MOTOR POTENTIALS OF STUTTERERS AND NON-STUTTERERS DURING SPEECH

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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Montreal

March 1979

ABSTRACT

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The purpose of this study was to evaluate differences in hemispheric asymmetry between stutterers and non-stutterers, prior to and during production of words and syllables, as a test of the Orton-Travis Cerebral Dominance Theory. It was predicted that differences between right-handed stutterers and non-stutterers would be observed in the form of reduced left hemisphere dominance in the stutterers, perhaps involving a clear right hemisphere dominance. The results revealed that Averaged Electroencephalographic Response (AER) amplitudes of the left hemisphere were significantly greater than those of the right for normal speakers, but not for stutterers, at speech onset and during speech only. No significant differences were observed between severe and mild stutterers, nor were there consistent effects of different linguistic stimuli. These findings, which supported the hypothesis that stutterers have a lower margin of cerebral dominance than non-stutterers during fluent speaking conditions, were discussed relative to other findings for normal speakers and stutterers.

RESUME

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Potentiels électrocorticaux moteurs de bègues et de non-bègues pendant la parole

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Le but de la recherche était de vérifier la théorie de dominance cérébrale d'Orton-Travis en étudiant les divers degrés d'assymétrie inter-hémisphérique auprès de bègues et de non-bègues droitiers et ce, avant et pendant la production de mots et de syllabes. On s'attendait à observer une diminution de la dominance hémisphérique gauche chez les bègues et peut-être même un renversement de la dominance inter-hémisphérique. Les résultats indiquent que pour les non-bègues, l'amplitude des AER (réponses électro-corticales intégrées) de l'hémisphère gauche, au début et pendant la parole,est significativement plus importante que celle de l'hémisphère droit. Cette relation ne s'observe pas chez les bègues. La différence entre les bègues dits légers et sévères, ainsi que l'effet de différents stimulis linguistiques, n'ont pas été significatifs. Les conclusions appuient l'hypothèse voulant que les bègues aient une dominance cérébrale plus partagée que les non-

bègues en état de fluidité. Elles font l'objet d'une discussion à la lumière de recherches faites auprès de bègues et de locuteurs normaux.

ACKNOWLEDGEMENTS

I am grateful to my original supervisor, Dr. M. Seitz, for his unwavering support at every stage of this study. His assistance and advice in the design and implementation of the study and suggestions in the preparation of the manuscript have been essential to the development of my knowledge in this field.

I am deeply indebted to Dr. D.G. Doehring for his invaluable assistance, particularly with the data analysis, organization and presentation of the material. His numerous suggestions, calm guidance and encouragement are more than appreciated.

I am especially thankful to my colleague Dr. L. Mononen for his patient tutoring in regard to the instrumentation. The editorial comments and suggestions of Dr. B. Bryans are very much appreciated.

Sincere thanks to Eric Covington for help in programming the data analysis, and to Irene Hoshko for advice with regard to statistical treatment of the data. Special thanks are due to Ros Russon Neilson for her assistance in the implementation of the study, to Julie Fortier for preparation of the French abstract, and to Anne Jeannotte who typed the manuscript, prepared the figures and helped in verification of the text.

Very special thanks to the persons who volunteered as subjects in my study.

Finally, I would like to thank my family; Hannah for such patience, and my dear husband Len, whose love and unselfish support and encouragement has made the completion of this project possible.

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INTRODUCTION

The possible role of neurophysiological factors in stuttering has been the subject of considerable discussion since the early part of the century. Some of the major issues will be briefly mentioned here, followed by a more detailed review. The idea that the interhemispheric relationship in stutterers might be different than in normal speakers was developed by Orton and Travis (Orton, 1927; Travis, 1931). The Orton-Travis Theory posited that where the left hemisphere is dominant for verbal skills, that hemisphere will have "motor lead control" which is necessary for synchronized timing of the bilateral motor impulses which are important in speech production. According to Orton and Travis, the paired speech muscles receive impulses from the contralateral hemispheres, but the dominant hemisphere imposes its timing pattern on the non-dominant one. In this way, the paired speech muscles receive smoothly coordinