Response Pattern Two, systematic lengthening of segments, apparently does not depend upon the preceding initial consonant in the Control group. RTP subjects, with the exception of the initial consonant /t/, slightly lengthen vowel segments in all initial consonant environments. As noted earlier, the RTP subjects produce a Duration Response Pattern One, selective lengthening of vowel segments; however, their response pattern appears more influenced by vowel position (front versus back) than by initial consonant environments. LTP subjects also produce a Duration Response Pattern One; however, the LTP response pattern appears influenced by initial consonants. Virtually no vowel lengthening occurs following /t/ and /str/, vowel segments are shorter following /d/ and /s/, and slight vowel lengthening occurs following /r/ and /tr/. These observations are confirmed in the analysis of variance by significant interactions of consonant-by-condition [F=5.606, df=5,60 (p<.01)] and group-by-consonant-by-condition [F=1.885, df=15,60 (p<.01)]. Additional examination of only RTP-LTP data does not indicate a significant group-by-consonant-by-condition; however, a significant

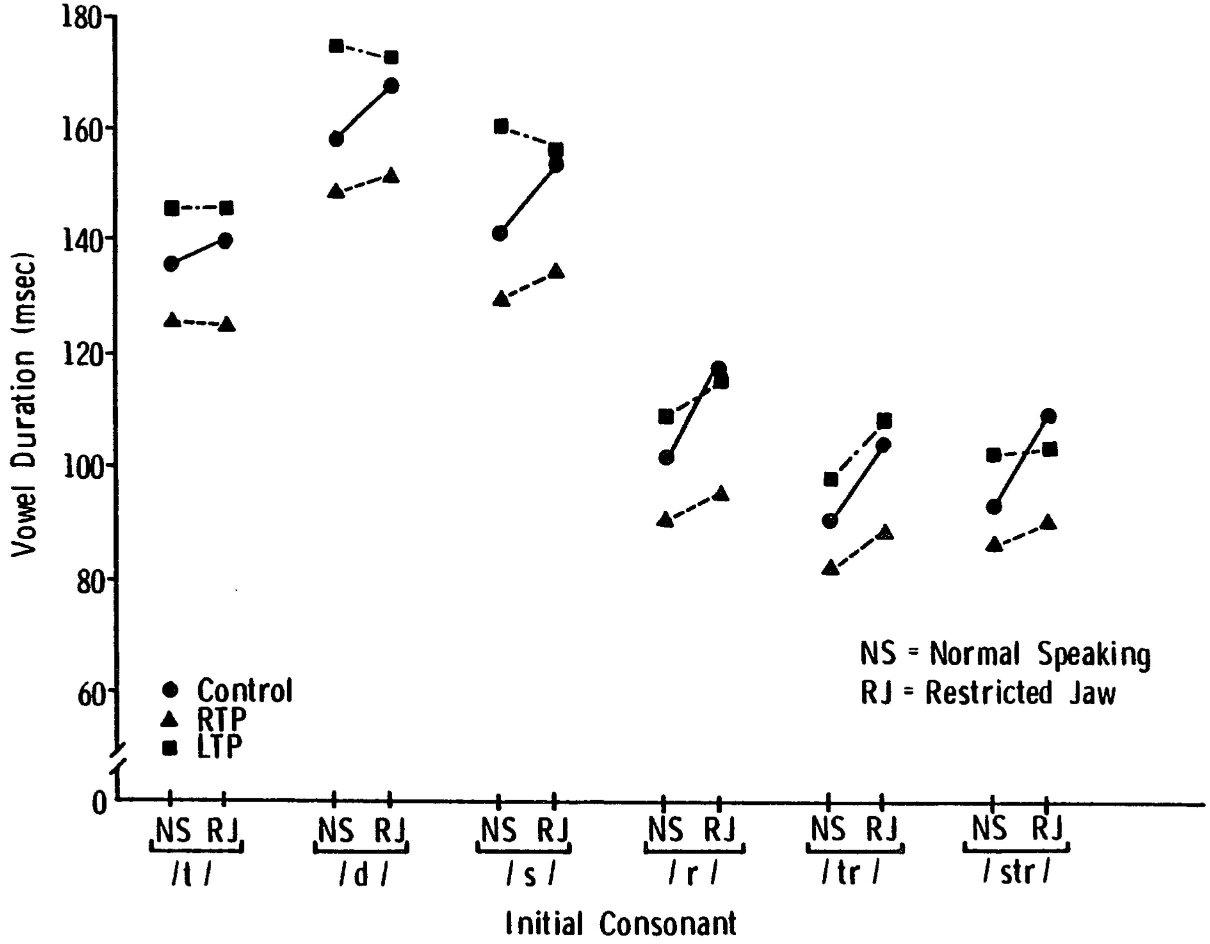


Figure III-21. Mean vowel duration as a function of initial consonant or cluster produced by Control, RTP, and LTP groups during normal and restricted-jaw speaking.

group-by-consonant-by-condition interaction is found in further analyses contrasting Control and Pathological data [F=2.429, df=5,60 (p<.01)].

Although it is possible the groups may alter segment durations with practice during restricted-jaw speaking, Figure III-22 indicates this is not the case. Vowel nuclei durations remain fairly constant across normal-speaking trials for the Control group. Longer durations occur during restricted jaw-speaking; however, no systematic shortening of segments toward normal-speaking durations is apparent for the Control group. Similarly, the RTP group increases vowel duration slightly but shows little duration change across trials during restricted-jaw speaking. Minimal vowel duration changes occur across speaking conditions, or within trials, of a given speaking condition for the LTP group. No significant condition-by-trial interactions appear in the analyses of variance.

Voice-onset time in restricted-jaw speaking. Figure III-23 indicates mean voice-onset-time for the initial consonants, /t, d, tr, str/, produced during normal and restricted-jaw speaking by the three groups. Duration Response Pattern Two, systematic lengthening of all segments, characterizes voice-onset-times produced by the Control group during restricted-jaw speaking. Duration Response Pattern One, selective lengthening of segments, occurs for the voice-onset-times produced by the cortically injured groups; however, RTP and LTP groups show different selective response patterns. RTP subjects lengthen voice-onset time in the initial consonants, /d/, /t/, and /tr/;

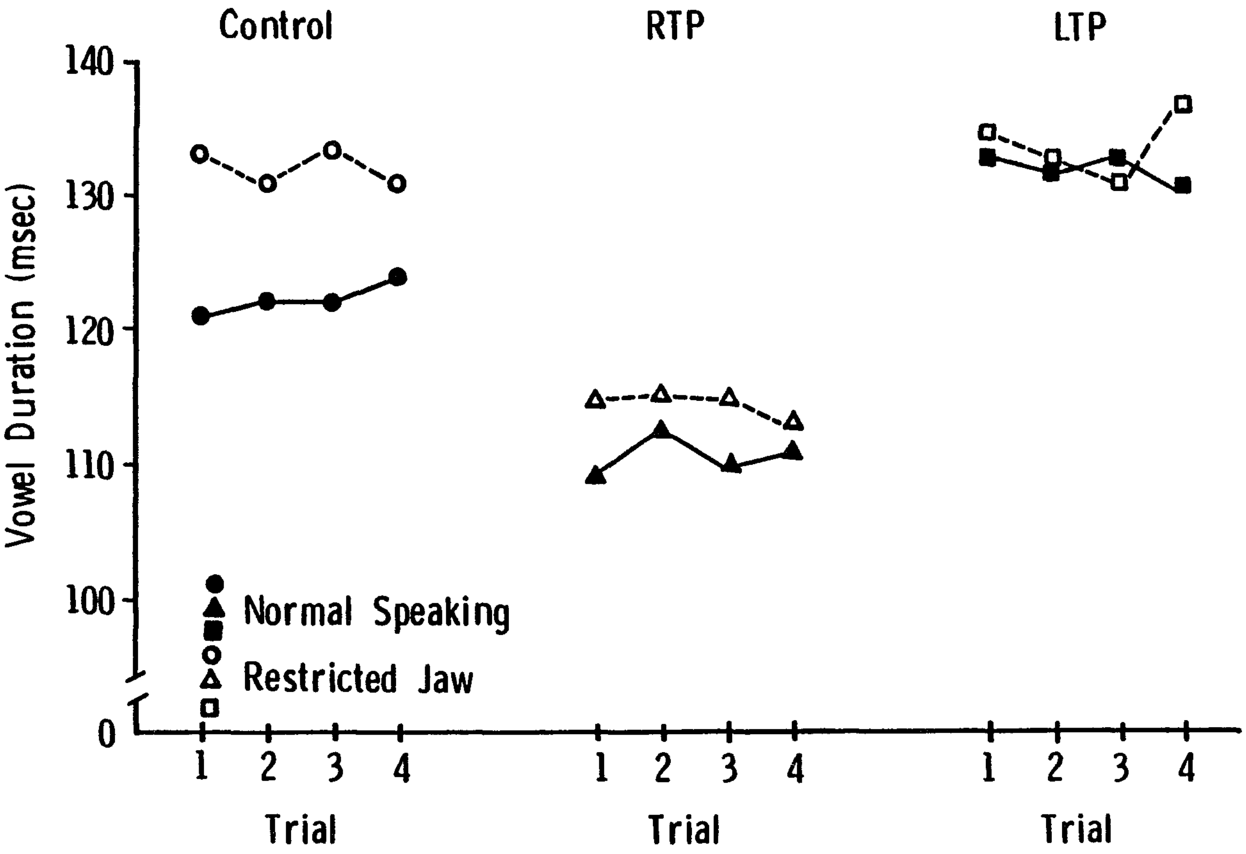


Figure III-22. Mean vowel duration as a function of trial and speaking condition for Control, RTP, and LTP groups.

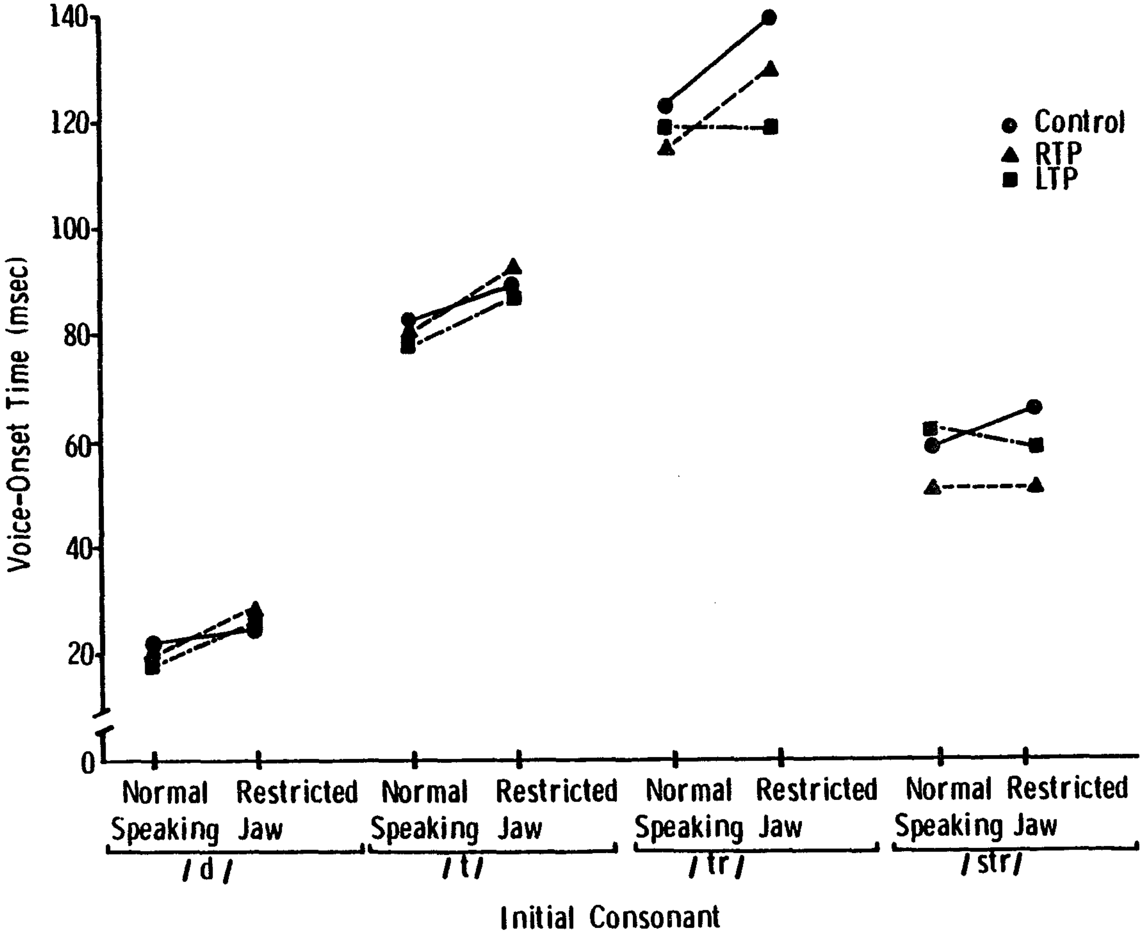


Figure III-23. Mean voice-onset time produced by Control, RTP, and LTP groups during normal and restricted-jaw speaking.

however, no duration changes occur for three-element /str/ clusters. A similar lengthening of voice-onset time for the singleton consonants, /d/ and /t/, is seen for the LTP group; however, the LTP group shows virtually no change in voice-onset-time for two-element /tr/ clusters and shorter voice-onset-times for three-element /str/ clusters. A significant main effect for condition occurs in the analysis of variance [$F=8.13$, $df=1,12$ ($p<.01$)] although a significant consonant-by-condition does not.

Different duration response patterns between the three groups also are evident in the next Figure (III-24), illustrating voice-onset time as a function of vowel nuclei. Duration Response Pattern Two, systematic lengthening of voice-onset-time prior to all vowel nuclei, occurs for the Control group suggesting the response pattern is not dependent on a particular vowel or consonant context. The RTP subjects show a less consistent response. RTP subjects increase voice-onset-time in all vowel contexts during restricted-jaw speaking (Duration Response Pattern Two); however, they produce Duration Response Pattern One in the examination of voice-onset time as a function of initial consonant or clusters. Duration-response patterns produced by RTP subjects apparently depend on the particular initial consonant or clusters--RTP duration patterns parallel the Control group's pattern, except in initial three-element consonant clusters. A consistent but different response pattern occurs in the LTP data--LTP subjects produce a Duration Response Pattern Two for voice-onset-time as a function of vowel and initial consonants. Voice-onset-time is

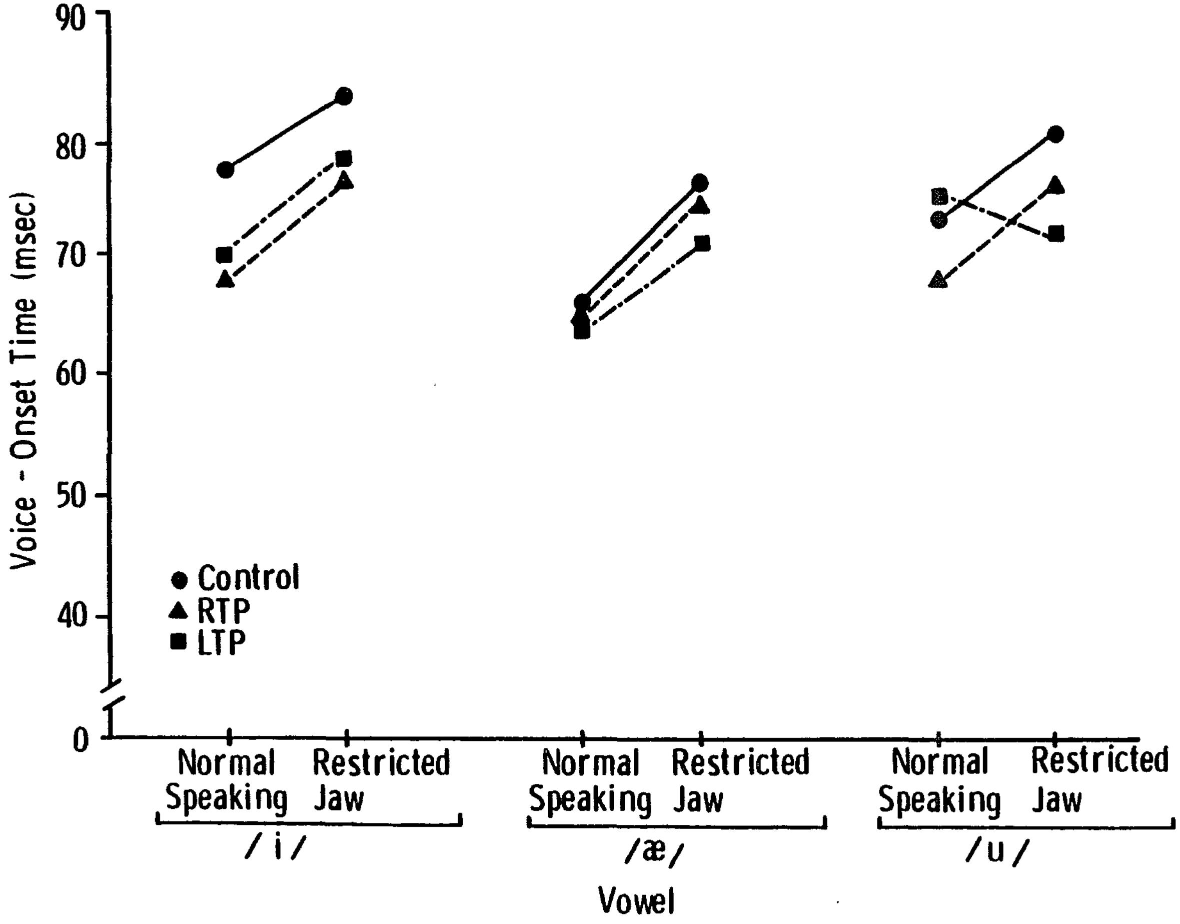


Figure III-24. Mean voice-onset time as a function of vowel nuclei produced by Control, RTP, and LTP groups during normal and restricted-jaw speaking.

lengthened prior to the front vowels, /i/ and /ae/, and shorten prior to the back vowel, /u/. Duration response patterns produced by the LTP group appear influenced by both consonant and vowel environments--LTP and Control subjects only produce similar duration responses for initial singleton consonants, /t/ and /d/, and the front vowels, /i/ and /ae/. Significant vowel-by-condition [F=7.44, df=2,24 ($p<.01$)] and group-by-vowel-by-condition interactions occur [F=5.466, df=6,24 ($p<.01$)] in the analysis of variance. Further analysis reveals a significant group-by-vowel-by-condition interaction for the RTP-LTP data [F=8.502, df=2,12 ($p<.01$)] and a significant Control/Pathological-by-vowel-by-condition interaction [F=7.16, df=2,24 ($p<.01$)].

Although the previous figures suggest the three groups use slightly different duration-response patterns during restricted-jaw speaking, it is not clear if the duration-response patterns of the groups change with practice. Figure III-25 illustrates voice-onset-time as a function of speaking condition and trial for each of the three groups. No systematic practice trends are shown in the figure for any of the groups. A slightly different presentation of these data is depicted in the next figure (III-26), displaying the standard deviations for voice-onset-time as a function of trial and speaking condition. Standard deviations of the Control and RTP subjects increase during the restricted-jaw condition; however, LTP subjects who are slightly more variable in normal speaking than Control and RTP subjects have similar standard deviations in normal and restricted-jaw

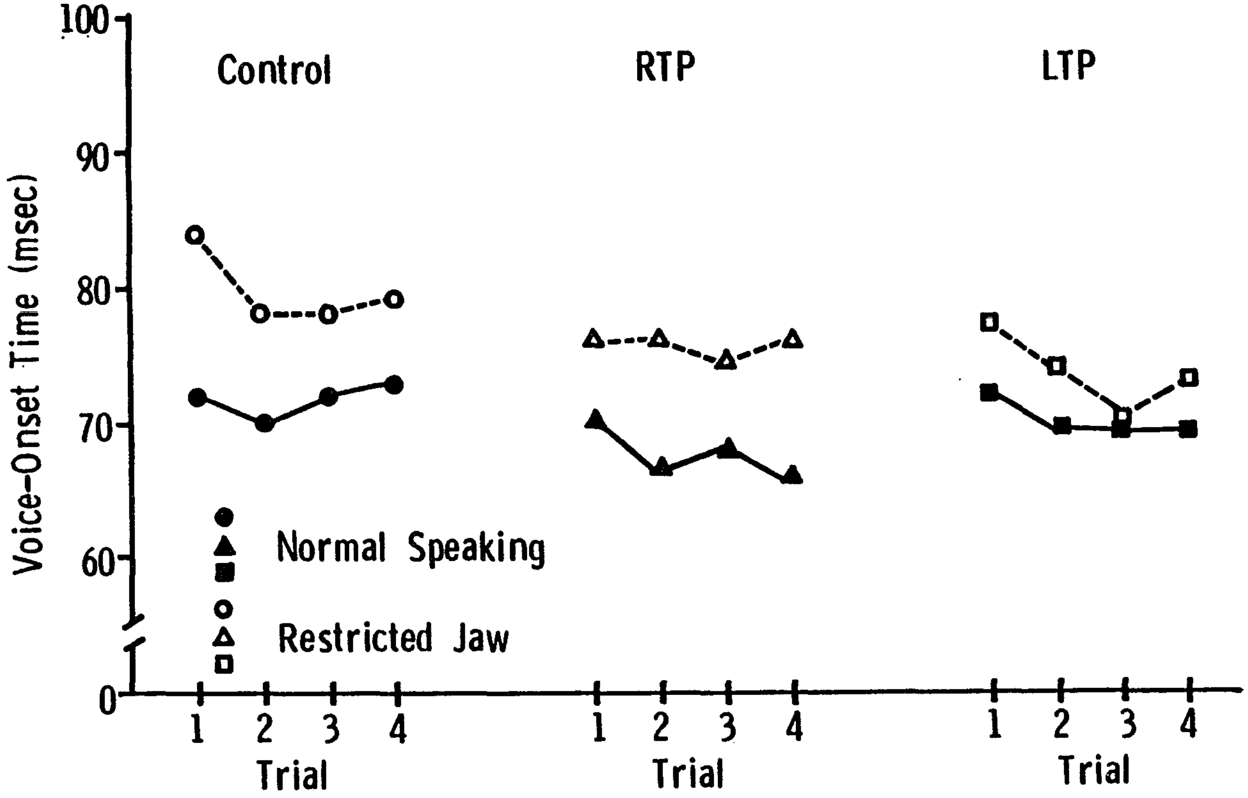


Figure III-25. Mean voice-onset time as a function of trial and speaking condition for Control, RTP, and LTP groups.

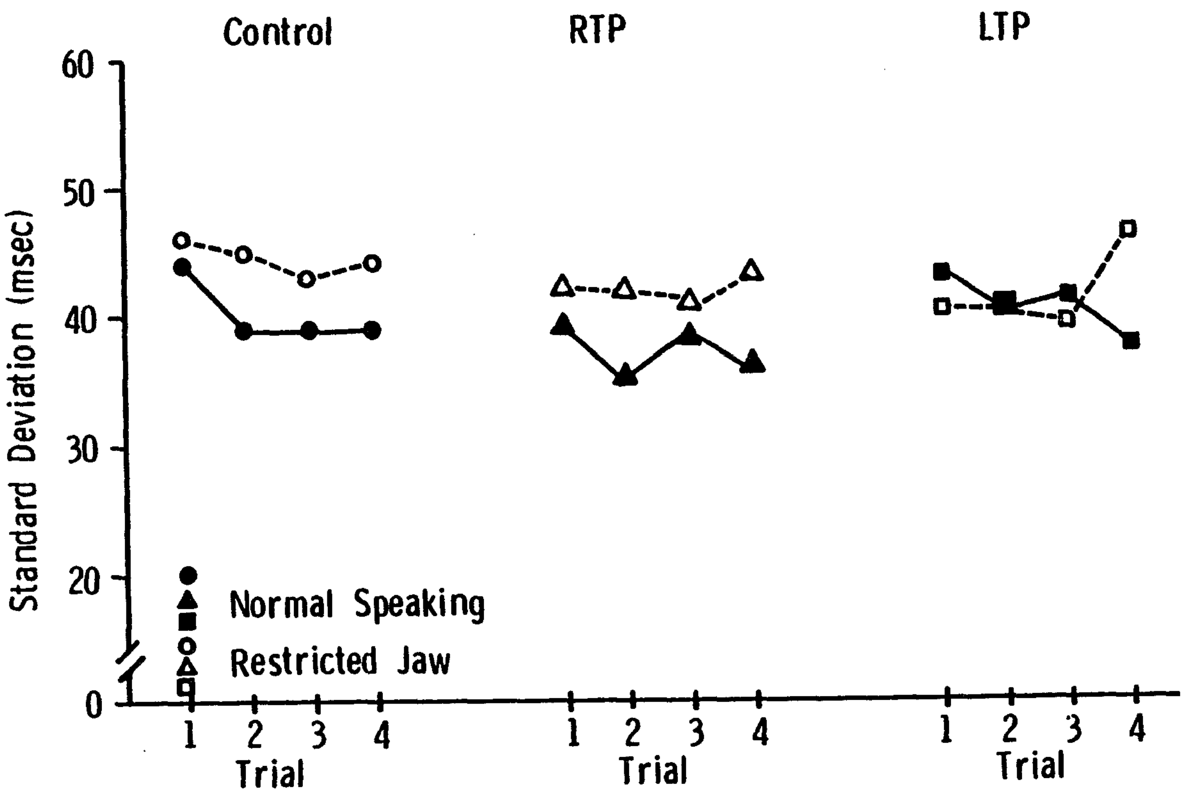


Figure III-26. Mean standard deviations of voice-onset time as a function of trial and speaking condition for Control, RTP, and LTP groups.

speaking. No significant condition-by-trial interactions occur in the analyses of variance.

Friction duration in restricted-jaw speaking. Duration-response patterns of friction segments are shown in Figure III-27 for the three groups. Duration Response Pattern Two, lengthening of all segments, is evident for friction durations of the Control subjects. Duration Response Pattern One, selective lengthening of segments, is evident in the RTP and LTP durations. RTP subjects slightly increase friction duration in the singleton consonant (/s/) and show virtually no change in friction duration in /str/ clusters. A different Durational Response Pattern One is evident for the LTP group--LTP subjects increase friction in singleton consonants (/s/) and decrease friction in /str/ clusters. A significant consonant-by condition interaction reflects the durational patterns in a more detailed analysis of RTP and LTP data [$F=6.065$, $df=1,6$ ($p<.05$)].

Figure III-28 depicts friction duration as a function of vowel nuclei for the three groups. Control subjects produce Duration Response Pattern Two, regardless of vowel, following the friction segments. These data support earlier observations, suggesting the duration-response pattern produced by Control subjects is independent of the particular consonant or vowel spoken. Duration Response Pattern One occurs for the two cortically injured groups. RTP subjects lengthen friction segments prior to the front vowels, /i/ and /ae/; however, RTP subjects produce shorter friction segments prior to the back vowel, /u/. RTP subjects lengthen friction segments in singleton

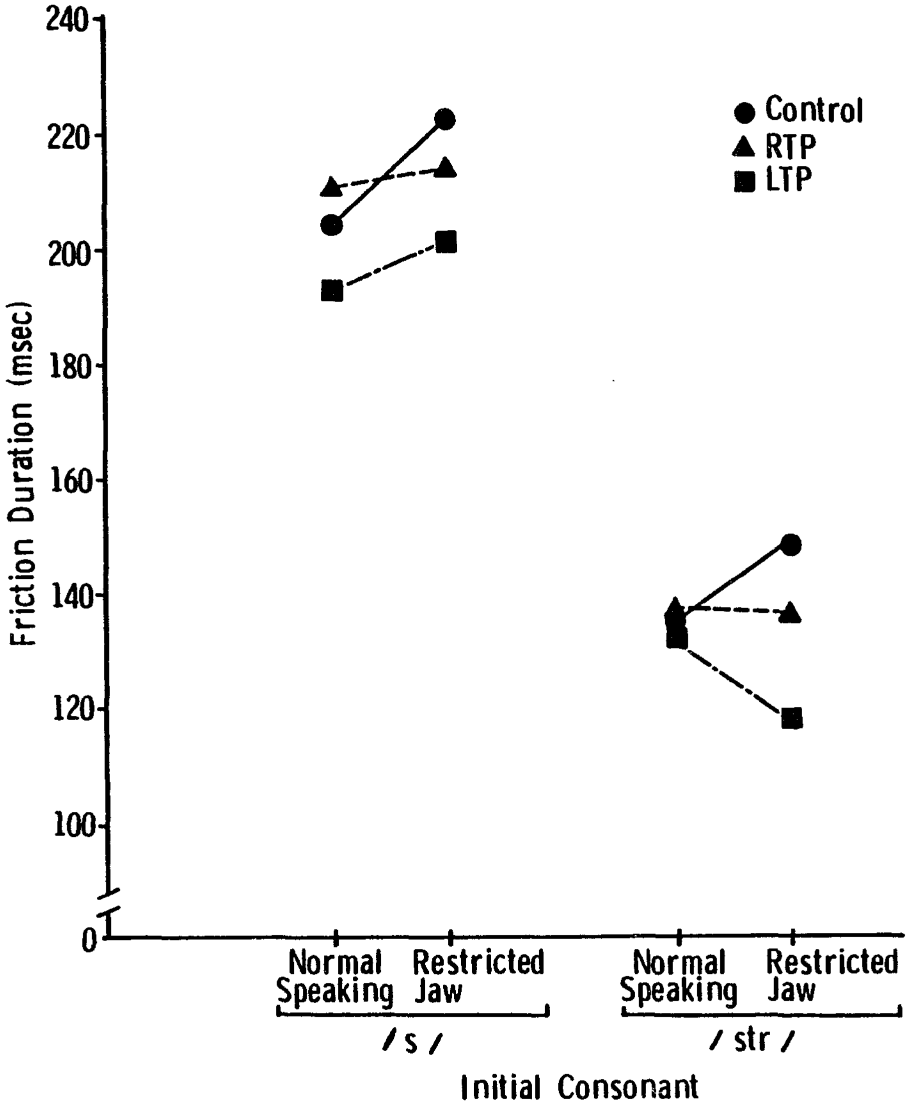


Figure III-27. Mean friction duration produced by Control, RTP, and LTP groups during normal and restricted-jaw speaking.

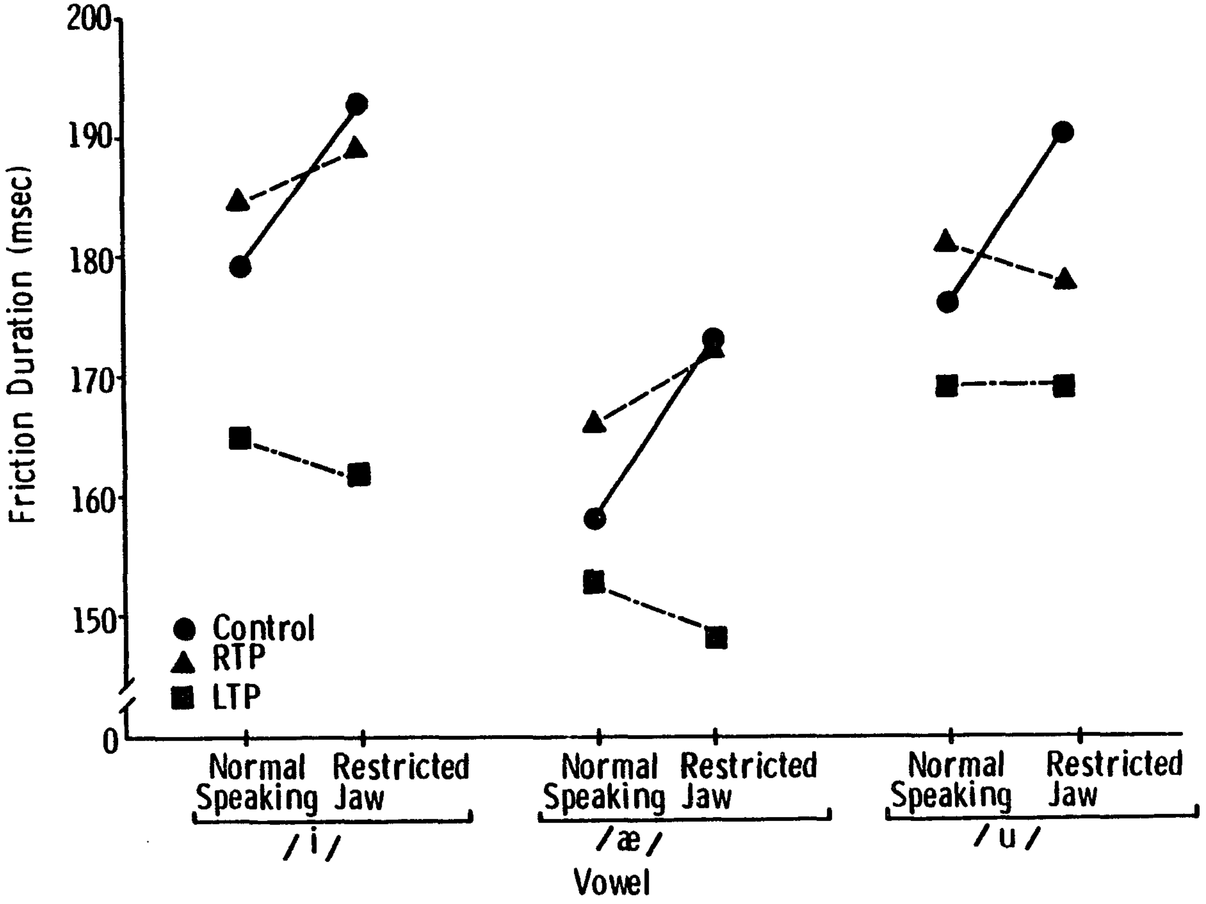


Figure III-28. Mean friction duration as a function of vowel nuclei produced by Control, RTP, and LTP groups during normal and restricted-jaw speaking.

consonants and prior to front vowels in a manner similar to the Control Group. On the other hand, LTP subjects produce shorter friction segments before the front vowels and comparable friction segments prior to the back vowel, /u/. Control and LTP subjects respond in a similar manner in only one instance--lengthening of friction segments for singleton consonants.

Figure III-29 portrays friction duration as a function of trial and speaking condition for the three groups. No systematic practice effect is evident for Control or RTP groups. Alternatively, LTP subjects tend to decrease friction duration to more closely approximate normal-speaking durations as a function of trial. The next Figure (III-30) illustrates the standard deviations as a function of trial and speaking condition for the three groups. All three groups are more variable in the restricted-jaw speaking condition as represented by the larger standard deviations. In addition, the RTP group tends to be more variable and the LTP group less variable as a function of trial in normal speaking. Standard deviations, in conjunction with the mean durations presented in Figure III-29, rule out practice effects in the duration response patterns produced by Control and RTP subjects. Standard deviations of the LTP group appear to slightly decrease as a function of trial during restricted-jaw speaking and may represent a tendency to approach the shorter-friction segments produced during normal speaking. A significant consonant-by-repetition interaction is not found in the analyses comparing the four groups, although a closer examination of RTP and LTP data reveals a significant

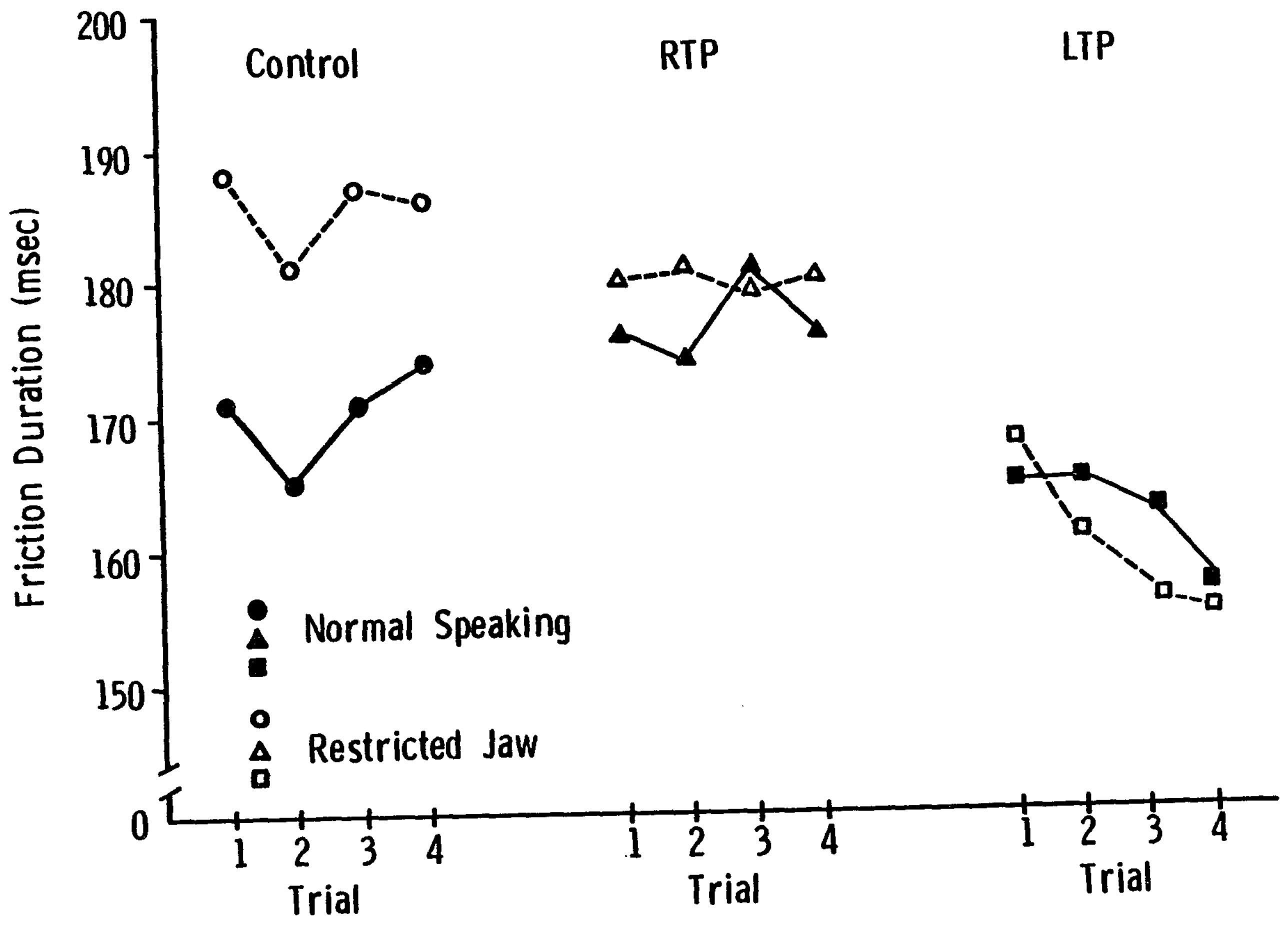


Figure III-29. Mean friction duration as a function of trial and speaking condition for Control, RTP, and LTP groups.

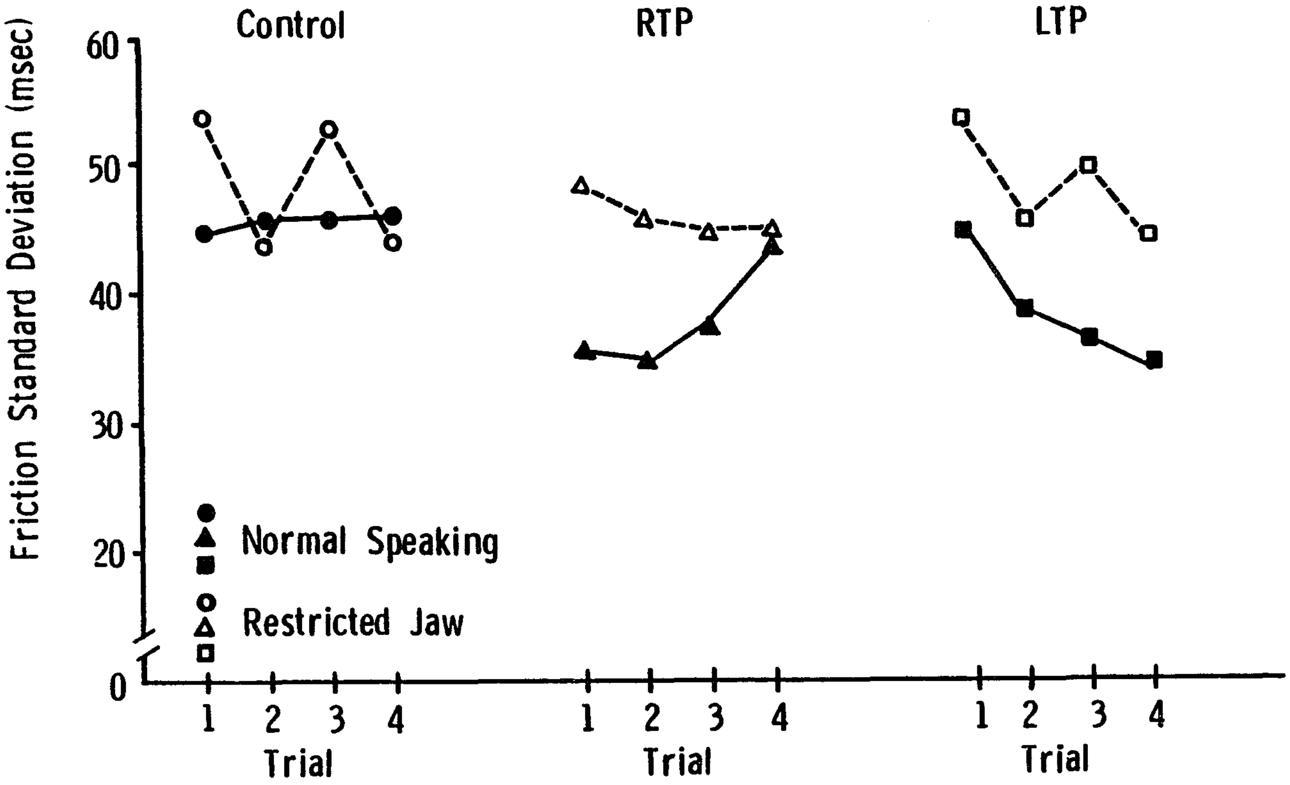


Figure III-30. Mean standard deviation of friction segments as a function of trial and speaking condition for Control, RTP, and LTP groups.

consonant-by-repetition interaction [F=3.25, df=3,18 (p<.05)]. In addition, a significant group-by-consonant-by-repetition interaction is found in an orthogonal breakdown contrasting Control and Pathological data [F=3.88, df=3,36 (p<.01)].

TR2 durations in restricted-jaw speaking. Duration-response patterns for TR2 are shown in Figure III-31. Control and LTP subjects produce two different Duration Response Pattern Twos. As in the previous duration measures, Control subjects systematically lengthen TR2 segments during restricted-jaw speaking. On the other hand, LTP subjects systematically shorten TR2 segments during restricted-jaw speaking. RTP subjects produce a Duration Response Pattern One by lengthening TR2 segments in singleton, /r/, shortening TR2 segments in three-element clusters, and retaining similar TR2 durations in two-element clusters. These observations are verified by significant consonant-by-condition [F=6.19, df=6,24 (p<.01)] and group-by-consonant-by-condition [F=2.59, df=6,24 (p<.05)] interactions. Additional analysis indicates the group interaction is primarily due to differences between the Control and Pathological data which show a significant group-by-consonant-by-condition interaction [F=4.27, df=2,24 (p<.05)]--no significant interaction occurs in the analysis contrasting only the RTP and LTP data.

Figure III-32 depicts TR2 duration as a function of vowel and speaking condition for the three groups. Control and LTP subjects produce a Duration Response Pattern Two regardless of the vowel following TR2 segments. However, Control subjects systematically

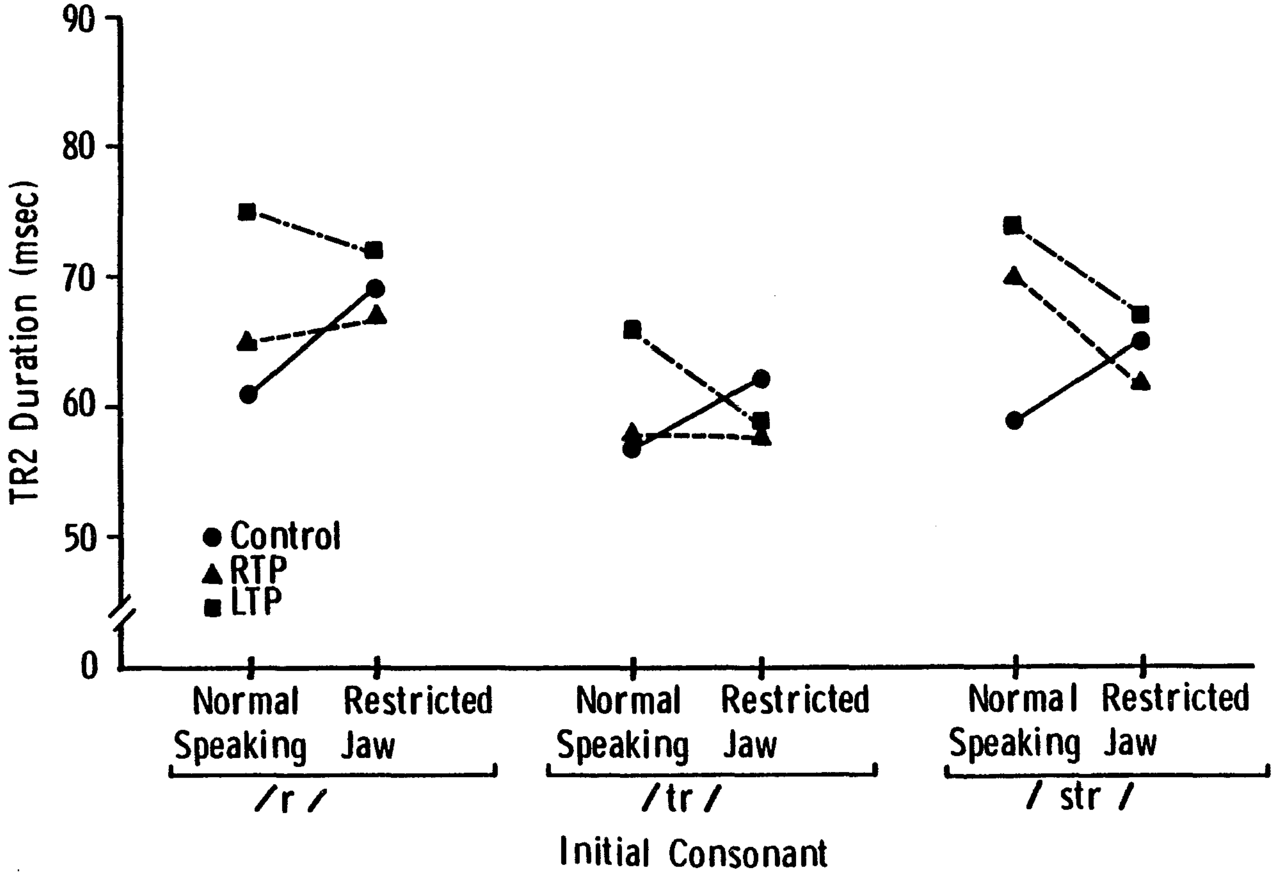


Figure III-31. Mean TR2 duration produced by the Control, RTP, and LTP groups during normal and restricted-jaw speaking.

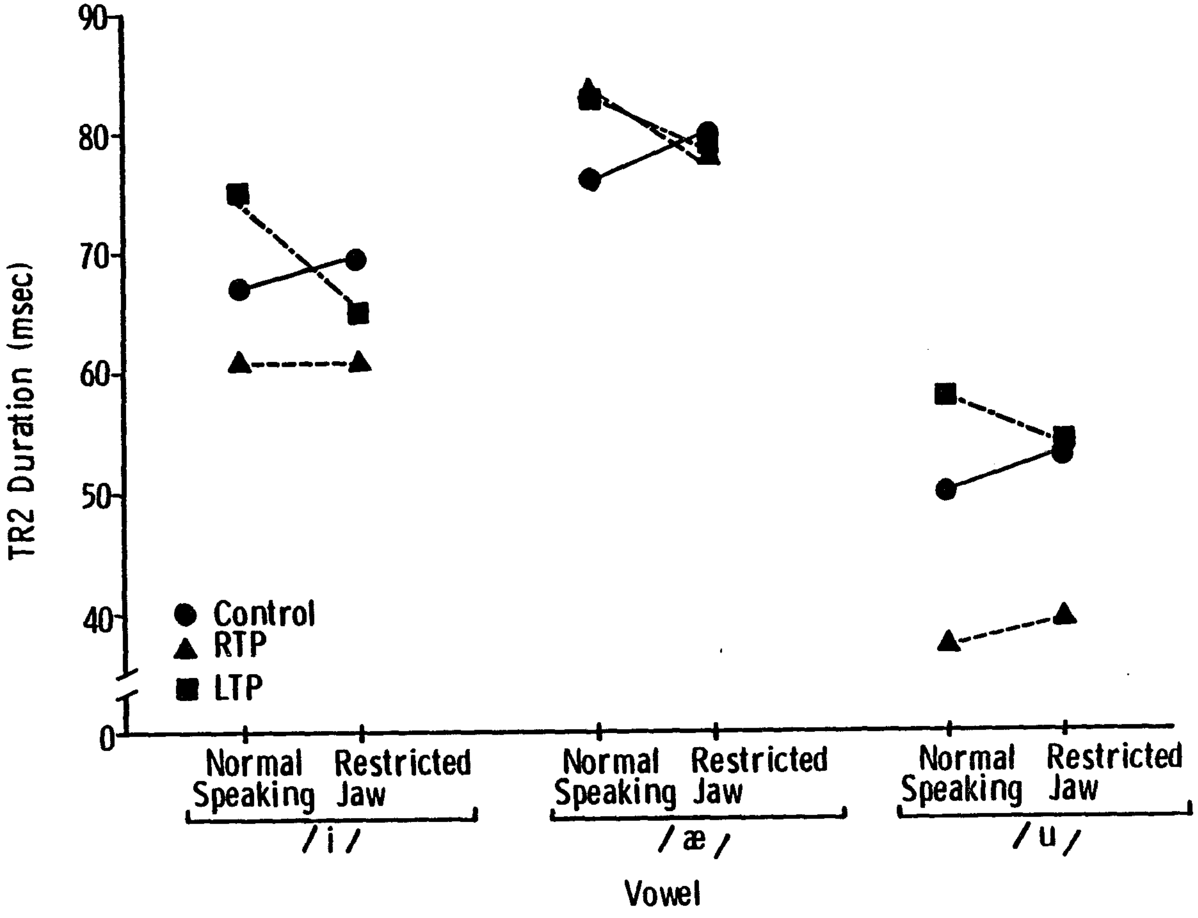


Figure III-32. Mean TR2 duration as a function of vowel produced by Control, RTP, and LTP groups during normal and restricted-jaw speaking.

lengthen TR2 and LTP subjects systematically shorten TR2 before the vowel nuclei. These data suggest Duration Response Pattern Two occurs independently of the particular vowel or consonant spoken by the Control and LTP groups. RTP subjects produce a Duration Response Pattern One as a function of the various vowels following the TR2 segments. No duration changes are evident for TR2 segments occurring prior to the high, front vowel, /i/, slight increases in TR2 occur prior to /u/ and TR2 decreases prior to the low, front vowel, /ae/. RTP and Control subjects produce similar response patterns for singleton /r/ segments and segments occurring prior to the high-back vowel, /u/. In addition, RTP and LTP subjects produce a similar response pattern for three-element clusters and the low-front vowel, /ae/. Although a significant vowel-by-condition interaction did not occur in the analysis of variance contrasting the four groups, a significant vowel-by-condition interaction is found in the orthogonal breakdown contrasting RTP-LTP [F=7.5, df=2,12 (p<.01)] and Control-Pathological [F=5.64, df=2,24 (p<.01)] data.

Figure III-33 illustrates TR2 duration as a function of trial and speaking condition in order to determine if duration-response patterns change during restricted-jaw speaking. No systematic practice effects are evident for the RTP and LTP groups; however, Control subjects tend to shorten TR2 segments to more closely approximate normal speaking across trials during restricted jaw speaking. The next Figure (III-34) shows the standard deviations of TR2 duration as a function of trial and speaking condition. Standard deviations decrease as a function of

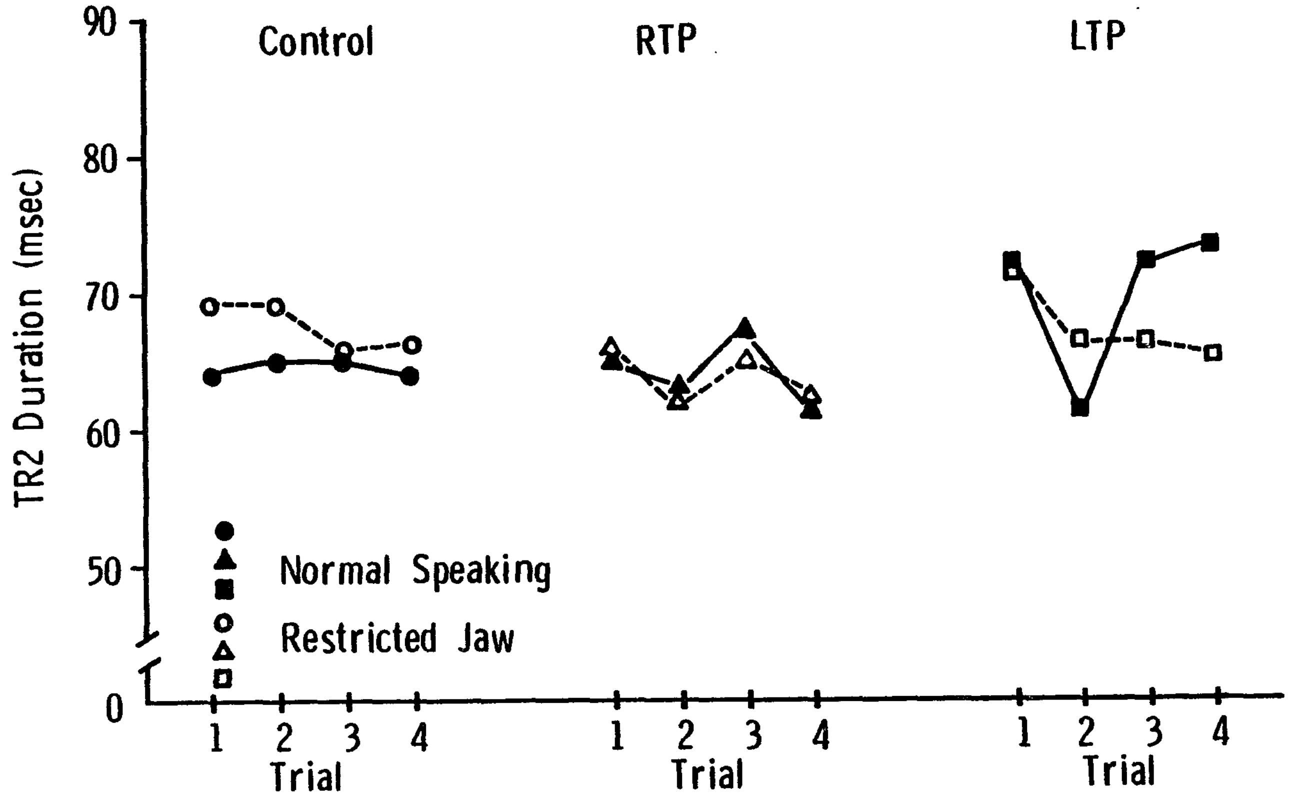


Figure III-33. Mean TR2 duration as a function of trial and speaking condition for Control, RTP, and LTP groups.

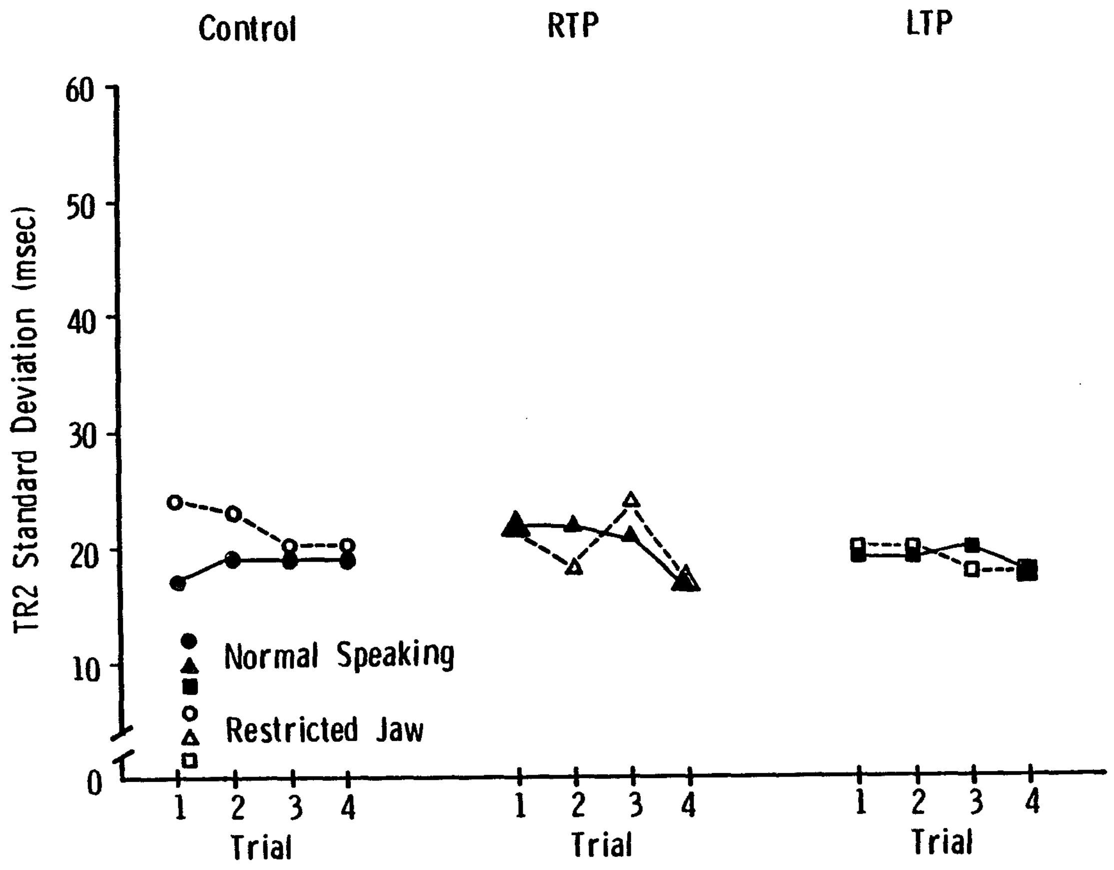


Figure III-34. Mean standard deviation of TR2 as a function of trial and speaking condition for Control, RTP, and LTP groups.

trial during restricted-jaw speaking for the Control subjects, suggesting practice effects may occur although no such trend is found for the cortically injured groups. Although the Control group tends to change TR2 durations as a function of trial and speaking condition, no significant group-by-condition-by-trial interaction is found in the analysis of variance.

Summary of Duration Measures during Restricted-Jaw Speaking

The next table (Table III-15) summarizes the duration-response patterns produced by the Control, RTP, and LTP groups. Lengthening of duration during restricted-jaw speaking is designated by a plus (+), shorter durations are indicated by a minus (-), and no duration change is designated by a zero (0). Designations are provided for each of the acoustic segment measures [vowel nuclei (VN), voice-onset-time (VOT), friction (FRIC), and TR2] and total-word (TW) durations. Control subjects produce longer segments and total word durations in restricted jaw speaking. RTP subjects lengthen the front vowels, /i/ and /ae/, and shorten the back vowel, /u/, during restricted-jaw speaking. Voice-onset-time is increased during restricted-jaw speaking for the initial consonants, /t/, /d/, and /tr/; however, voice-onset time does not change for the three-element cluster, /str/, produced by RTP speakers. In addition, longer voice-onset-times are produced prior to each vowel nuclei in restricted-jaw speaking by the RTP subjects. The RTP group increases friction duration for the singleton consonant, /s/, and prior to the front vowels, /i/ and /ae/; however, no change in friction duration occurs for the three-element cluster, /str/. TR2

TABLE III-15

SUMMARY OF DURATION-RESPONSE PATTERNS PRODUCED DURING RESTRICTED-JAW SPEAKING

	Consonants						Vowels		
Group	/t/	/d/	/s/	/r/	/tr/	/str/	/i/	/ae/	/u/
Control									
VN	+	+	+	+	+	+	+	+	+
VOT	+	+			+	+	+	+	+
FRIC			+			+	+	+	+
TR2			+	+	+	+	+	+	+
TW	+	+	+	+	+	+	+	+	+
RTP									
VN	0	+	+	+	+	+	+	+	-
VOT	+	+			+	0	+	+	+
FRIC			+			0	+	+	-
TR2				+	0	-	0	-	+
TW	+	+	+	+	+	+	+	+	+
LTP									
VN	0	-	-	+	+	+	+	0	0
VOT	+	+			0	-	+	+	-
FRIC			+			0	-	-	0
TR2				-	-	-	-	-	-
TW	+	+	+	+	+	-	+	+	0

segments are lengthened in the initial consonant, /r/, and prior to the high-back vowel, /u/, by the RTP speakers during restricted-jaw conditions. No duration changes are noted for TR2 segments in two-element cluster contexts, and TR2 segments are shorter for three-element consonant clusters. Similarly, TR2 segments are shorter prior to the low, front vowel, /ae/, and show no duration change prior to the high-front vowel, /i/. Although several segmental measures do not lengthen during restricted-jaw speaking, overall duration (as indicated by total-word duration) increases for the RTP subjects.

LTP subjects lengthen vowel-nuclei segments associated with the high-front vowel, /i/; however, no durational changes occur for the vowel nuclei, /ae/ and /u/. Initial consonant or cluster context also effects the duration of vowel nuclei during restricted-jaw speaking. Vowel-nuclei durations increase for the initial consonant or clusters containing /r/ and decrease for the initial consonants, /d/ and /s/. Voice-onset-time increases during restricted-jaw speaking for the singleton stop-consonants, /t/ and /d/, although no duration changes are noted for the two-element cluster, /tr/. Shorter voice-onset-times are produced in initial, three-element consonant clusters during restricted-jaw speaking by LTP speakers. Voice-onset-time is also effected by the following vowel--voice-onset-time increases prior to the front vowels, /i/ and /ae/, and decreases prior to the back vowel, /u/. Lengthening of friction occurs only for segments associated with the singleton consonant, /s/. Duration decreases during restricted-jaw speaking for friction segments contained in the three-element consonant cluster, /str/. Vowel nuclei also influence friction duration during restricted-jaw speaking. Friction duration decreases prior to the front vowels, /i/ and /ae/. Consistent duration patterns are evident for the TR2 measures. TR2 segments are shorter in restricted-jaw speaking than in normal speaking for all consonant and vowel contexts. Total-word duration increases during restricted-jaw speaking for all initial consonant and vowel contexts except the three-element consonant cluster, /str/, and the high-back vowel, /u/.

Table III-16 summarizes the mean total-word durations in normal and restricted-jaw speaking, as well as the percent of change in total-word duration. Control subjects show the largest percent changes--/i/ has the greatest percent change (8.5%), /ae/ has the next greatest percent change (7.9%), and /u/ has the least percent change (6.5%). Similar percent-change patterns are found for the RTP and LTP groups--largest percent changes occur for /i/ [RTP (4.8%) and LTP (3.3%)], followed by /ae/ [RTP (3.4%) and LTP (1.7%)], and /u/ [RTP (2.5%) and LTP (0.5%)]. Although the three groups show similar percent-change patterns, the Control group produces larger percentages. Control subjects also show the largest percent total-word change for targets containing the three-element consonant cluster, /str/; however, RTP and LTP subjects do not show a similar trend.

TABLE III-16

SUMMARY TABLE OF TOTAL-WORD DURATION IN NORMAL- AND RESTRICTED-JAW SPEAKING FOR CONTROL, RTP, AND LTP GROUPS

					Vowel				
Group	/i/^{N}	/i/^{R}	%	/ae/^{N}	/ae/^{R}	%	/u/^{N}	/u/^{R}	%
Control									
t	208.8	223.0	6.4	253.2	254.0	0.3	196.4	205.4	4.4
d	161.5	178.1	9.3	222.6	240.2	7.3	159.7	164.7	3.0
s	339.5	370.3	8.3	373.8	405.6	7.8	335.2	352.4	4.9
r	233.5	249.5	6.4	272.1	298.4	8.8	237.3	251.9	5.8
tr	270.6	291.8	7.3	304.3	332.9	8.6	258.9	276.3	6.3
str	419.4	472.6	11.3	433.0	486.3	10.9	398.4	446.2	10.7
Mean	272.2	297.6	8.5	309.8	336.2	7.9	264.3	282.8	6.5
RTP									
t	189.3	206.0	8.11	244.4	260.4	6.1	189.6	186.3	-1.8
d	155.4	165.7	6.2	213.9	232.8	8.1	144.3	143.0	-0.9
s	325.1	340.3	4.7	374.8	369.9	-1.3	311.1	312.5	0.5
r	230.4	239.9	3.9	259.6	285.4	9.0	217.1	225.7	3.8
tr	241.9	265.3	8.8	293.4	311.4	5.8	230.8	252.0	8.4
str	420.8	424.4	0.8	444.4	434.5	-2.3	402.3	414.3	2.9
Mean	260.5	273.6	4.8	305.1	315.7	3.4	249.2	255.6	2.5
LTP									
t	219.1	232.1	5.6	243.7	258.1	5.6	210.2	211.7	0.7
d	175.0	194.9	10.2	231.9	228.4	-1.5	178.0	180.2	1.2
s	350.6	347.9	-0.8	375.3	378.7	0.9	334.9	349.4	4.2
r	254.9	260.1	1.2	291.9	288.4	-1.2	248.4	266.0	6.6
tr	275.6	282.0	2.3	303.7	317.4	4.3	274.4	260.4	-5.4
str	402.6	417.5	3.6	431.6	420.0	-2.8	417.1	404.5	-2.9
Mean	279.7	289.1	3.3	310.0	315.2	1.7	277.2	278.7	0.5

CHAPTER IV

DISCUSSION

Data from the descriptive studies (Descriptive Study I--Oral- and Limb-Apraxia Assessment and Descriptive Study II--Articulation Assessment) provide a gross, qualitative means of assessing the integrity of buccofacial and limb musculature for non-speech gestures and articulatory accuracy for monosyllabic production in the cortically injured groups.

Data from the Experimental Study--Forced Adaptation are discussed within four general areas--the first two examine temporal and spectral characteristics of Control and cortically injured subjects during normal speaking; the third area considers frequency- and duration-response patterns generated by the Control group during restricted-jaw speaking, and the fourth area focuses on frequency- and duration-response patterns generated by RTP and LTP groups during restricted-jaw speaking.

Oral- and Limb-Apraxia Assessment

Oral, non-verbal apraxia is not present in the cortically injured subjects in this study, as indicated by the quality of gestures produced during oral-apraxia assessment. Although several studies (De Renzi et al., 1966; Creech, Wertz, and Rosenbeck, 1973; LaPointe and Wertz, 1974; Teixeira, Defran, and Nichols, 1974; Moore, Rosenbek, and LaPointe, 1976) report patients with left hemisphere lesions often demonstrate oral, non-speech apraxia, the LTP group appears capable of executing isolated buccofacial gestures requiring appropriate use of the tongue, lips, and jaw. Subjects in the RTP group also appear capable of executing gestures with buccofacial musculture--a finding which parallels previous studies reporting the rare occurrence of oral, non-speech apraxia in right-hemisphere lesioned subjects [see, for instance, Kimura (1961); Kimura and Archibald (1974); Mateer and Kimura (1977)]. There are, although small, interesting performance differences between the two cortically injured groups, despite the fact that neither group appears orally apractic on De Renzi et al. (1966) oral apraxia assessment items. Overall performance of the RTP group is slightly better than the LTP group and the range of scores for the RTP subjects is smaller than that observed for the LTP group (20-17.5 versus 20-15 respectively).

The quality of limb gestures is poorer than buccofacial gesturing for all cortically injured subjects, as indicated by overall-mean-performance scores. Scores for LTP subjects barely overlap the range of scores achieved by the RTP subjects. Although RTP and LTP groups demonstrate some degree of limb apraxia based on the scoring criteria of De Renzi and his colleagues (De Renzi et al., 1966), performing arm and hand gestures is more difficult for the LTP group. These findings are the result of the differing difficulty of individual items within the limb apraxia assessment between groups. Specifically, three items--'salute,' 'wave goodbye,' and 'indicate someone is crazy'--are performed with 100% accuracy by the RTP group. Only one item, 'show you are hungry,' is performed with less than 75% accuracy by the RTP group. Items presenting the least difficulty for the LTP group include 'waving goodbye,' 'indicating hunger,' and 'snapping fingers'; however, these items are executed with only 75% accuracy. Items presenting the most difficulty for the LTP group include patterns of movement such as, 'indicate someone is crazy' (44% accuracy), or 'make the sign of the cross' (31% accuracy).

Differences between the two cortically injured groups appear to extend not only to degree of severity (i.e., LTP subjects perform less accurately than RTP subjects) but also to the basic composition of gestures (i.e., some items are more difficult to execute than others). Further investigation using larger populations and a greater pool of gestures may assist in further delineating possible differences in motor systems not involved directly in communication between persons with right- and left-hemisphere lesions.

Articulation Assessment

Discrimination and articulation performance on the monosyllabic word list devised by Shankweiler and Harris (1966) indicate a number of differences between RTP and LTP subjects. Nearly twice as many discrimination errors occur for the LTP subjects than for the RTP subjects. These data relate to previous investigations examining the effects of cortical lesions upon central processes used in speech perception--subjects with cortical lesions often have normal auditory acuity but perform poorly on identification and discrimination of speech signals (see for example, Berlin, Cullen, Lowe-Bell, and Berlin, 1974). Articulation and discrimination evaluations also suggest measures of discrimination are critical for evaluating speech production errors of subjects with cortical lesions. Failure to examine discrimination abilities may result in an overestimation of production errors in cortically injured subjects when exemplars are aurally presented.

Articulatory error patterns produced by RTP and LTP groups are interesting for a number of reasons. First, RTP subjects produce articulation errors, although articulation errors following right hemsiphere injury are rarely reported [see, for a detailed review, Searleman (1977)]. Although several recent studies focus on the linguistic skills of persons with right-hemisphere damage, these investigations do not clearly differentiate between speech and language production skills [see, for example, Searleman (1977)]. That is, these studies do not clearly separate performance traits associated with speech (i.e., articulation) versus language (i.e., syntax, naming). Production of articulation errors by RTP subjects suggests additional examination of speech production (articulation and its underlying gesture patterns) as opposed to language-production skills, might reveal important contributions by the right hemisphere to the organization and execution of motor speech acts.

RTP and LTP groups produce slightly different articulatory error patterns. Place substitutions constitute half of the misarticulations produced by subjects with right-hemispheric damage while such errors constitute only one-third of the misarticulations observed for the LTP group. The majority of errors made by LTP subjects are substitutions of manner or voicing. Several studies report most errors produced by cortically injured subjects occur on consonant clusters or sibiliants [see, for example, Shankweiler and Harris (1966); or Trost and Canter (1974)]; however, this is not the case with the RTP and LTP subjects of this study. RTP subjects most often misarticulated stop-consonants by substituting inappropriate place features (i.e., bilabial for velar place) and LTP subjects most often produced manner or voicing errors for fricatives and stop consonants (i.e., substituting /t/ for /s/ or /p/ for /b/).

The finding that RTP and LTP subjects produce fewer articulation errors in this study than their previous medical records indicate, suggests that some recovery of articulation function has occurrred over the 10-year time period following their initial neurosurgery. Although LTP subjects produce articulatory errors, they produce fewer errors relative to previous studies which examined articulatory proficiency of subjects with left-hemisphere lesions. Differences between the number of articulatory errors produced by LTP subjects in this study and previous reports may, in part, reflect differences related to the etiology, location, and extent of damage associated with cortical injuries. Most previous studies examining articulatory skills following cortical injury use patients who have wide-spread cortical damage resulting from cerebral vascular accidents [see, for example, Fry (1959); Critchley (1953); Shankweiler and Harris (1966); Darley et al. (1975)] or closed head trauma [see, for instance, Newcombe (1969)], whereas subjects in this study received focal, circumscribed lesions from low-velocity missile fragments, thus, minimizing contra coup injury as well as damage to adjacent cortical areas. In addition, subject populations often are characterized by extensive lesions encompassing primary motor or sensory areas. Subjects participating in this study, on the other hand, have focal lesions to association areas of the cortex not normally found in the patient populations used in other speech investigations. These data suggest circumscribed, as opposed to wide-spread lesions to association areas in either the right or left hemisphere may subtly influence the accuracy of monosyllabic articulation.

Spectral and Temporal Characteristics of Control Subjects during Normal Speaking (Free-moving Jaw)

As a first step, productions of the Control group were studied to determine if frequency and duration measures during the normal speaking (unrestricted-jaw) condition fell within the range of previously reported values. Formant frequencies of the front, high and low vowels, /i/ and /ae/, were comparable to those found in previous studies [see, for instance, Peterson and Barney (1952) and Stevens and House (1963)]. Large formant frequency differences between previously reported data and this study's findings are found for the high, back vowel, /u/; however, these differences appear to arise from the particular contextual framework in which /u/ was placed for this study. That is, formant frequencies of /u/ following initial dental contexts (i.e., /s, t, d/) were found to vary by appreciable amounts. These findings were similar to those reported by Stevens and House (1963).

In addition, formant frequency patterns of the Control subjects reflected a shift of formant frequencies toward central values during contextual speech as reported by previous investigations [see, for example, Lindblom (1963)].

Initial consonants systematically influence the formant frequency values of vowels in the Control group's productions. For example, higher F_2 frequencies occurred when target vowels follow singleton consonants, /t, s, d/ and lower F_2 frequencies occur when target vowels follow initial consonant contexts containing /r/, suggesting Control speakers may extend the lip rounding used in /r/ productions into the following vowel. Extension of lip rounding from initial consonant or cluster contexts containing /r/ lengthens the vocal tract slightly, thus, producing slightly lower F_2 frequencies in the following vowel [see, for a discussion, Fant (1960)].

Duration measures were similar to previous reports of contextual speech; Control subjects produced the longest total-word durations for target stimuli containing the low-front vowel, /ae/, and the three-element consonant cluster, /str/. The shortest total-word durations occurred for target stimuli containing the high-back vowel, /u/, and the initial consonant, /d/. Control subjects produced longer vowel segments for the low, front vowel, /ae/, than for the high, front and back vowels, /i/ and /u/. These data were in agreement with previous studies showing low vowels (such as /ae/) were inherently longer, presumably because the jaw must assume a lower position (Peterson and Lehiste, 1960).

Duration of consonant segments also paralleled previous reports regarding contextual speech. Voice-onset times fell into the ranges reported by Lisker and Abramson (1964), although the voice-onset-time measures of /t/ in /tr/ contexts fell outside the upper range of values reported by Lisker and Abramson (1964). Friction was longer for /s/ segments in initial singleton- versus consonant-clusters--a finding which was similar to data reported by Klatt (1973).

Control subjects produced comparable TR2 durations in /r/ and /tr/ consonant contexts and slightly increased TR2 durations in /str/ clusters. These data differed somewhat from those reported by Russell (1977) where speakers systematically shortened TR2 segments as initial consonant contexts increased from singleton to three-element clusters; however, these differences may relate to contextual framworks used in this study and Russell's study (1977). In support of this conclusion, Klatt (1973) reported /r/ production was longer when its preceding cluster member was articulated in approximately the same place of articulation.

Spectral and Temporal Characteristics of Cortically Injured Speakers during Normal Speaking (Free-moving Jaw)

As mentioned in Chapter I, cortical lesions may influence spatio-temporal patterns underlying speech; thus, the speech production characteristics of cortically injured subjects may differ from Control subjects prior to the restricted-jaw condition. Obviously, spatio-temporal patterns underlying speech must take into account anatomical features of a given speaker. For example, overall vocal tract length and the ratio of pharyngeal- to oral-cavity size influence formant frequency patterns--lower formant frequencies often reflect a longer vocal tract with a larger pharyngeal-to-oral cavity area ratio [see, for example, Stevens and House (1963); Fant (1973); and Borden and Harris (1980)]. Thus, if two subjects, one with a short vocal tract and one with a long vocal tract, produce vowels with exactly the same articulator positions, formant frequencies will be lower for the subject with the larger vocal tract.

In general, Control subjects produced lower F_1 and higher F_2 vowel formant frequencies relative to RTP or LTP groups. If overall vocal tract length and pharyngeal-to oral-cavity-area ratios were smaller for the Control group relative to the cortically injured groups, one would expect to see higher F_1 and F_2 frequencies for all vowels produced by the Control group relative to formant frequencies produced by the cortically injured groups. Obviously, this was not the case. Similarly, no overall consistent lower or higher formant frequency pattern was found between the RTP and LTP groups--RTP subjects produced lower formant frequencies for /u/ and higher formant frequencies for /ae/ than the LTP group. Lack of a consistent difference in formant frequency pattern between Control and cortically injured groups suggested gross, anatomical features of a given speaker (i.e., vocal tract size) played a minor (if any) role in the findings of this study. Thus, formant frequency patterns produced by Control and cortically injured speakers during normal speaking probably reflect subtle differences in articulator positions used by the speakers in the three groups to alter area/length relationships for vowel production.

One might expect, given slightly different sets of articulator positions, that the cortically injured speakers respond somewhat differently to contextual frameworks containing multiple gestures. Although the three groups show a similar frequency pattern as a function of initial consonant, the actual formant frequency values differ between the groups lending support to the possibility of subtle group differences in articulator position.

A large literature base suggests temporal disruptions were one of the major impairments following cortical injury [see, Chapter I for a review] and one might have expected to see slightly different duration patterns between the three groups. LTP subjects produced the longest total-words and RTP subjects produced the shortest total-words of the three groups. In general, total-words reflected the segmental duration patterns--LTP subjects were usually longer and RTP subjects were usually shorter. The only exception to this observation occurred for initial /str/ contexts. In this context, RTP subjects produced longer total-words than either LTP or Control groups. Examination of specific segment durations for /str/ context words indicated RTP speakers produced shorter friction, voice-onset time, TR2, and vowel segments than Control and LTP subjects; the major contributor to longer total-word duration for RTP subjects was the closure period associated with /t/.

This study found extremely consistent differences among the groups in duration measures which agreed with many previous studies examining the speech of patients with left hemisphere lesions [see, for a discussion, Darley et al. (1975)]. Although many of these studies were perceptually based (clinical judgements acquired through listening and transcription), acoustic production measures of voice-onset time indicate persons with left hemisphere damage produced longer voice-onset times [see, for example, Freeman et al. (1978); Blumstein et al. (1980)]. Duration data for the RTP subjects is even more interesting because there is a paucity of comparative data. A few anectodal reports suggest patients with right hemisphere damage produce 'rapid' or 'fast' speech [see, for example, the case reports of Penfield and Roberts (1959) and Russell and Espir (1961)].

Durational patterns of speech segments produced by the cortically injured and Control subjects suggest the groups use slightly different temporal strategies during normal speaking. It is tempting to speculate that such differences reflect neurologically imposed limits on the accomodatation (or optimization) of articulatory movements necessary to contextual speech.

Adaptive Motor Speech Function in Control Subjects

Frequency response patterns produced during restricted-jaw speaking by Control subjects are not comparable to the frequency patterns produced in normal speaking--Control subjects tend to increase F_1 and significantly decrease F_2 and F_3 during restricted jaw speaking. Significant formant frequency differences between the two speaking conditions differ from previous studies examining acoustic patterns of isolated vowels produced in normal and restricted-jaw speaking [see, for example, Lindblom et al. (1979) and Gay and Turvey (1979)]. Acoustic patterns of isolated vowels generated during restricted-jaw conditions closely approximate normal speaking frequencies; however, studies examining frequency response patterns of contextual vowels produced during restricted-jaw conditions report frequency shifts similar to the Control data obtained in this study (Garrison et al., 1979).

Speaking is influenced during restricted-mandible conditions by abnormally separated jaws and fixation of a structure which normally moves during speech. This creates little difficulty for the motor speech system during isolated vowel productions; however, production of vowels in context under these abnormal physiological conditions imposes additional limits (e.g., time and consonant-articulator position) that preclude compensatory movements to achieve equivalent vowel frequency patterns observed in the unrestricted-jaw-speaking condition.

Under normal physiological circumstances, acoustic patterns associated with isolated vowel production are achieved by altering area/length relationships in the vocal tract. Area/length relationships of the vocal tract and their acoustic consequences may be specified by examining three factors, relative length of the vocal tract, tongue position, and degree of tongue constriction [see, for example, Fant (1973)]. Stevens and House (1955) report nine English vowels including /ae/, /i/, and /u/ may be produced if the degree of tongue constriction is held constant and proper manipulation occurs of mouth opening and constriction location. In general, F_1 frequencies are higher when a narrow tongue constriction occurs nearer the glottis in conjunction with an unrounded, large mouth opening (Stevens and House, 1955; Fant, 1962). Increases in F_2 are more pronounced when a narrow tongue constriction is accompanied by the point of constriction located forward from the glottis and an increase in the ratio describing the length of the vocal tract to mouth opening (Stevens and House, 1955; Fant, 1962).

Stevens and House (1955) suggest a one-to-one correspondence between vocal-tract dimensions and F_1-F_2 frequencies. However, there are occasions in which different articulator positions produce similar formant values because of equivalence in the vocal-tract transfer function (Stevens and House, 1955). Specifically, comparable formant patterns for isolated vowels produced in normal and restricted-jaw speaking may be accomplished by slightly shifting articulator positions to produce equivalent vocal tract transfer functions because of the relative "static" nature of such isolated productions. For example, Netsell et al. (1979) suggest the tongue assumes a more "extreme" position during restricted jaw speaking conditions which, in turn, may be capable of producing a degree of constriction similar to normal-speaking conditions. Similar acoustic isolated vowel patterns in free-moving and restricted-jaw speaking are possible if the system maintains a constant degree of constriction and alters mouth opening ratios and tongue constriction location slightly.

Several authors hypothesize abnormal physiological conditions (such as jaw restriction) do not present a problem to the motor speech system because of it's organization [see, for a review, Fowler et al. (1979)]. Fowler and Turvey (1981) suggest a given vowel is inherently constrained by muscle organization of the vocal tract and must achieve a fixed tongue position-to-palate relationship. Several combinations of jaw and tongue-jaw positioning may be used to retain the fixed tongue position-to-palate relationships inherent in the musculture. Thus, a given vowel may be produced under abnormal physiological conditions by manipulating various combinations of jaw and tongue-jaw positions to achieve the necessary tongue-palate relationship. This approach (albeit using a different referent and vocabulary) parallels early observations of Stevens and House (1955) who suggest comparable acoustic patterns are accomplished by slightly shifting articulator positions within a range capable of producing similar formant frequencies.

Alternatively, Lindblom and his colleagues (Lindblom and Sundberg, 1971a; Lindblom et al., 1979; Gay, Lindblom and Lubker, 1981) argue the rapid accuracy of articulatory adjustments underlying isolated vowel production during restricted-jaw speaking may result from central rather than peripheral operations. These authors suggest the motor system uses central strategies capable of translating a vowel target (or its sensory goal) into spatio-temporal patterns of motor events. Shaping of spatio-temporal patterns appears controlled (or regulated) by a pre-planning or simulation strategy which permits the system to simulate normal and experimentally induced abnormal peripheral conditions. Mapping and simulation strategies allow the system to predict and correct maneuvers which might produce errors prior to their actual execution. Moreover, these authors suggest a given vowel is "specified with respect to the acoustically most significant area-function features, the points of constriction along the length of the vocal tract" [Gay et al. (1981), page 18).

As indicated in the above discussions, the motor speech system responds to isolated vowel production under normal and abnormal peripheral conditions by adjusting articulator positions of the vocal tract. It is not clear, however, if the system relies upon peripheral organization of vocal tract musculature or more elaborate central simulation strategies to implement articulatory adjustments during restricted jaw speaking. The common denominator of these hypotheses of motor system adjustment during restricted jaw speaking lies in the implicit (sometimes, explicit) notion that vocal tract adjustments, however controlled, operate in a range capable of producing formant frequencies similar to normal speaking.

Isolated vowel adaptation during abnormal peripheral conditions provides the underpining of two general hypotheses regarding speech production. First, a range of articulator positions are capable of producing similar formant frequencies and secondly, the system aims for a particular set of these positions, a target, within the general range. Depending on the point of reference, a target may be a particular area/length relationship (Stevens and House, 1963; Halle and

Stevens, 1964), articulatory configuration (Henke, 1967), or spatial coordinate (MacNeilage, 1970). The general problem with target hypotheses (regardless of referent) is twofold: first, targets are based on isolated phones rarely used for communication purposes and, second, a speaker during contextual speech falls short of these targets. For example, formant frequencies of isolated and vowels in context during normal speaking are not the same--formant frequencies of vowels in context approach more neutral frequencies associated with a schwa vowel [see, for example, Lindblom (1963)]. Thus, the notion of a "target" draws attention away from one of the main "properties" of the motor speech system--the range of articulatory positions capable of producing perceptually "acceptable" vowels under isolated and contextual conditions.

Producing vowels in context under normal peripheral conditions requires the system to expand the range of articulatory movement in order to encompass adjustments necessary for vowel and consonant production. Production of vowels in context during restricted-jaw speaking requires a complex response by the system. That is, the motor speech system must not only provide area/length adjustments for vowel and consonant production but adjust to a physically constrained articulator under dynamic conditions. Control subjects produce the greatest F_2 frequency changes on high, front and back vowels, /i/ and /u/. On the surface, this observation seems entirely reasonable--vowels which required the greatest tongue movement and tightest constriction (relative to the open, stable jaw position) are most likely to change if the system is additionally stressed by a contextual framework containing gestures requiring multiple positions and movements.

Adjustments provided by the system during abnormal peripheral conditions are not simple extensions of previously observed contextual effects. That is, there is no adjustment of contextual speech under abnormal peripheral conditions by further neutralization of formant frequencies patterns. One would expect to see F_2 lower for /i/, raise for /u/ and remain constant for /ae/ if this was the case; however, selective lowering does not occur. F_2 frequencies for each vowel are lower during restricted-jaw speaking. Moreover, the basic frequency relationships of the vowels (i.e., higher F_2 frequencies for /i/ versus /u/ and /ae/) are retained in the adjustments during restricted-jaw speaking. These data suggest adjustment to the restricted-jaw speaking condition may be accomplished using a different portion of the articulatory-position range capable of producing lower F_2 frequencies while preserving formant relationships characteristic of a given vowel.

Although lower F_2 frequencies are produced by the Control subjects under restricted jaw speaking, these tend to increase and approach values produced during normal speaking with increasing trials. This observation suggests articulator positions in restricted-jaw speaking may be "optimized" via sensory information. The potential usefulness of sensory feedback to monitor and aid production of contextual speech is not a new proposal. Paillard (1960) suggests motor relay stations modify and restructure motor patterns in accordance with information from peripheral sensory resources. Timing and rate of articulatory activities appear mediated by proprioceptive feedback (Abbs and Eilenberg, 1976). Perkell (1969) suggests two neuromuscular systems operate: vowels appear influenced by acoustic and myotactic feedback and consonant production appears influenced by fast-acting, intra-oral pressure and tactile feedback systems. Similar divisions of control are suggested by Ladefoged (1967) who hypothesizes that vowel production depends on auditory monitoring and consonant production is monitored via tactile and proprioceptive feedback. Borden (1980) suggests that coordinated skill movement in speech requires three types of feedback information: external feedback information supplied via auditory and tactile functions, response feedback provided by proprioceptive information from muscle spindles, and internal feedback generated by cerebral, thalamic, and cerebellar loops.

Although these various proposals suggest a major role for one or more forms of sensory feedback in normal speaking, it is not entirely clear how the information provided by feedback processes is used. It is equally unclear as to whether equal weighting is given to auditory, proprioceptive, and tactile feedback. Previous investigations of isolated vowel production during restricted-jaw speaking attempt to eliminate (or diminish) the influences of various types of feedback information by selecting measurement sites which are relatively free of feedback information. Several acoustic studies examining isolated-vowel production during restricted-jaw speaking measure formant frequencies at the first glottal pulse of the spectrographic display in order to examine a point occurring prior to any possible auditory feedback [see, for example, Lindblom and Sundberg (1971a)]. As previously mentioned, formant frequencies measured at this point are comparable between free-moving and restricted jaw productions of isolated vowels. These data suggest a minor (if any) role is played by auditory feedback in the articulatory adjustments underlying restricted jaw productions of isolated vowels. Additional support for a relatively minor auditory feedback role is found in the Garrison et al. (1979) study which acquired formant frequencies of isolated and contextual vowels. Formant patterns produced under free-moving and restricted-jaw speaking are not comparable regardless if the frequency measures are acquired at the first glottal pulse, middle or off-set of the vowel segment. Samples of lateral skull x-rays during restricted jaw production of isolated vowels indicate tongue shape is preserved (Lindblom and Sundberg, 1971b); however, comparisons of fiber distribution of the genioglossus muscle and tongue position during restricted-jaw speaking suggest proprioceptive functions of muscle spindles are not involved in adapting tongue positions (Lindblom and Sundberg, 1971b). Auditory and proprioceptive feedback apparently contribute only minor roles in monitoring speech production activities.

It is not clear exactly what role sensory feedback may play in adjusting articulation during restricted jaw speaking; however, the relative long-term (across several trials) systematic frequency changes observed for Control subjects in this study (during restricted jaw speaking) indicate the range of articulatory movement may be adjusted to more closely approximate the range of values used in normal speaking. That is, the motor speech system aims, not for specific vowel target positions, but rather for an optimal range of articulator positions which take into account (or allow for) the dynamic maneuvers associated with surrounding phones in the contextual framework as well as the physical constraints imposed on a particular articulator.

Adjustments to articulator positions during restricted-jaw speaking may encompass dynamic changes, as well. It is not clear if the motor speech system also adjusts the temporal course of speech to accomodate for the articulator-position range underlying formant frequency changes in restricted-jaw speaking. Control subjects systematically lengthen word and individual segment durations during restricted-jaw conditions. On first blush, these data seem entirely straight forward--gestures must travel a greater distance when the jaw is held in an open, stable position, and, therefore, take more time. However, interruptions to normal speaking via unexpected loads to the jaw do not alter lip closure durations (Folkins and Abbs, 1975). In addition, Netsell et al. (1978) report comparable durations of consonant and vowel segments during free-moving and restricted-jaw speaking conditions that are maintained by considerable velocity adjustments to upper and lower lip movement. Data from these two previous perturbation studies suggest the motor speech system normally maintains comparable time frames of consonant-vowel production during abnormal peripheral conditions by adjusting articulator velocity. Why, then, is there significant lengthening of total-word and individual acoustic segments for Control subjects during restricted-jaw productions of contextual speech?

One approach to addressing this question is to inquire if the Control subjects maintain individual segment-to-total-word duration ratios. That is, if one considers total-word duration to represent an operationally defined sampling window or the time frame used in normal and restricted-jaw speaking, will individual segment durations vary independently? Table IV-1 summarizes the percent time an individual segment occupies of the total-word during restricted-jaw and normal speaking. Percentages of individual/total-word durations are remarkably similar between the two conditions suggesting proportional duration increases are used in adjusting to an abnormal peripheral condition.

Generalized slowing of articulation during restricted-jaw speaking may represent a temporal strategy used to assist in optimizing its response to abnormal peripheral conditions. Reorganization of temporal characteristics may include rather gross, temporal alterations or the systematic changing of duration relationships for acoustic segments underlying phonetic distinctions (such as voice-onset time of /t/ and /d/) implying an underlying temporal reorganization of gestures. Examination of the duration tables in Chapter II indicates voice-onset time distinctions for /t/ and /d/ are retained in restricted jaw speaking--voice-onset times for both stop consonants are simply longer. Similarly, the relative duration of segments in singleton to cluster

TABLE IV-1

PERCENT TIME INDIVIDUAL SEGMENTS CONTRIBUTE TO TOTAL-WORD DURATION IN NORMAL AND RESTRICTED-JAW SPEAKING BY CONTROL GROUP

	Normal Speaking						Restricted-Jaw					
Context	Fric	VOT	TR2	VN	SS	CL1	Fric	VOT	TR2	VN	SS	CL1
/i/												
t		42.5		57.5				43.1		56.9		
d		15.0		85.0				15.1		84.1		
s	63.4			36.6			63.0			37.0		
r			26.3	40.5	33.2				27.1	41.6	31.3	
tr		50.3	23.5	26.2				49.5	20.5	30.0		
str	34.2	14.1	17.8	18.4		15.5	32.5	14.2	17.2	20.6		15.5
/ae/												
t		31.9		68.1				33.7		66.3		
d		9.5		90.5				10.7		89.2		
s	50.9			49.1			51.4			48.6		
r			24.6	50.6	24.8				26.1	49.8	24.1	
tr		36.2	25.1	38.6				39.7	21.7	38.5		
str	29.0	12.0	19.5	26.7		12.8	28.5	12.5	17.9	27.0		14.1
/u/												
t		41.2		58.8				41.9		58.1		
d		14.3		85.7				15.8		84.2		
s	64.3			35.6			64.4			35.6		
r			23.5	44.4	32.1				25.0	42.5	32.5	
tr		51.2	15.1	33.6				49.7	16.3	34.0		
str	34.2	15.2	12.0	22.3		16.3	34.4	14.6	12.3	22.9		15.9

contexts are preserved in restricted-jaw speaking--singleton segments are longer than comparable segments in a cluster context.

Spatial and temporal representations of a given gesture do not appear to be independent entities operating in separate ranges. Instead, a given gesture appears as an integrated spatio-temporal representation. This is not a new hypothesis. Several authors [see, for example, Fowler (1980); Fowler et al. (1981)]; incorporate integrated spatio-temporal representations in 'intrinsic timing' models for speech. For example, Fowler and her colleagues (Fowler, 1980) suggest many previous models of speech production exclude timing from a speaker's representation of an utterance. They propose timing is incorporated as an integral part of an utterance. Relative timing of gestures tends to be invariant during experimentally imposed rate changes (Kent, Carney, and Severeid (1974) indicating the inherent temporal coordination of gestures is encompassed in the overall phonological specification. Relative timing of individual segments within a given word (noted by the percent time an individual segment occupies within a total-word) is preserved by Control speakers in normal and restricted-jaw speaking conditions, although the total-word and individual segments are longer during restricted-jaw speaking. These data suggest the relative timing of gestures is retained not only in experimentally imposed rate changes but in 'adaptive' rate changes used to adjust to abnormal peripheral conditions. Moreover, duration response patterns produced by Control subjects during restricted-jaw speaking suggest the retention of critical timing and frequency relationships may be founded, in part, by the ability of the motor speech system to optimize the range of spatio-temporal dimensions during normal and abnormal peripheral conditions.

Adaptive Motor Speech Function in Cortically Injured Speakers

As mentioned in the previous section, Control subjects appear to use a twofold response strategy to accomodate (or adapt) to abnormal peripheral conditions: (1) the range of articulatory gestures underlying area/length relationships in the vocal tract is shifted and (2) articulation is slowed. Cortically injured speakers produce slightly different articulatory and temporal patterns during normal speaking than Control subjects. They may, however, produce response patterns during restricted-jaw speaking which resemble strategies used by Control subjects. Alternatively, one might assume that since the cortically injured subjects differ from Control subjects during normal speaking, they might respond differently during abnormal peripheral conditions. Different response strategies would be evident if frequency and duration patterns differ either in magnitude or direction of change.

In general, the overall frequency response patterns produced during restricted-jaw speaking by RTP and LTP subjects are not comparable to the frequency patterns produced by Control subjects--Control subjects produce greater F_2 frequency shifts than RTP or LTP speakers during restricted-jaw speaking. Although F_2 frequencies lower for each of the vowel nuclei produced by Control subjects, the largest F_2 frequency shifts occur for the high, front and back vowels, /i/ and

/u/, which require the greatest tongue movement and constriction relative to an open, stable jaw. RTP and LTP subjects produce the greatest F_2 frequency shifts for the high, front vowel, /i/, whereas only minimal F_2 frequency shifts are noted for /ae/ and /u/. Although LTP subjects lower F_2 frequencies for /u/ during restricted-jaw speaking, these changes are small and do not approach the F_2 frequencies achieved by RTP subjects for /u/ during normal speaking. These data suggest LTP subjects may change lip position slightly but do not alter articulatory gestures contributing to /u/ productions as much as Control or RTP subjects during restricted-jaw speaking. Minimal F_2 frequency shifts also occur for /u/ productions generated by RTP speakers during restricted jaw speaking. Minimal frequency shifts suggest RTP subjects fail (or choose not) to alter articulatory gestures underlying high, back-vowel productions as much as Control subjects during restricted-jaw speaking. Magnitude of these frequency shifts during restricted-jaw speaking indicates that the three groups may use slightly different response strategies.

Additional evidence for slightly different frequency response patterns occurs in the frequency shifts of low, front vowel productions. Control subjects produce lower F_2 frequencies for /ae/ during restricted-jaw speaking; however, cortically injured speakers do not appear to alter the articulatory gestures underlying /ae/ in a similar manner. Formant frequencies of /ae/ remain relatively constant for cortically injured groups during normal and restricted-jaw speaking. It is not immediately clear why the cortically injured groups fail to (or choose not to) alter the articulatory gestures underlying /ae/. Failure to do so may, in part, be related to the size of jaw separation used in this study. Restricting the jaw 1 cm is roughly the size of jaw opening used in normal speaking for /ae/ productions and, thus, may provide a nearly equivalent speaking situation requiring little adaptation for RTP and LTP subjects. On the other hand, selective adaptation of articulatory gestures underlying one vowel versus another may represent limitations associated with the flexibility and adaptability of the motor speech systems in cortically injured speakers.

Although Control subjects systematically increase F2 frequencies towards normal-speaking formant frequencies during restricted-jaw speaking, cortically injured subjects do not. Systematic frequency changes toward normal speaking values suggest that Control subjects attempt to optimize articulatory dimensions during restricted-jaw speaking by using some form(s) of sensory feedback to aid articulator positioning with practice. Lack of a significant trial or practice effect in the frequency response patterns of cortically injured speakers suggests RTP and LTP subjects may not optimize articulatory gesture ranges by aiming adjustments towards values which yield formants comparable to normal speaking. That is, if the articulatory range used during <u>normal</u> speaking is limited or less flexible, this may carry over to physiologically restricted conditions. Alternatively, cortically injured speakers may not be capable of receiving, interpreting, or using sensory information from the periphery to adequately adjust (or optimize) articulation.

Formant frequency response patterns of cortically injured speakers differ from Control subjects along three dimensions: (1) direction of change, (2) magnitude of change, and (3) consistency of change. As mentioned earlier, Lindblom and his colleagues [see, for a review, Gay et al. (1981)] suggest that the motor speech system uses central strategies capable of translating a vowel target into spatio-temporal patterns of motor events. Shaping of patterns appears controlled by pre-planning or "simulation" strategies which predict and adjust gestures prior to their execution. Direction, magnitude and consistency differences between cortically injured and Control speakers suggest that the central strategies underlying spatio-temporal patterns may differ between the groups. Although this study does not directly address the differences in central strategies between the groups, it is tempting to speculate the strategies may differ on three accounts. First, cortical lesions may influence the translation of vowels into spatio-temporal patterns. Secondly, cortical lesions may influence pre-planning or simulation strategies. Third, cortical lesions may limit the capability or consistency in predicting and adjusting gesture maneuvers prior to their execution. Although the Lindblom et al. (1979) central simulation model represents only one proposal regarding motor speech control, it appears amenable for constructing frameworks for additional investigations with cortically injured subjects.

Given that a cortical lesion to either the right or left hemisphere appears to reduce the flexibility and range of articulatory positions available to speakers, it seems reasonable to inquire if cortical lesions also limit temporal flexibility. RTP and LTP subjects demonstrate slightly different timing characteristics during normal speaking. RTP subjects produce shorter segments and LTP subjects produce longer segments relative to Control subjects. One of the more striking aspects of the normal-speaking duration observations is the constancy of response by the RTP and LTP subjects. Specifically, the segments produced by RTP subjects are always shorter (with one previously discussed exception) and those of the LTP group are always longer than Control subjects. Response patterns produced by cortically injured subjects may continue to reflect the general slower-faster durations noted during normal speaking. That is, LTP subjects may produce longer durations and RTP speakers may produce shorter durations, relative to the Control subjects, during restricted-jaw speaking. Alternatively, an abnormal peripheral condition may place additional constraints (or stress) upon the capabilities of cortically injured speakers.

Control subjects systematically lengthen segments during restricted-jaw speaking. Duration Response patterns produced by cortically injured subjects differ substantially from Control speakers. Although RTP subjects systematically lengthen most total-word durations, they do not increase duration during restricted-jaw speaking as much as Control subjects. Furthermore, RTP subjects do not increase total-word durations of three-element consonant clusters. As noted earlier, RTP subjects generally produce shorter total-word durations than Control or LTP subjects during normal speaking except for target words containing the initial consonant cluster, /str/. Examination of the individual segment durations reveal RTP subjects shorten segments in /str/ words during restricted jaw speaking; however, overall duration of three-element cluster words remains constant across conditions suggesting RTP subjects may significantly increase the closure period associated with /t/ in /str/. LTP subjects, on the other hand, selectively lengthen total-word durations. Total-word durations increase for initial singleton consonant, remain constant for stimuli containing an initial two-element consonant cluster, and decrease slightly for stimuli containing a three-element consonant cluster. Individual segment durations during restricted-jaw speaking are also inconsistent--some segments lengthen, some segments shorten, and some segments show no change.

Inconsistency in magnitude and direction of change across total-word and individual-segment durations during restricted-jaw speaking suggest that duration response patterns may be contextually dependent in RTP and LTP speakers. For example, relative size of the target word (i.e., CVC versus CCVC versus CCCVC) appears to influence the duration and frequency response patterns for RTP and LTP subjects. Control subjects lengthen a given segment (i.e., voice-onset time or TR2) regardless of the target word size. RTP subjects, on the other hand, lengthen segments in CVC and CCVC contexts but show an inconsistent response pattern for segments in CCCVC contexts. LTP subjects appear to use similar response pattern strategies for target words of the form CVC but use inconsistent response patterns for target words of the form CCVC and CCCVC. Contextually dependent response patterns in cortically injured speakers is puzzling. The natural question is, why?

One possibility is that cortically injured speakers may reorganize the relative timing of gestures depending upon the particular context or speaking condition. Table IV-2 and Table IV-3 indicate the relative time a given segment occupies during the total-word frame for the two cortically injured groups during normal and restricted-jaw speaking. As mentioned earlier, relative timing of gestures (represented by segment to total-word duration percentages) is retained across the two speaking conditions for the Control group. Similarly, examination of Table IV-2 and Table IV-3 reveal the cortically injured groups preserve the relative timing of gestures in normal- and restricted-jaw-speaking conditions. Moreover, the percent time devoted to a given segment produced either in normal or restricted-jaw speaking is similar for the three groups, although RTP subjects produce shorter words and LTP subjects produce longer words relative to the Control group. That is, one might consider that RTP subjects speak at a faster rate and LTP subjects speak at a slower rate relative to a moderate rate (i.e., Control rate). These data relate in a rather general way to previous observations by Kent et al. (1974) examining the effects of experimentally imposed rate changes and indicate the temporal

TABLE IV-2

PERCENT TIME INDIVIDUAL SEGMENTS CONTRIBUTE TO TOTAL-WORD DURATION IN NORMAL AND RESTRICTED-JAW SPEAKING BY RTP GROUP

	Normal Speaking						Restricted-Jaw					
Context	Fric	VOT	TR2	VN	SS	CL1	Fric	VOT	TR2	VN	SS	CL1
/i/												
t		43.7		56.2				45.0		55.0		
d		14.2		85.8				16.6		83.3		
s	66.9			33.1			67.0			33.0		
r			26.0	36.5	37.5				25.3	35.8	38.9	
tr		48.1	22.1	29.9				49.1	21.4	29.5		
str	36.1	12.0	17.2	17.4		17.3	35.8	12.8	15.9	18.2		17.3
/ae/												
t		33.4		66.6				36.0		64.0		
d		10.3		89.7				14.9		85.1		
s	51.3			48.7			52.6			47.4		
r			30.6	39.1	30.3				32.6	45.1	22.3	
tr		37.3	27.6	35.1				39.8	25.1	35.1		
str	31.5	10.8	20.5	24.3		12.9	31.7	10.3	17.2	25.7		15.1
/u/												
t		43.1		56.9				48.5		51.5		
d		15.8		84.2				18.1		81.9		
s	67.7			32.3			66.1			33.9		
r			24.7	62.5	12.8				26.5	58.0	15.5	
tr		50.3	16.7	33.0				53.1	12.9	30.9		
str	37.3	13.9	12.1	19.7		17.0	36.1	13.1	11.0	20.5		19.3

TABLE IV-3

PERCENT TIME INDIVIDUAL SEGMENTS CONTRIBUTE TO TOTAL-WORD DURATION IN NORMAL AND RESTRICTED-JAW SPEAKING BY LTP GROUP

	Normal Speaking						Restricted-Jaw					
Context	Fric	VOT	TR2	VN	SS	CL1	Fric	VOT	TR2	VN	SS	CL1
/i/												
t		36.7		63.3				40.0		60.3		
d		10.8		89.2				17.4		82.5		
s	58.1			41.9			58.4			41.6		
r			29.6	38.9	31.5				26.9	43.9	29.2	
tr		44.0	25.4	30.6				43.0	19.8	37.2		
str	31.5	15.1	19.7	23.1		10.6	29.0	15.3	16.0	24.1		15.6
/ae/												
t		30.7		69.3				34.5		65.5		
d		9.2		90.8				10.7		89.3		
s	47.8			52.2			50.6			49.4		
r			28.6	43.9	27.5				37.2	24.1	38.7	
tr		35.0	25.9	39.1				37.2	24.1	38.7		
str	29.4	12.0	19.9	28.3		10.4	24.9	11.8	19.7	27.0		16.6
/u/												
t		37.8		62.2				39.2		60.8		
d		11.6		88.4				14.0		86.0		
s	58.0			42.0			59.7			40.3		
r			29.6	38.9	31.5				26.9	40.2	34.9	
tr		46.7	18.6	34.7				45.3	16.3	38.4		
str	34.5	16.6	13.6	22.8		12.5	31.9	14.8	13.2	24.1		16.0

characteristics of the cortically injured groups resemble speakers without cortical injuries who either speed or slow speech. Although it is a common observation that cortically injured subjects experience temporal disruptions during speech, data from this study indicate these disruptions may reflect an overall rate change rather than specific temporal reorganization of articulatory gestures.

Speech production under normal and abnormal peripheral conditions requires the motor speech system to provide area/length adjustments for vowels and consonants under dynamic conditions. Cortical lesions may influence motor speech performance along a number of dimensions. For example, data from normal and restricted-jaw speaking suggests RTP and LTP subjects use a slightly different (or limited) set and range of articulatory dimensions to adjust area/length relationships in the vocal tract. If articulatory dimension sets and ranges consist of integrated spatio-temporal patterns, it is possible cortical lesions may affect either the amount of information integrated or the actual integration process, itself. Limitations to the amount of information integrated into spatio-temporal patterns could possibly occur in two fashions: (1) an equal limitation of spatial and temporal information; or (2) an unequal limitation of spatial and temporal information. Unequal limitations may result in the system placing greater weight on spatial versus temporal information or vice versa. The actual integration process, itself, may also influence the limited set or range of articulator positions available to cortically injured speakers. If equal amounts of spatial and temporal information are available, integration processes may place more weighting on one type of information versus another to meet contextual requirements. These are tempting possibilities; however, they are not directly addressed by this study.

In summary, frequency response patterns produced by Control speakers suggest the motor speech system uses a range of articulator positions to produce contextual speech under normal and abnormal peripheral conditions. In addition, duration response patterns produced by Control subjects indicate temporal relationships of gestures are retained during abnormal peripheral conditions suggesting gesture timing may be inherent to phonological representations. Adjustments to frequency and durational relationships during normal and abnormal peripheral conditions suggest the range of articulator positions is composed of integrated spatio-temporal representations.

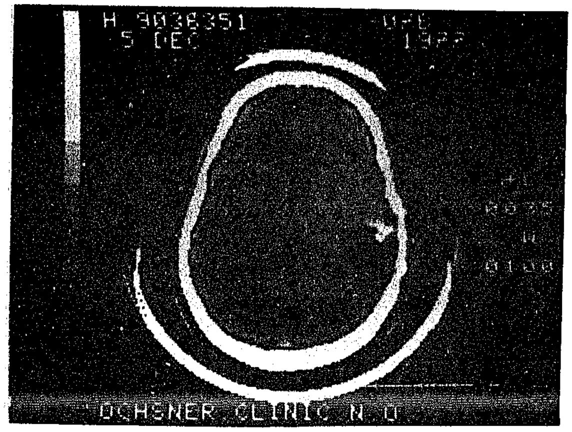
Cortically injured speakers appear to use a slightly different set or range of articulator gestures to adjust area/length relationships in the vocal tract than Control subjects. Frequency and duration response patterns during restricted-jaw speaking suggest motor speech systems of cortically injured speakers are less flexible and more influenced by contextual frameworks. In addition, data from the normal-and restricted-jaw speaking conditions indicate cortically injured speakers may have difficulty integrating spatio-temporal information underlying articulatory maneuvers.

Appendix A. Summary of individual performance on neurobehavioral and lesion-documentation assessments.

SUBJECT: RTP1

WOUNDED: March 8, 1969

BIRTHDATE: July 22, 1947



COMPUTER TOMOGRAPHY NOTES:

Date: December 6, 1977

Summary: Beneath the surgical defect in the right temporal region there is a well circumscribed low density which extends from the superficial cortex to the atrium of the right lateral ventricle. It measures about 3x2x2 cm and the anterior margin corresponds to the clips in the dura just beneath the inner table of the calvarium. I believe that this lesion is principally in the posterior portion of the Sylvian fissure. Involvement of the temporal lobe is minimal. He has slight, but definite uniform enlargement of the entire right lateral ventricle with localized enlargement of the atrium. Septum pellucidum and third ventricle are midline. Other than what I presume to be hemostasis clips, I see no opaque foreign bodies intracranially.

Examiner: Dr. Roger B. Tutton
Department of Radiology
Oschner Clinic

NEUROLOGICAL NOTES: RTP1

Date: December 6, 1977

Summary: On routine testing, there were few abnormal findings and those present were minimal. In his cranial nerve testing, there was a tendency for his Weber sign to lateralize to the left. On reflex examination, there was a slight decrease appreciation to pinprick over the left arm and left leg. All other higher sensation testing was normal and there was no evidence of any ideomotor apraxia. The patient had some difficulty with right-left orientation on self and quite a bit of difficulty on the examiner. There was a great delay and an obvious struggle for correct right-left orientation.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

ELECTROENCEPHALOGRAM NOTES:

Date: December 5, 1977

Summary: Abnormal EEG showing theta range activity in the right hemisphere greater in the mid-posterior temporal derivations than elsewhere. There are other asymmetries: increased prominence in amplitude of beta rhythm frontally on the right, presence of a mu rhythm on the right. The record shows mild dysfunction in the right temporal lobe and to a lesser extent more generally in the right hemisphere, posteriorly more than anteriorly.

Examiner: Dr. Gregory S. Ferris
Department of Neurology
Louisiana State University School of Medicine

NEUROPSYCHOLOGICAL NOTES:

RTP1

Date: December 6, 1977

Summary:

Wechsler Adult Intelligence Scale

Full Scale I.Q.--122
Verbal I.Q.--128
Performance I.Q.--112

Weschler Memory Scale

Memory Quotient--101

Trail Making Test

Right Hemisphere Percentile--40
Left Hemisphere Percentile--60

Finger Tapping Test

Right Hand--58
Left Hand--51

Tactile Recognition Test

No astereognosis for either hand.

Wide Range Achievement Test

Reading--16.8 grade
Spelling--12.0 grade

Examiner:

Dr. F. W. Black
Department of Neurology
Louisiana State University School of Medicine

SPEECH AND LANGUAGE NOTES: RTP1

Date: December 5, 1977

Summary: Aphasia testing reveals several very interesting findings. First, the patient had, by and large, normal conversational speech except that he paused on rather regular occasions to search for individual words. In running speech, he produced a few literal paraphasias; however, in specific repetition tasks, reading aloud, and naming tasks, he produced scattered literal paraphasias. His comprehension was by and large normal, however, he did make some small errors on paragraph comprehension. Writing seemed completely normal, although he did make several spelling errors with difficult words. He produced only rare actual verbal substitutions (verbal or semantic paraphasias)...In taking the history, the patient does say that many of his problems particularly his speech problems, are exacerbated by fatigue and alcohol. [Examination was completed with the Boston Diagnostic Aphasia Examination].

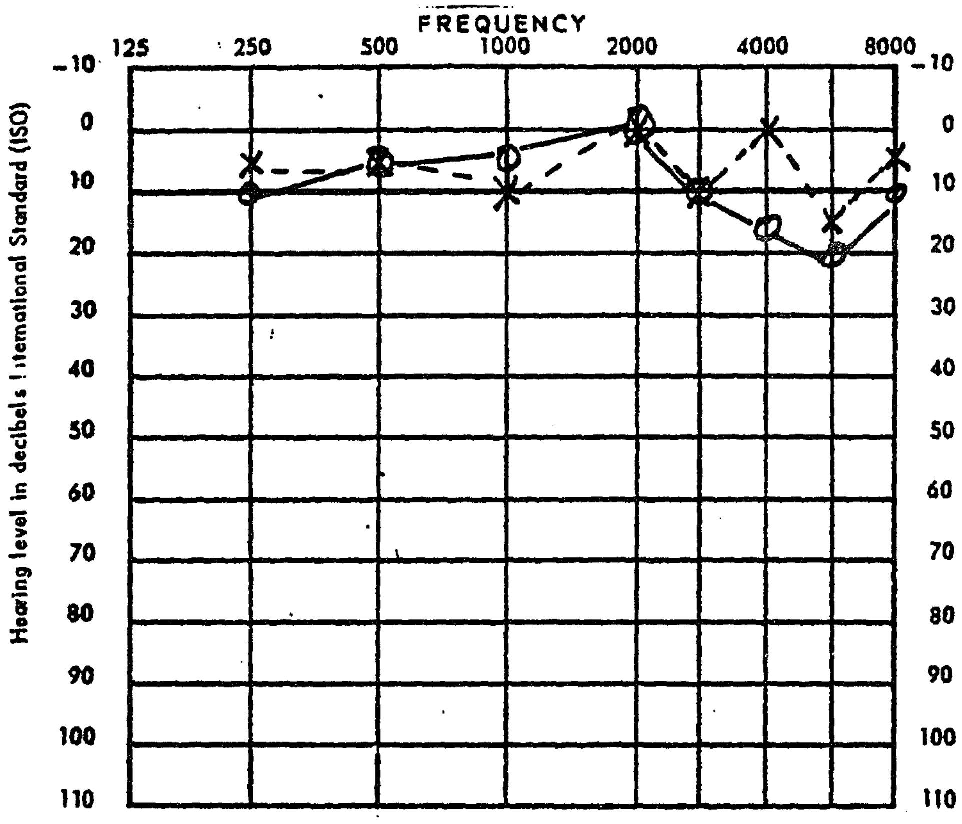
Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

AUDIOLOGICAL NOTES:

RTP1

Date: December 4, 1977

Summary:



Examiner: Dr. Charles I. Berlin
Kresge Hearing Research Laboratory of the South
Department of Otorhinolaryngology
Louisiana State University School of Medicine

RTP1

INITIAL SURGICAL NOTES:

Date: March 8, 1969

Summary: A horseshoe incision was made with the patient in a supine position. A 1cm hole was in the bone. Craniectomy. A 1 x 2cm hole in dura. About 50cc clot extruded spontaneously. Tract debrided. Dura closed with 4-0 silk and graft. Skin closed 2 layers. EBC 500cc.

Examiner: Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

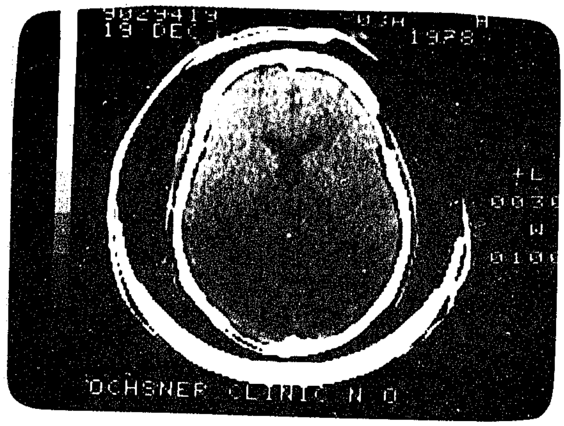
SURGICAL DIAGRAM:

Date: March 8, 1969

Summary:

Examiner: Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SUBJECT: RTP2



WOUNDED: July 16, 1969

BIRTHDATE: December 1, 1946

COMPUTER TOMOGRAPHY NOTES:

Date: December 19, 1978

Summary: There is a small defect in the cranial vault in the right frontal bone close to the floor of the anterior fossa. Just deep to the posterior lip is a tiny opacity that looks like a miniscule metallic foreign body. It could be a vascular clip, but we usually get more artifact formation from clips. The only abnormal area of brain tissue seems to be immediately beneath the craniectomy defect extending for about 2 cm below the surface of the brain. This is a varied density piece of tissue not purely like an old scar nor is the aneterior horn of the right lateral ventricle particularly enlarged.

Examiner: Dr. Roger B. Tutton
Department of Radiology
Ochsner Clinic

NEUROLOGICAL NOTES: RTP2

Date: December 20, 1978

Summary: The neurological examination was completely within normal limits ... The patient also had no evidence of finger agnosia, right-left disorientation, or ideomotor apraxia.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

ELECTROENCEPHALOGRAM NOTES:

Date: December 18, 1978

Summary: This is a normal record showing low voltage and predominantly fast background activity. There are some minor asymmetries, with slightly slow activity anteriorly, thought to represent eye movement for the most part but possibly of cerebral origin, and asymmetry of the alpha rhythm, which is slightly less regular and more contaminated with faster frequencies in the left hemisphere posteriorly. Since statistically, the alpha rhythm is often normally better developed on the right than the left, this asymmetry would very likely represent a normal situation rather than a dysfunction on the left.

Examiner: Dr. Gregory S. Ferris
Department of Neurology
Louisiana State University School of Medicine

NEUROPSYCHOLOGICAL NOTES: RTP2

Date: December 20, 1978

Summary: Wechsler Adult Intelligence Scale

Full Scale I.Q.--122
Verbal I.Q.--128
Performance I.Q.--112

Weschler Memory Scale

Memory Quotient--112

Trail Making Test

Right Hemisphere Percentile--75
Left Hemisphere Percentile--75-90

Finger Tapping Test

Right Hand--56.66
Left Hand--56.33

Tactile Recognition Test

Within normal limits.

Wide Range Achievement Test

Reading--17.1 grade
Spelling--12.4 grade

Examiner: Dr. F. W. Black
Department of Neurology
Louisiana State University School of Medicine

SPEECH AND LANGUAGE NOTES: RTP2

Date: December 20, 1978

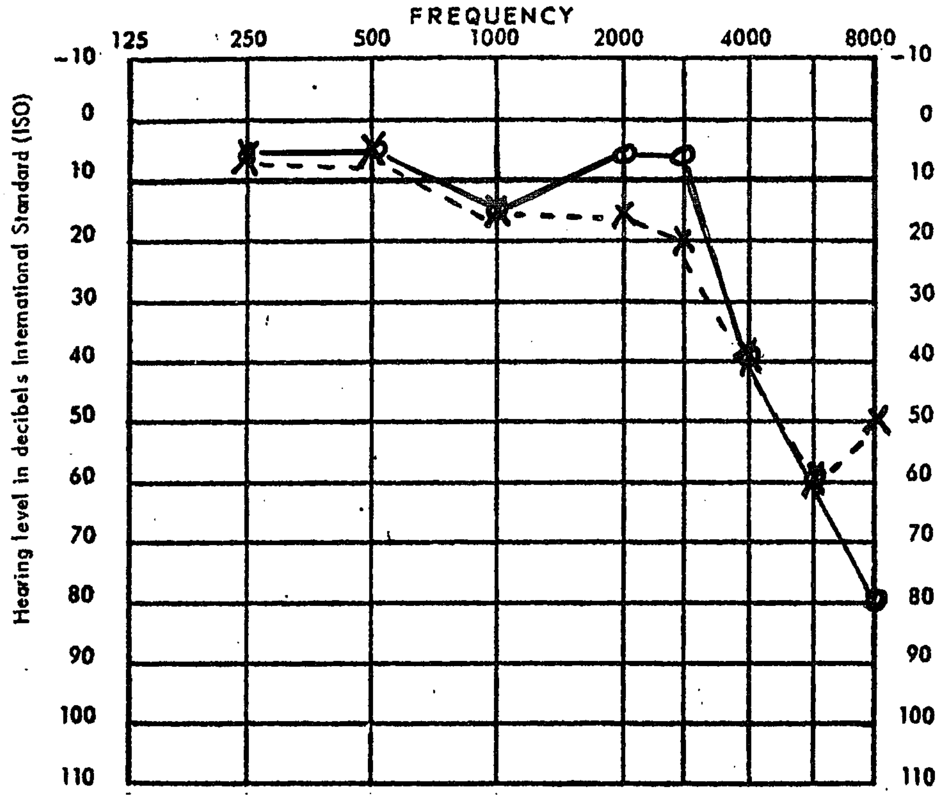
Summary: The complete Boston Diagnostic Aphasia Examination was within normal limits.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

AUDIOLOGICAL NOTES: RTP2

Date: December 17, 1978

Summary:



Examiner: Dr. Charles I. Berlin
Kresge Hearing Research Laboratory of the South
Department of Otorhinolaryngology
Louisiana State University School of Medicine

INITIAL SURGICAL NOTES: **RTP2**

Date: July 16, 1969

Summary: Supine endohalo head to left. Prepped, draped wound irrigated and debrided. Curvalinear incision incorporating wound right frontal craniectomy. Dura opened stellate, brain resected. Dura closed with 4-0 silk. Muscles, galez skin closed 3-0 silk.

Examiner: Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SURGICAL DIAGRAM:

Date: July 16, 1969

Summary:

Examiner: Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SUBJECT: RTP3

WOUNDED: March 8, 1969

BIRTHDATE: August 1, 1948

COMPUTER TOMOGRAPHY NOTES:

Date: March 20, 1979

Summary: He has a craniectomy defect on the right side of the calvarium closed to the lambdord. There is a tiny metallic foreign body, presumably, a hemostasis clip at the anterior-inferior margin of the craniectomy defect. Immediately beneath the bone defect, there is very little, if any, apparent gliosis in the cerebral tissue. The body and atrium of the right lateral ventricle are normal in size and position, as is the calcification within the glomus of the right choroid plexus.

Examiner:
Dr. Roger B. Tutton
Department of Radiology
Ochsner Clinic

NEUROLOGICAL NOTES: RTP3

Date: March 19, 1979

Summary: The entire neurological examination was within normal limits. On some of the verbal agility tasks he did exteremely well but on rapid movements of the tongue he had some clumsiness.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

ELECTROENCEPHALOGRAM NOTES:

Date: March 20, 1979

Summary: Clinically normal waking and sleeping EEG. Some minor differences are noted for research purposs, namely, slightly higher amplitude of both background alpha rhythms, sleep spindles, and theta range activity in the right hemisphere than the left. The differences are especially noticeable in the temporal and posterior derivations.

Examiner: Dr. Gregory S. Ferris
Department of Neurology
Louisiana State University School of Medicine

NEUROPSYCHOLOGICAL NOTES: RTP3

Date: March 19, 1979

Summary: Wechsler Adult Intelligence Scale

Full Scale I.Q.--97
Verbal I.Q.--92
Performance I.Q.--105

Weschler Memory Scale

Memory Quotient--93

Trail Making Test

Right Hemisphere Percentile--75-90
Left Hemisphere Percentile--25-50

Finger Tapping Test

Right Hand--70.33
Left Hand--71.33

Tactile Recognition Test

Within in normal limits.

Wide Range Achievement Test

Reading--9.1 grade
Spelling--7.2 grade

Examiner: Dr. F. W. Black
Department of Neurology
Louisiana State University School of Medicine

SPEECH AND LANGUAGE NOTES: RTP3

Date: March 19, 1979

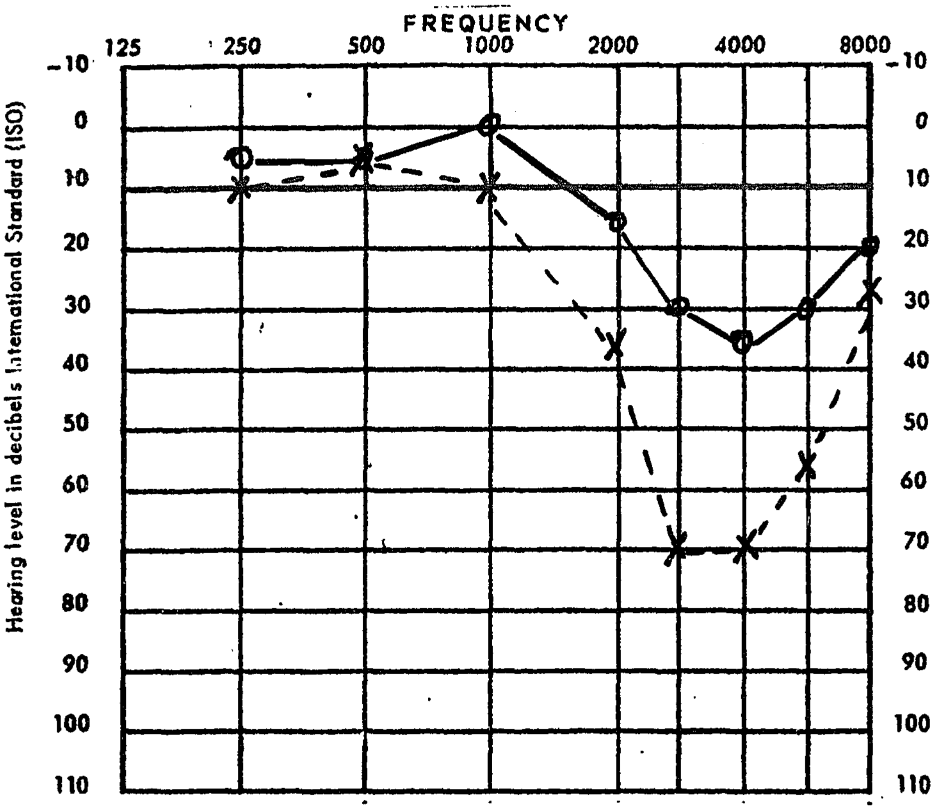
Summary: The patient has complained of no residual difficulties including geographic problems, memory, reading, writing, or mathmatics. He has noticed no difficulty in singing and no problem with carrying out any skilled movement...The entire Boston Diagnostic Aphasia Examination was administered and the patient had no difficulty on any of the verbal language tests. He made several errors on the reading paragraphs and in spelling, but I feel that these are probably more educational than they are secondary to any acquired brain lesion. In his case history, he does describe a very slight language impairment primarily characterized by the inability to produce speech at a rapid rate when necessary.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

AUDIOLOGICAL NOTES: RTP3

Date: March 19, 1979

Summary:



Examiner: Dr. Charles I. Berlin
Kresge Hearing Research Laboratory of the South
Department of Otorhinolaryngology
Louisiana State University School of Medicine

INITIAL SURGICAL NOTES: RTP3

Date: March 8, 1969

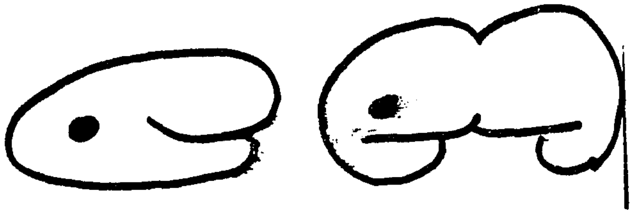
Summary: An S-shaped incision. .5cm hole in bone. .5cm hole in dura caused by several depressed bone fragments. Metallic fragments extradurally, brain debrided. Dura closed with 4-0 silk and small graft. Skin closed 2 layers.

Examiner: Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SURGICAL DIAGRAM:

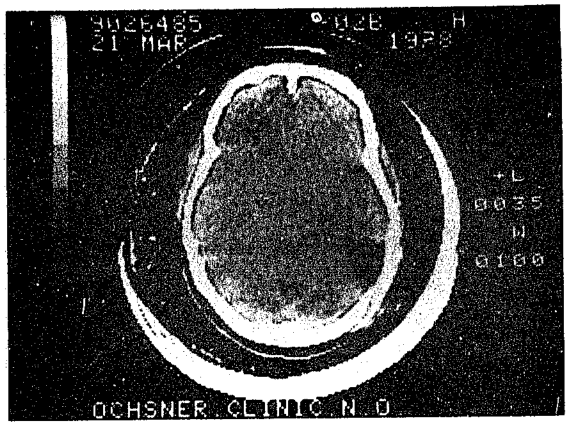
Date: March 8, 1969

Summary:



Examiner: Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SUBJECT: RTP4



WOUNDED: December 15, 1968

BIRTHDATE: May 19, 1968

COMPUTER TOMOGRAPHY NOTES:

Date: March 21, 1978

Summary: Metallic foreign material in the right frontal polar region is rather superficially placed and could be a clip on the dura. In addition, there is a bone defect in the right parietal bone with underlying metallic material resembling clips. Approximately mid-convexity in the right frontal lobe, at the same level as the junction of the anterior horn with the body of the right lateral ventricle, there is a roughly equilateral triangular area of decreased density that probably measures 2 cm on a side. This is seen on the 4-A and 4-B slices. On the 3-B slice, near the area of the insula, there is a rougly curvilinear decreased density density which would indicate additional loss of tissue on the medial aspect and superior aspect of the temporal lobe. Separated from these two previously mentioned areas, there is a third located immediately beneath the acrylic bone flap in the right parietal temporal area. Again, this is roughly triangular in shape with its base against the exterior. It extends to the atrium of the right lateral ventricle. It probably measures 3 to 3.5 cm across the base and extends a similar distance intercranially. The anterior margin of this lesion is at the group of clips at the anterior margin of the flap. The ventricle is not enlarged or displaced. The left hemisphere looks normal.

Examiner: Dr. Roger B. Tutton
Department of Radiology
Ochsner Clinic

NEUROLOGICAL NOTES: RTP4

Date: March 22, 1978

Summary: On neurologic testing, the patient had only a slight increase in reflexes in the left arm and leg, but no other neurologic findings. There was a questionable decrease in optokinetic nystagmus with the flag going to the right, but this was not a distinct finding.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

ELECTROENCEPHALOGRAM NOTES:

Date: March 21, 1978

Summary: Normal waking and sleeping EEG. There are minor asymmetries with less prominent normal patterns on the left, and more theta activity in the left temporal region during drowsiness. These are well in limits of normal variation.

Examiner: Dr. Gregory S. Ferris
Department of Neurology
Louisiana State University School of Medicine

NEUROPSYCHOLOGICAL NOTES: RTP4

Date: March 22, 1978

Summary: Wechsler Adult Intelligence Scale

Full Scale I.Q.--94
Verbal I.Q.--93
Performance I.Q.--97

Weschler Memory Scale

Memory Quotient--83

Trail Making Test

Right Hemisphere Percentile--75
Left Hemisphere Percentile--60

Finger Tapping Test

Right Hand--39
Left Hand--38

Tactile Recognition Test

No asterognosis.

Wide Range Achievement Test

Reading--9.1 grade
Spelling--6.5 grade

Examiner: Dr. F. W. Black
Department of Neurology
Louisiana State University School of Medicine

SPEECH AND LANGUAGE NOTES: RTP4

Date: March 22, 1978

Summary: On the Boston Diagnostic Apahasia Examination, the patient had fluent language, although occasionally used a literal paraphasic substitution, such as "The sink is oversewing," instead of "overflowing." He made the same type of error in reading and in general conversation. I feel this is probably a reflection of his impulsive rapid speech rather than any true aphasia disturbance of an acquired type. On comprehension testing, he showed almost completely normal performance; he did miss one of the questions on the complex paragraph test, but when he saw me mark it wrong, he asked me to ask the question again, and he corrected himself on the second reading. He had some difficulty with certain single words. He was mixed-up on "eyebrow" and "eyelid" and on "thigh" and "hip." This does seem to be a genuine comprehension confusion of a semantic type. I am not sure whether this is acquired or congenital. His ability to name, read, repeat, and sing, all seem to be within normal limits. In essence, I do not think he has an aphasic disturbance of an acquired type, but does have some very mild language problems which may antedate his injury.

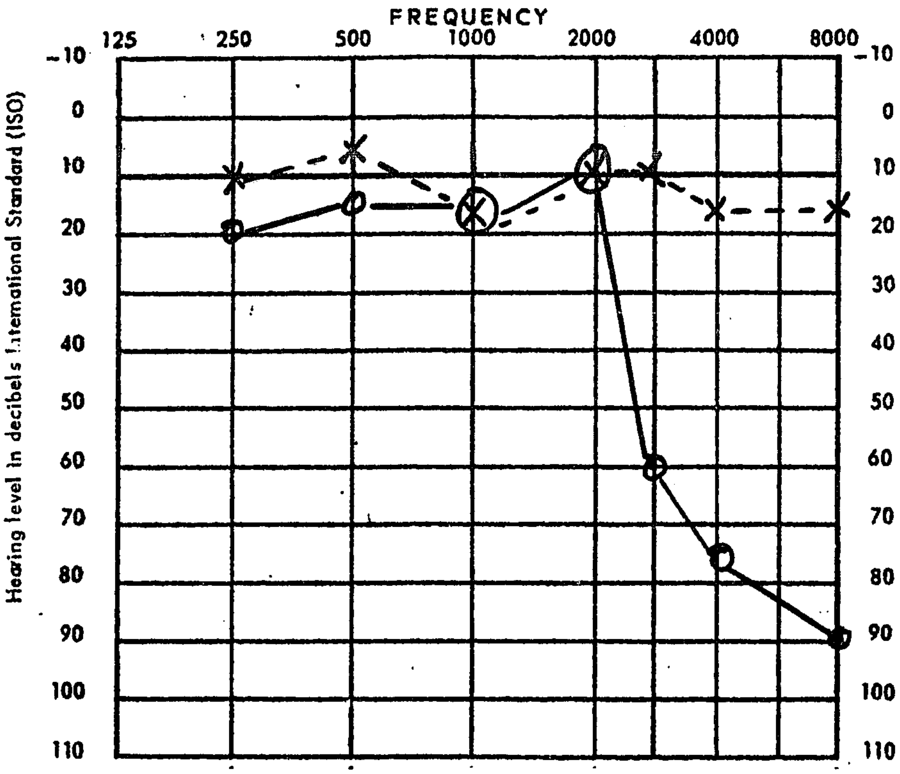
Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

AUDIOLOGICAL NOTES:

RTP4

Date: March 21, 1978

Summary:



Examiner: Dr. Charles I. Berlin
Kresge Hearing Research Laboratory of the South
Department of Otorhinolaryngology
Louisiana State University School of Medicine

INITIAL SURGICAL NOTES: RTP4

Date: December 15, 1968

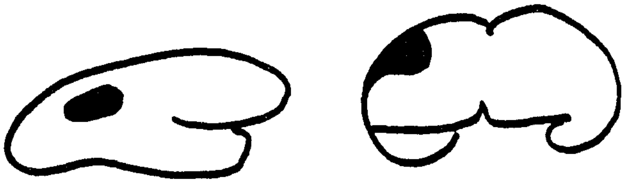
Summary: Removal 50cc intracerebral clot. Debridment of bone fragments. Second exploration removed two further bone fragments. Wound sutured with wire.

Examiner: Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SURGICAL DIAGRAM:

Date: December 15, 1968

Summary:



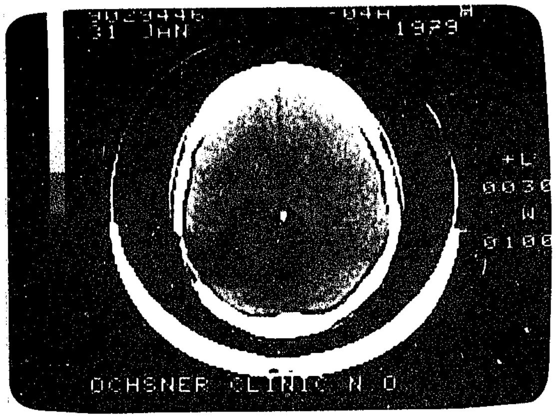
Examiner: Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SUBJECT: LTP1

WOUNDED: April 13, 1969

BIRTHDATE: October 18, 1948

COMPUTER TOMOGRAPHY NOTES:



Date: January 31, 1979

Summary: He has a craniectomy defect in the left parietal bone with a small linear opacity in the center of it which looks as though it is the density of bone. Immediately beneath the craniectomy defect, the cerebral cortex is decreased in density, and the underlying atrium of the left lateral ventricle and then also extends superiorly and medially involving only the white matter. It looks to me as though the involvement is exclusively parietal lobe. The right hemisphere is normal. I do not think there is any infratentorial involvement by this process either.

Examiner: Dr. Roger B. Tutton
Department of Radiology
Ochsner Clinic

NEUROLOGICAL NOTES: LTP1

Date: February 2, 1979

Summary: On my neurological examination his only abnormal findings were considerable unsteadiness on tandom walking with accompaning clumsiness on heel to shin testing. The cranial nerves were tested and showed only a right inferior quadrant field defect. Reflexes were normal and no pathologic reflexes were noted. On sensation testing there was some decrease in pin prick and vibratory appreciation below the ankle and the left foot. Again, these findings are secondary to a peripheral nerve lesion from shrapnel. On sensation testing, also, it was interesting to note that it took him over five trials to appreciate the double simultaneous stimulation of face and hand. His neurologic examination shows primarily the visual field defect. I am not sure about his difficulty with balance and clumsiness in the legs. It is possible that he has always been somewhat clumsy. There is no evidence of a specific cerebellar lesion, although his clinical pictures suggest cerebellar difficulty. I wonder if the years of Dilantin have anything to do with this.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

ELECTROENCEPHALOGRAM NOTES: LTP1

Date: January 29, 1979

Summary: Abnormal waking EEG showing extensive slow waves in the left hemisphere and a reduction of alpha background rhythm on the left. This is evidence of dysfunction and hypofunction in the left hemisphere, especially posteriorly.

Examiner: Dr. Gregory S. Ferris
Deparment of Neurology
Louisiana State University School of Medicine

NEUROPSYCHOLOGICAL NOTES: LTP1

Date: January 30, 1979

Summary: Wechsler Adult Intelligence Scale

Full Scale I.Q.--78
Verbal I.Q.--76
Performance I.Q.--85

Weschler Memory Scale

Memory Quotient--72

Trail Making Test

Right Hemisphere Percentile--0
Left Hemisphere Percentile--<10

Finger Tapping Test

Right Hand--63
Left Hand-- 59

Tactile Recognition Test

No astereognosis.

Wide Range Achievement Test

Reading--2.2 grade
Spelling--3.3 grade

Examiner: Dr. F. W. Black
Department of Neurology
Louisiana State University School of Medicine

SPEECH AND LANGUAGE NOTES: LTP1

Date: February 2, 1979

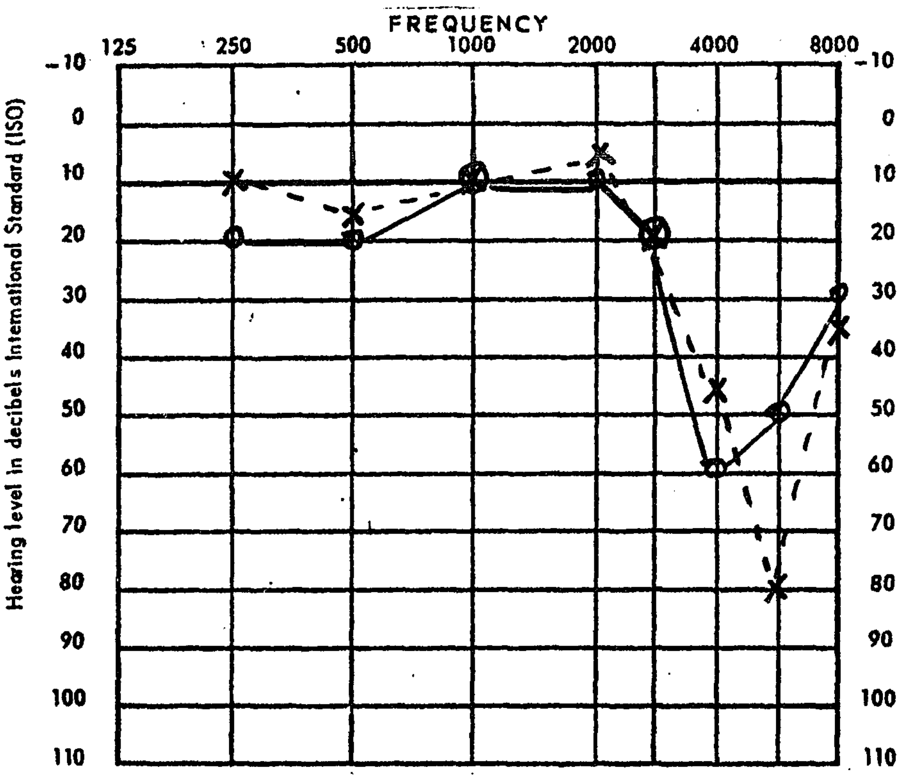
Summary: On aphasia testing using the Boston Diagnostic Aphasia Examination, we note that the patient is right-handed with a left-handed brother. He has a twelfth grade education with a single grade failure. On the examination his spontaneous speech shows a certain cautiousness and halting character with word finding pauses and a general tendency toward short sentences. He occasionally would produce a paraphasia of either phonemic or semantic type. Occasionally, he tends to be circumlocutory but usually is able to express his points adequately. Auditory comprehension showed some mild defects with difficult items particularly the long paragraphs. In general, his comprehension showed slowness rather than inaccuracy. He did make some errors, however, on body part identification with "in kind" substitutions made. In oral expression, there was a decrease in oral agility but no gross-facial ideomotor apraxia. On repetition he had errors with complicated sentences. His confrontation naming was good, although there was some slowness to his response. In general, I feel that the patient has a mild, mixed-type of aphasia in accompaniment with reading and writing problems. I am not sure if this literacy problem stems from early, poor education, or is the result of a left parietal wound.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

AUDIOLOGICAL NOTES: LTP1

Date: January 29, 1977

Summary:



Examiner: Dr. Charles I. Berlin
Kresge Hearing Research Laboratory of the South
Department of Otorhinolaryngology
Louisiana State University School of Medicine

INITIAL SURGICAL NOTES: LTP1

Date: April 13, 1969

Summary: Patient supine with the head to the right. Endohalo. Head shaved, prepped wound, debrided, draped. Curvelinear incision incorporating wound, craniectomy. Dura opened stellate. Brain debrided, bond chips out. Dura closed with graft and 4-0 silk. Galez and skin closed with 3-0 silk. Pre-op alert with some difficulty with speech.

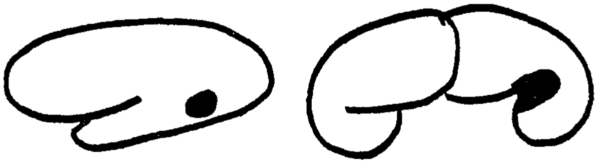
Examiner:

Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SURGICAL DIAGRAM:

Date: April 13, 1969

Summary:



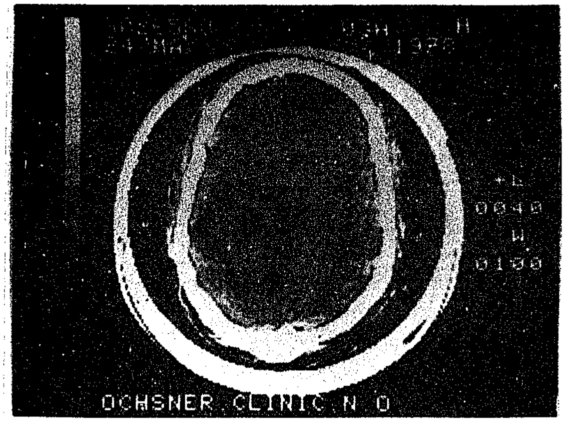
Examiner:

Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SUBJECT: LTP2

WOUNDED: June 8, 1969

BIRTHDATE: October 17, 1948



COMPUTER TOMOGRAPHY NOTES:

Date: May 24, 1978

Summary: We have a very unfortunate situation in that there is obviously a metallic plate in the calvarium that starts approximately midconvexity and extends rather high in the left parietal bone. This high density material completely ruins the higher scans as far as gleaning any useful information. The posterior fossa is normal and both temporal lobes are symmetrical in density. The third ventricle is a slit and midline. The anterior horn of the right lateral ventricle is slightly larger than the left but I am not sure how signficant this might be.

Examiner: Dr. Roger B. Tutton
Department of Radiology
Ochsner Clinic

NEUROLOGICAL NOTES: LTP2

Date: May 23, 1978

Summary: On neurological examination, I found very little problem. He has a very slight drift of his right arm when it is outstretched. His right and left hands seem to be about equally coordinated which leads me to believe the right hand perhaps has lost some of its coordination. On the cranial nerves, there is an anosmia (loss of sense of smell) on the left. There was enucleation of the left eye, and there is a slight decrease in sensation appreciation in the maxillary division of the left trigeminal nerve. There is a question of a slight lower right facial weakness but this is very, very mild. On reflex examination, there is a slight accentuation of the right Achilles reflex and there is a right Wartenberg hand sign. Sensation, other than the face sensation is normal. There is no evidence of extinction on double simultaneous stimulation.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

ELECTROENCEPHALOGRAM NOTES:

Date:

Summary:

Examiner:

NEUROPSYCHOLOGICAL NOTES: LTP2

Date: May 23, 1978

Summary: Wechsler Adult Intelligence Scale

Full Scale I.Q.--113
Verbal I.Q.--109
Performance I.Q.--118

Weschler Memory Scale

Memory Quotient--110

Trail Making Test

Right Hemisphere Percentile--75
Left Hemisphere Percentile-- 60

Finger Tapping Test

Right Hand--52
Left Hand--43

Tactile Recognition Test

No true astereognosis present.

Wide Range Achievement Test

Reading--15.3 grade
Spelling--11.6 grade

Examiner: Dr. F. W. Black
Department of Neurology
Louisiana State University School of Medicine

SPEECH AND LANGUAGE NOTES: LTP2

Date: May 23, 1978

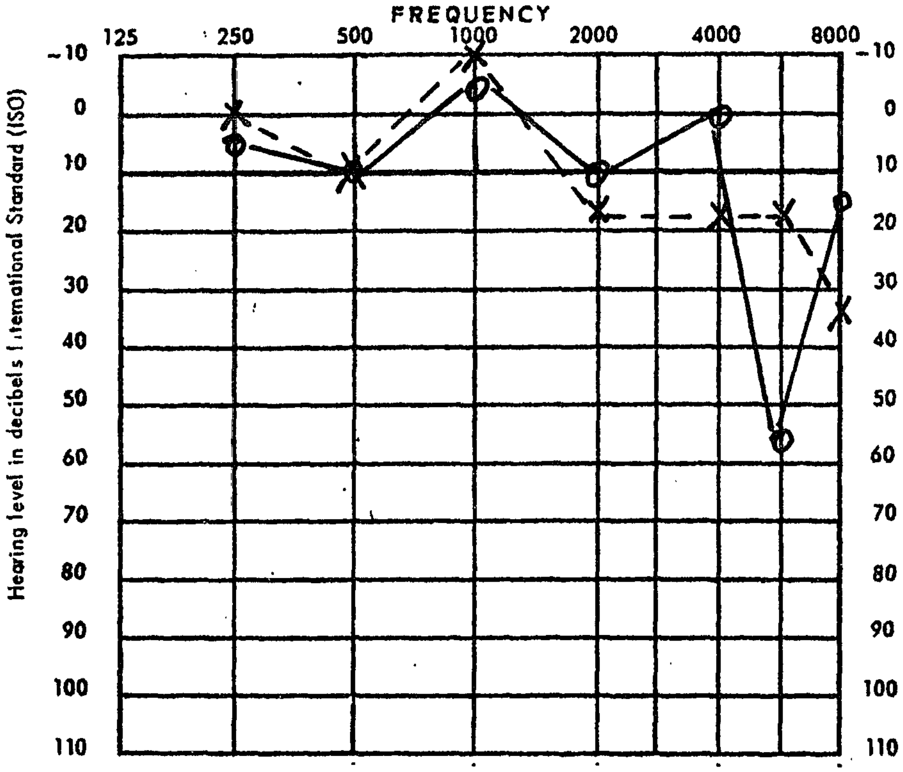
Summary: Aphasia examination using the Boston Diagnostic Aphasia Examination showed only some mild hesitancy and deliberateness of his spontaneous speech. There did seem to be a lack of complexity to his general narrative speech. Verbal fluency was very, very slightly decreased. Writing and reading showed mild deficits when long material was requested. There were no other deficits in language testing. The patient describes some hesitancy with his speech when he gets excited or tired. He also described some difficulty saying exactly what he wants to say on occasion and often finds himself rephrasing things. He often has to repeat words when he produces a paraphasia. He has experienced some difficulty in reading; this is usually in terms of long paragraph-length material. He notices a slight simplification and deliberateness to his spontaneous speech production since his injury.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

AUDIOLOGICAL NOTES: LTP2

Date: May 21, 1978

Summary:



Examiner: Dr. Charles I. Berlin
Kresge Hearing Research Laboratory of the South
Department of Otorhinolaryngology
Louisiana State University School of Medicine

INITIAL SURGICAL NOTES:

LTP2

Date: June 8, 1969

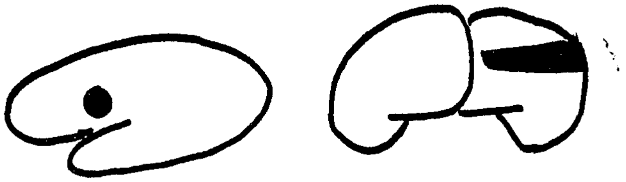
Summary: A left parietal craniectomy and brain debridment done. Post-op patient remains alert. He sees well. He has a mild right hemiparesis arm and leg. He has been afebrile.

Examiner: Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SURGICAL DIAGRAM:

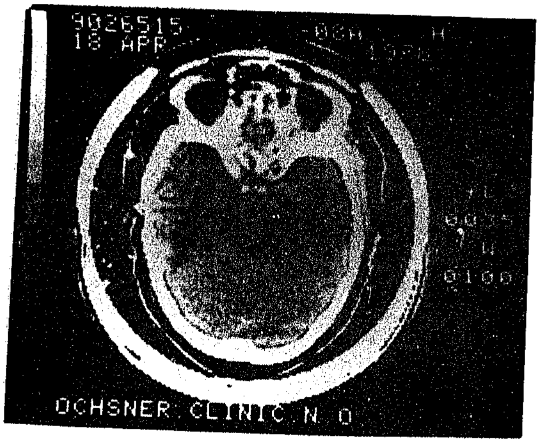
Date: June 8, 1969

Summary:



Examiner: Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SUBJECT: LTP3



WOUNDED: February 26, 1970

BIRTHDATE: May 25, 1933

COMPUTER TOMOGRAPHY NOTES:

Date: April 18, 1978

Summary: Post surgical defects in the left temporal region have some metallic clips that introduce artifactual information into the exam. I can see that there is a little decreased density of the tip of the left temporal lobe anteriorly as well as on its inferior surface. The body of the left ventricle is very slightly larger than the right. The metal clip on the dura in the left parietal region does not significantly obscure any anatomical detail. Right hemisphere is normal.

Examiner: Dr. Roger B. Tutton
Department of Radiology
Ochsner Clinic

NEUROLOGICAL NOTES: LTP3

Date: April 17, 1978

Summary: Neurologic evaluation reveals several relatively mild deficits. The first is a trigeminal nerve lesion on the left side of the face with decreased sensation which is quite marked and mild to moderate weakness in the muscles of mastication on the left. There is a very slight left lower facial weakness, but this is minimal. Visual acuity shows 20/25 on left. The gag reflex is suppressed bilaterally and corneal reflex is dramatically decreased on the left side...there are no pathologic reflexes. On motor examination, he is somewhat unsteady and tends to fall on tandem walking. One of his problems is related to fragment wounds of the right leg with inability to dorsiflex the right leg.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

ELECTROENCEPHALOGRAM NOTES:

Date: April 17, 1978

Summary: Abnormal EEG showing a random positive spike in the left temporal region. There is also some slightly slow acitivity in the left temporal region more than the right, but this is a very subtle finding and could be within limits of normal variation.

Examiner: Dr. Gregory S. Feriss
Department of Neurology
Louisianan STate University School of Medicine

NEUROPSYCHOLOGICAL NOTES: LTP3

Date: April 17, 1978

Summary: Wechsler Adult Intelligence Scale

Full Scale I.Q.--86
Verbal I.Q.--101
Performance I.Q.--86

Weschler Memory Scale

Memory Quotient--70

Trail Making Test

Right Hemisphere Percentile--50
Left Hemisphere Percentile--10

Finger Tapping Test

Right Hand--59
Left Hand--50

Tactile Recognition Test

Impaired bilaterally (2 out of 4 errors/hand).

Wide Range Achievement Test

Reading--5.4 grade
Spelling--3.7 grade

Examiner: Dr. F. W. Black
Department of Neurology
Louisiana State University School of Medicine

SPEECH AND LANGUAGE NOTES: LTP3

Date: April 17, 1978

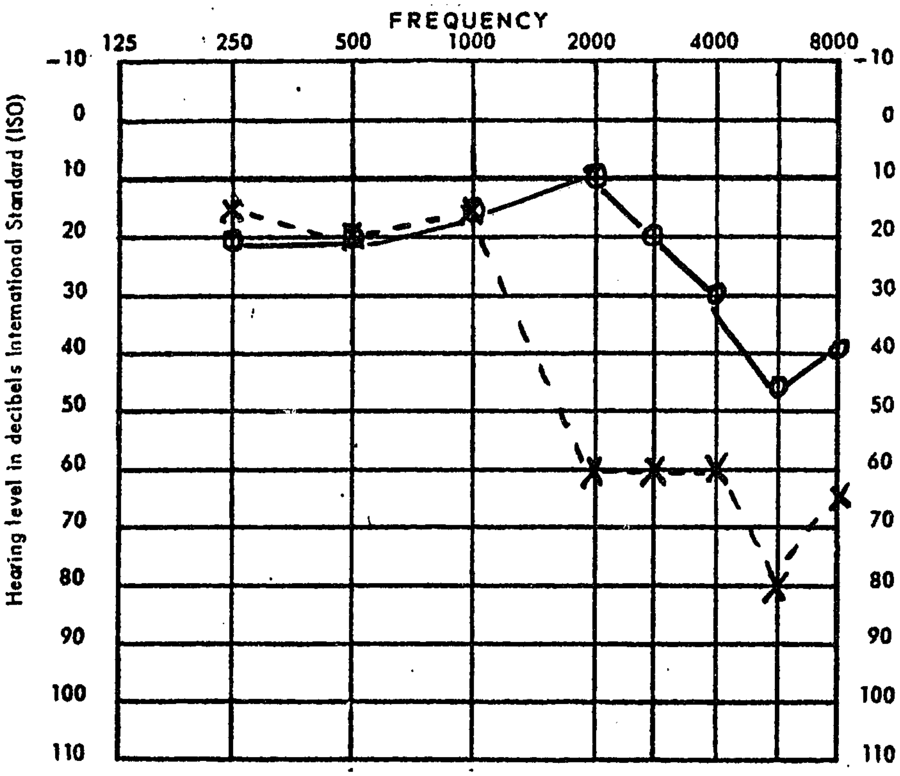
Summary: On aphasia testing, the patient shows an extremely mild anomic aphasia with moderate to marked difficulty in reading with a rather severe problem in writing. The patient had tremendous difficulty with spelling and any extended discourse writing. Pronounciation of language is good, and comprehension is fairly good, although he had some difficulty with long complicated paragraph material. His actual confrontation naming showed very few problems, although he did occasionally have to demonstrate the use of an object before he could arrive at the name. There were only a few evidences of paraphasic responses. One, he called the color blue, yellow and he had a great deal of trouble naming cactus. With the word, key, he had to show the use and it took him approximately 10 seconds to come up with the right answer. The color pink was also named very slowly, however, correctly. The patient did not show any evidence of stereognostic difficulty, but did show some naming problems with the stereognosis task which might lead one to believe that there was a true stereognosis, but this is not the case. There was no evidence of ideomotor apraxia in the limb or buccofacial commands of nonverbal tasks, however, verbal agility seems somewhat reduced with many rapid tasks with tongue.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

AUDIOLOGICAL NOTES: LTP3

Date: April 16, 1978

Summary:



Examiner: Dr. Charles I. Berlin
Kresge Hearing Research Laboratory of the South
Department of Otorhinolaryngology
Louisiana State University School of Medicine

INITIAL SURGICAL NOTES: LTP3

Date: February 26, 1970

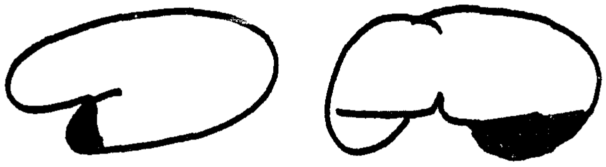
Summary: Left temporal craniectomy. When inspection made extra durally, the temporal lobe dura was seen to have a hole over anterior temporal tip. There was a dime size hole in left sphenoid bone (anterior wall of middle fossa). The hole was just superior to a nerve trunk which was most likely the maxillary div. of V as the mandibular division of V was identified lower down. This hole opened into the maxillary sinus. There were several large 1 x .5 bone chips extradurally. After these were removed, the dura was opened over lateral anterior temporal lobe and outer 3 cm resected revealing 3 small bone chips in brain. Fragment hole closed with silk and oversewn with a fascia graft extradurally. It was tested and found to be water tight. Temporal lobe dura closed with small graft.

Examiner:
Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SURGICAL DIAGRAM:

Date: February 26, 1970

Summary:



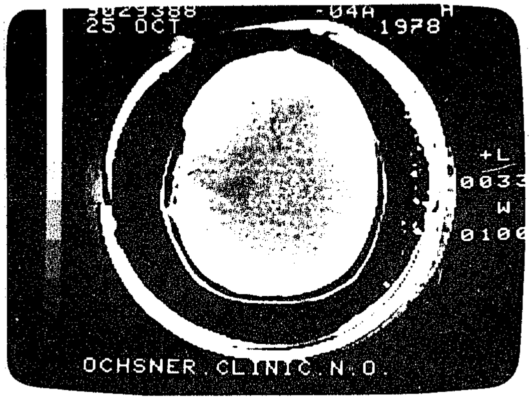
Examiner:
Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SUBJECT: LTP4

WOUNDED: February 28, 1969

BIRTHDATE: June 21, 1946

COMPUTER TOMOGRAPHY NOTES:



Date: October 25, 1978

Summary: There is a craniectomy defect in the left parietal region just behind the coronal suture. There is a small amount of metallic material at this craniectomy defect but it does not significantly impair visualization of the cerebral tissue. The body of the left lateral ventricle is very slightly larger on the right. There is no shift of the midline structures. The only brain parenchymal abnormalities seem to be located immediately beneath the bone flap and extend only about 2 cm into the brain substance. These are chaaracterized by a little decrease in density as though there may be some gliosis. As we approach the superior portion of the bone flap, it looks to me as though the brain tissue returns to normal and the same is true close to the inferior aspect.

Examiner: Dr. Roger B. Tutton
Department of Radiology
Ochsner Clinic

NEUROLOGICAL NOTES: LTP4

Date: October 24, 1978

Summary: On neurological examination there is somewhat a difficulty in separating problems which stem from his recent back injury from those originating from his cerebral missile wound. He has a broadbase gait and is unable to heel walk, however, he can walk tandem with some difficulty. He has a mild dysmetria and action tremor in the right arm and some bilateral leg weakness. Coordination shows difficulty on the right with some terminal intentional tremor and clumsiness with alternating and rapid movements. Patient has normal movements with left limbs. His cranial nerves show only a slight decrease in sensation around the corner of the mouth in the right with a very subtle facial droop. Reflexes showed a slight increase in the right bicep reflex and right Wartenberg but no other abnormalities. Sensation testing showed some decrease in all modalities in the right arm and leg. There is no evidence of ideomotor apraxia, right-left disorientation, or finger agnosia.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

ELECTROENCEPHALOGRAM NOTES:

Date: October 21, 1978

Summary: The prominent feature seen is some abnormality in the left hemisphere in which there is slowing of 4-5 cps. This recording is consistent with cerebral dysfunction involving the left hemisphere.

Examiner: Dr. Gregory S. Ferris
Department of Neurology
Louisiana State University School of Medicine

NEUROPSYCHOLOGICAL NOTES: LTP4

Date: October 21, 1978

Summary: Wechsler Adult Intelligence Scale

Full Scale I.Q.--133
Verbal I.Q.--130
Performance I.Q.--132

Weschler Memory Scale

Memory Quotient--143+

Trail Making Test

Right Hemisphere Percentile--75
Left Hemisphere Percentile--75

Finger Tapping Test

Right Hand--39
Left Hand--68

Tactile Recognition Test

Normal limits.

Wide Range Achievement Test

Reading--18 grade
Spelling--14 grade

Examiner: Dr. F. W. Black
Department of Neurology
Louisiana State University School of Medicine

SPEECH AND LANGUAGE NOTES: LTP4

Date: October 24, 1978

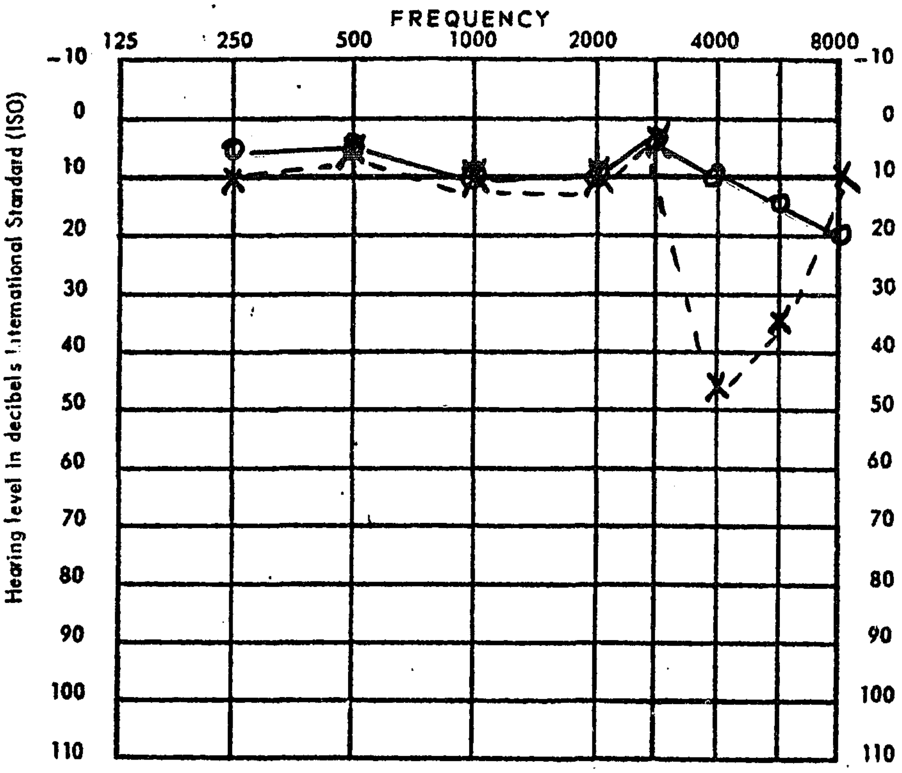
Summary: I administered the entire Boston Diagnostic Aphasia Examination. A very slight problem with articulation and rare problems with word choice was noticed. This certainly is not enough to classify as a true language disturbance. On one occasion during verbal commands, he showed some preserveration but this was not a characteristic of his performance in general. Of note, is the fact that the patient is left-handed and this probably explains the paucity of language findings...he has a mild language residual which I would consider not as a significant aphasia, however, there are some subtle problems with word and syllable substitutions on rare occasions.

Examiner: Dr. Richard L. Strub
Department of Neurology
Louisiana State University School of Medicine

AUDIOLOGICAL NOTES: LTP4

Date:

Summary:



Examiner: Dr. Charles I. Berlin
Kresge Hearing Research Laboratory of the South
Department of Otorhinolaryngology
Louisiana State University School of Medicine

INITIAL SURGICAL NOTES: LTP4

Date: February 24, 1969

Summary: Pre-op patient dysphasic moderate to severe. Area prepped and draped. Left parietal horseshoe flap. Left parietal craniectomy. Dura opened stellate. Brain debrided and in-driven bone chips excised. 20-30 cc brain removed. Dura closed with 4-0 silk and graft. (The lateral ventricle was enlarged by tract). Muscles and galez skin closed with 3-0 silk.

Examiner: Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

SURGICAL DIAGRAM:

Date: February 24, 1969

Summary:

Examiner: Neurosurgical Team
United States Armed Forces
Chu Lai, Republic of Vietnam

Appendix B. Summary of significant ANOVA values for Control, RTP, and LTP groups.

APPENDIX B

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR F_1 FORMANT FREQUENCY MEASURES OF CONTROL, RTP, AND LTP GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	73724180.408	36862090.204	330.904	**
Error	24	2673551.288	11397.970		
Consonant	5	193074.264	38614.852	6.573	**
Error	60	352435.657	5873.927		
Vowel x Condition	2	87545.460	43772.730	3.612	*
Error	24	290834.878	12118.119		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR F_1 FORMANT FREQUENCY MEASURES OF CONTROL SUBJECTS ONLY.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	40337456.000	20168720.000	168.604	**
Error	12	1435456.000	119621.312		
Consonant	5	232801.750	46560.347	5.376	**
Error	30	259790.000	8659.664		
Vowel x Consonant x Repetition	30	82468.375	2748.945	1.539	*
Error	180	321318.562	1785.103		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNFICANT ANOVA VALUES FOR F_1 FORMANT FREQUENCIES IN RTP AND LTP GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	33542624.000	16771312.000	162.489	**
Error	12	1238576.000	103214.625		

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES OF F_1 FORMANT FREQUENCIES IN CONTROL AND PATHOLOGICAL GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	73709040.000	36854512.000	330.842	**
Error	24	2673504.000	111396.000		
Consonant	5	193074.125	38614.824	6.574	**
Error	60	352419.312	5873.652		
Vowel x Consonant	10	100157.875	10015.785	1.977	*
Error	120	607709.687	5064.246		
Vowel x Condition	2	95440.437	47720.218	3.938	*
Error	24	290794.375	12116.429		
Group x Consonant x Condition	5	49036.542	9807.308	3.816	**
Error	60	154200.625	2570.010		

* Significant beyond the 5-percent level

**Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR F_2 FORMANT FREQUENCIES FOR CONTROL, RTP, AND LTP GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	261083648.000	130541824.000	198.796	**
Error	24	15759856.000	656660.625		
Consonant	5	18176384.000	3635276.000	117.252	**
Group x Consonant	15	941600.000	62773.332	2.024	*
Error	60	1860224.000	31003.730		
Vowel x Consonant	10	5476736.000	547673.562	24.495	**
Error	120	2683024.000	22358.531		
Condition	1	4324551.000	4324551.000	58.018	**
Error	12	894442.000	74536.812		
Vowel x Condition	2	406153.000	203076.500	4.937	*
Error	24	987174.000	41132.250		
Consonant x Repetition	15	174245.812	11616.386	1.759	*
Error	180	1188087.000	6600.480		
Condition x Repetition	3	150400.812	50133.601	5.101	**
Error	36	353811.937	9829.109		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR F_2 FORMANT FREQUENCIES FOR CONTROL SUBJECTS ONLY.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	123151872.000	61575936.000	238.511	**
Error	12	3098016.000	258168.000		
Consonant	5	12744653.000	2548930.000	74.551	**
Error	30	1025700.000	34190.000		
Vowel x Consonant	10	4627136.000	462713.562	20.641	**
Error	60	1344988.000	22416.464		
Condition	1	3482926.000	3482926.000	86.884	**
Error	6	240520.000	40086.664		
Vowel x Condition	2	365922.000	182961.000	7.636	**
Error	12	287512.000	23959.332		
Vowel x Consonant x Repetition	30	296051.062	9868.367	1.566	*
Error	180	1133984.000	6299.410		
Condition x Repetition	3	90158.000	30052.664	5.054	*
Error	18	107030.812	5946.156		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR F_2 FORMANT FREQUENCIES FOR RTP AND LTP SUBJECTS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	138440064.000	69220032.000	65.603	**
Error	12	12661536.000	1055128.000		
Consonant	5	6073102.000	1214620.000	43.660	**
Error	30	834593.00	27819.765		
Vowel x Consonant	10	1491954.000	149195.375	6.694	**
Error	60	1337263.000	22287.714		
Condition	1	1154937.000	1154937.000	10.595	*
Error	6	654013.000	109002.125		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES OF F_2 FORMANT FREQUENCIES FOR CONTROL AND PATHOLOGICAL GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	261083648.000	130541824.000	198.793	**
Error	24	15760096.000	656670.625		
Consonant	5	18176384.000	3635276.000	117.252	**
Group x Consonant	5	641280.000	128256.000	4.136	**
Error	60	1860224.000	31003.730		
Vowel x Consonant	10	5476736.000	547673.562	24.497	**
Group x Vowel x Consonant	10	642384.000	64238.398	2.873	**
Error	120	2682784.000	22356.531		
Condition	1	4324551.000	4324551.000	58.019	**
Error	12	894441.000	74536.750		
Vowel x Condition	2	406153.000	203076.500	4.937	*
Error	24	987111.000	41129.625		
Consonant x Repetition	15	174245.812	11616.386	1.759	*
Error	180	1188089.000	6600.492		
Condition x Repetition	3	150400.812	50133.601	5.100	**
Error	36	353820.875	9828.355		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR F_3 FORMANT FREQUENCIES FOR CONTROLS, RTP, AND LTP GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	71904352.000	35952176.000	81.678	**
Error	24	10563968.000	440165.312		
Consonant	5	15321525.000	3064305.000	63.623	**
Error	60	2889781.000	48163.015		
Vowel x Consonant	10	1195563.000	119556.250	3.020	**
Error	120	4749963.000	39583.023		
Condition	1	4516821.000	4516821.000	49.299	**
Error	12	1099449.000	91620.750		
Group x Consonant x Condition	15	546192.00	36412.796	2.177	*
Error	60	1003234.000	16720.566		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR F_3 FORMANT FREQUENCIES FOR CONTROL SUBJECTS ONLY.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	45858032.000	22929008.000	78.675	**
Error	12	3497264.000	291438.625		
Consonant	5	10496064.000	2099212.000	60.316	**
Error	30	1044095.000	34803.164		
Condition	1	1883395.000	1883395.000	35.067	**
Error	6	322244.000	53707.332		
Consonant x Condition	5	257970.000	51594.000	2.802	*
Error	30	552333.000	18411.097		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR F_3 FORMANT FREQUENCIES OF RTP AND LTP SUBJECTS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	27503872.000	13751936.000	23.351	**
Error	12	7067056.000	588921.312		
Consonant	5	5326237.000	1065247.000	17.313	**
Error	30	1845838.000	61527.929		
Condition	1	2667457.000	2667457.000	20.594	**
Error	6	777148.000	129524.625		

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR F_3 FORMANT FREQUENCIES FOR CONTROL AND PATHOLOGICAL GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	71904352.000	35952176.0001	81.678	**
Error	24	10563968.000	440165.312		
Consonant	5	15321525.000	3064305.000	63.623	**
Error	60	2889781.000	48163.015		
Vowel x Consonant	10	1195563.000	119556.250	3.020	**
Error	120	4749963.000	39583.000		
Condition	1	4516821.000	4516821.000	49.299	**
Error	12	1099440.00	91620.00		
Group x Consonant x Condition	5	350891.00	70178.187	4.197	**
Error	60	1003243.000	16720.714		

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR FUNDAMENTAL FREQUENCY OF CONTROL, RTP, AND LTP GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	217175.125	108587.562	94.727	**
Error	24	27511.625	1146.317		
Consonant	5	44639.750	8927.949	43.874	**
Error	60	12209.437	203.490		
Vowel x Consonant	10	11529.125	1152.912	9.200	**
Error	120	15036.625	125.305		
Condition	1	49734.941	49734.941	47.157	**
Error	12	12655.878	1054.656		
Vowel x Condition	2	3317.808	1658.904	17.524	**
Error	24	2271.875	94.661		

** Significant at the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR FUNDAMENTAL FREQUENCY OF CONTROL SUBJECTS ONLY.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	105650.312	52825.156	29.560	**
Error	12	21422.312	1785.192		
Consonant	5	27385.812	5477.160	25.380	**
Error	30	6473.976	215.799		
Vowel x Consonant	10	7579.562	757.956	4.915	**
Error	60	9252.523	154.208		
Condition	1	19899.890	19899.890	12.858	*
Error	6	9285.332	1547.555		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR FUNDAMENTAL FREQUENCY IN RTP AND LTP GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	111608.125	55804.062	109.930	**
Error	12	6091.562	507.630		
Consonant	5	19345.726	3869.145	20.241	**
Error	30	5734.347	191.144		
Vowel x Consonant	10	4777.335	477.733	4.955	**
Error	60	5784.152	96.402		
Condition	1	30391.386	30391.386	54.096	**
Error	6	3370.796	561.799		
Vowel x Condition	2	3007.363	1503.681	19.316	**
Error	12	934.140	77.845		

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES OF FUNDAMENTAL FREQUENCY FOR CONTROL AND PATHOLOGICAL GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	217175.125	108587.562	94.726	**
Error	24	27511.750	1146.322		
Consonant	5	44639.750	8927.949	43.873	**
Error	60	12209.605	203.493		
Vowel x Consonant	10	11529.125	1152.912	9.200	**
Error	120	15036.457	125.303		
Condition	1	49734.941	49734.941	47.156	**
Error	12	12656.046	1054.670		
Vowel x Condition	2	3317.808	1658.904	17.525	**
Error	24	2271.707	94.654		

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES OF VOWEL NUCLEI DURATION FOR CONTROL, RTP, AND LTP GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	16567.679	8283.839	273.338	**
Error	24	727.347	30.306		
Consonant	5	23258.851	4651.769	321.175	**
Error	60	869.015	14.483		
Vowel x Consonant	10	1962.445	196.244	43.569	**
Group x Vowel x Consonant	30	282.265	9.408	2.088	**
Error	120	540.496	4.504		
Condition	1	377.483	377.483	8.547	*
Error	12	529.985	44.165		
Consonant x Condition	5	92.242	18.448	5.606	**
Group x Consonant x Condition	15	93.051	6.203	1.885	*
Error	60	197.444	3.290		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR VOWEL NUCELI DURATION IN CONTROL SUBJECTS ONLY.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	9737.031	4868.515	140.085	**
Error	12	417.046	34.753		
Consonant	5	10740.535	2148.106	124.944	**
Error	30	515.773	17.192		
Vowel x Consonant	10	900.136	90.013	18.389	**
Error	60	293.683	4.894		
Condition	1	465.768	465.768	15.688	**
Error	6	178.129	29.688		
Consonant x Condition	5	94.758	18.951	4.802	**
Error	30	118.393	3.946		

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR VOWEL NUCLEI DURATION IN RTP AND LTP GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	6972.355	3486.177	134.640	**
Group x Vowel	2	226.074	113.037	4.365	*
Error	12	310.710	25.892		
Consonant	4	12684.570	2536.914	215.244	**
Error	30	353.585	11.786		
Vowel x Consonant	10	1144.214	114.421	27.892	**
Group x Vowel x Consonant	10	152.710	15.271	3.722	**
Error	60	246.132	4.102		
Consonant x Condition	5	37.551	7.510	2.863	*
Error	30	78.677	2.622		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR VOWEL NUCLEI DURATION IN CONTROL AND PATHOLOGICAL GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	16567.679	8283.839	273.338	**
Error	24	727.347	30.306		
Consonant	5	23258.851	4651.769	321.175	**
Error	60	869.015	14.483		
Vowel x Consonant	10	1962.445	196.244	43.569	**
Group x Vowel x Consonant	10	119.199	11.919	2.646	**
Error	120	540.496	4.504		
Condition	1	377.483	377.483	8.547	*
Error	12	529.985	44.165		
Consonant x Condition	5	92.242	18.448	5.606	**
Group x Consonant x Condition	5	39.970	7.994	2.429	*
Error	60	197.444	3.290		

* Significant beyond the 5-percent level ** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR FRICTION SEGMENTS OF CONTROLS, RTP AND LTP GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	776.287	388.143	43.541	**
Error	24	213.944	8.914		
Consonant	1	15332.648	15332.648	193.560	**
Error	12	950.562	79.213		
Vowel x Consonant	2	43.183	21.591	3.642	*
Error	24	142.281	5.928		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR FRICTION SEGMENTS IN CONTROL SUBJECTS ONLY.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	491.810	245.905	19.367	**
Error	12	152.357	12.696		
Consonant	1	8251.769	8251.769	85.815	**
Error	6	576.941	96.156		

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR FRICTION SEGMENTS IN RTP AND LTP GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	297.671	148.835	28.996	**
Error	12	61.595	5.132		
Consonant	1	7102.738	7102.738	114.106	**
Error	6	373.480	62.246		
Vowel x Consonant	2	51.296	25.648	4.511	**
Error	12	68.218	5.684		
Cosonant x Condition	1	96.499	96.499	6.065	*
Error	6	95.457	15.909		
Consonant x Repeition	3	24.895	8.298	3.251	*
Error	18	45.940	2.552		
Group x Vowel x Condition x Repetition	6	65.116	10.852	3.092	*
Error	36	126.352	3.509		

* Significant beyond the 5-percent level ** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR FRICTION SEGMENTS IN CONTROL AND PATHOLOGICAL GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	776.287	388.143	43.540	**
Error	24	213.947	8.914		
Consonant	1	15332.648	15332.648	193.560	**
Error	12	950.566	79.213		
Vowel x Consonant	2	43.183	21.591	3.642	*
Error	24	142.281	5.928		
Group x Consonant x Repetition	3	49.947	16.649	3.884	*
Error	36	154.298	4.286		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR VOICE-ONSET TIME SEGMENTS IN CONTROLS, RTP, AND LTP GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	211.541	106.270	12.706	**
Error	24	200.725	8.363		
Consonant	3	34332.671	11444.222	293.872	**
Error	36	1401.941	38.942		
Vowel x Consonant	6	156.390	26.065	3.763	**
Error	72	498.625	6.925		
Condition	1	295.143	295.143	8.136	*
Error	12	435.292	36.274		
Vowel x Condition	2	20.041	10.020	7.448	**
Group x Vowel x Condition	6	44.125	7.354	5.466	**
Error	24	32.289	1.345		
Repetition	3	44.790	14.930	3.374	*
Error	36	159.291	4.424		
Group x Consonant X Condition x Repetition	27	85.335	3.160	1.673	*
Error	108	203.909	1.888		

* Significant beyond the 5-percent level ** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES OF VOICE-ONSET TIME SEGMENTS IN CONTROL SUBJECTS ONLY.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	177.143	88.571	6.730	*
Error	12	157.928	13.160		
Consonant	3	19067.492	6355.828	174.292	**
Error	18	656.394	36.466		
Vowel x Consonant	6	104.164	17.360	2.656	*
Error	36	235.277	6.535		
Condition	1	189.110	189.110	6.923	*
Error	6	163.887	27.314		

* Significant beyond the 5-percent level.

** Significant beyond the 1-percent level.

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR VOICE-ONSET TIME SEGMENTS IN RTP AND LTP SUBJECTS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	57.326	28.663	8.037	**
Error	12	42.795	3.566		
Consonant	3	15406.564	5135.515	123.995	**
Error	18	745.507	41.417		
Vowel x Condition	2	20.328	10.164	11.582	**
Group x Vowel x Condition	2	14.933	7.466	8.509	**
Error	12	10.530	0.877		
Group x Consonant x Condition x Repetition	9	45.410	5.045	2.676	*
Error	54	101.779	1.884		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR VOICE-ONSET TIME SEGMENTS IN CONTROL and PATHOLOGICAL GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	212.541	106.270	12.706	**
Error	24	200.725	8.363		
Consonant	3	34332.671	11444.222	293.872	**
Error	36	1401.941	38.942		
Vowel x Consonant	6	156.390	26.065	3.763	**
Error	72	498.628	6.925		
Condition	1	295.143	295.143	8.136	*
Error	12	435.292	36.274		
Vowel x Condition	2	20.041	10.020	7.448	**
Group x Vowel x Condition	2	19.272	9.636	7.162	**
Error	24	32.289	1.345		
Repetition	3	44.790	14.930	3.374	*
Error	36	159.291	4.424		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR TR2 SEGMENTS IN CONTROL, RTP, AND LTP GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	2406.348	1203.174	101.952	**
Error	24	283.232	11.801		
Consonant	2	365.282	182.641	27.066	**
Error	24	161.948	6.747		
Vowel x Consonant	4	271.286	67.821	10.197	**
Error	48	319.240	6.650		
Consonant x Condition	2	60.191	30.095	6.192	**
Group x Consonant x Condition	6	75.694	12.615	2.595	*
Error	24	116.642	4.860		
Group x Vowel x Consonant x Repetition	36	93.750	2.604	1.520	*
Error	144	246.646	1.712		
Group x Vowel x Condition x Repetition	18	84.519	4.695	2.278	**
Error	72	148.387	2.060		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR TR2 SEGMENTS IN CONTROL GROUP ONLY.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	1104.860	552.430	30.842	**
Error	12	214.934	17.911		
Consonant	2	242.420	121.210	13.391	**
Error	12	108.615	9.051		
Vowel x Consonant	4	182.057	45.514	6.312	**
Error	24	173.040	7.210		
Consonant x Condition	2	80.807	40.403	7.514	**
Error	12	64.517	5.376		

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR TR2 SEGMENT DURATION IN RTP AND LTP GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	1331.125	665.562	116.885	**
Error	12	68.329	5.694		
Consonant	2	167.979	83.989	18.898	**
Error	12	53.331	4.444		
Vowel x Consonant	4	100.193	25.048	4.113	*
Error	24	146.151	6.089		
Group x Vowel x Condition	2	14.090	7.045	4.283	*
Error	12	19.736	1.644		
Vowel x Consonant x Repetition	12	45.590	3.799	2.163	*
Group x Vowel x Consonant x Repetition	12	41.876	3.489	1.987	*
Error	72	126.415	1.755		
Group x Consonant x Condition x Repetition	6	28.153	4.692	3.088	*
Error	36	54.699	1.519		

* Significant beyond the 5-percent level

** Significant beyond the 1-percent level

APPENDIX B

(Continued)

SUMMARY OF SIGNIFICANT ANOVA VALUES FOR TR2 SEGMENT DURATION IN CONTROL AND PATHOLOGICAL GROUPS.

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-ratio	p
Vowel	2	2406.348	1203.174	101.952	**
Error	24	283.232	11.801		
Consonant	2	365.282	182.641	27.066	**
Error	24	161.948	6.747		
Vowel x Consonant	4	271.286	67.821	10.197	**
Error	48	319.249	6.651		
Group x Vowel x Condition	2	27.002	13.501	5.646	**
Error	24	57.382	2.390		
Consonant x Condition	2	60.191	30.095	6.192	**
Group x Consonant x Condition	2	41.539	20.769	4.273	**
Error	24	116.642	4.860		
Group x Vowel x Consonant x Repetition	12	42.985	3.582	2.091	*
Error	144	246.651	1.712		
Group x Consonant x Condition x Repetition	6	28.719	4.786	2.492	*
Error	72	138.283	1.920		

*Significant beyond the 5-percent level

** Significant beyond the 1-percent level

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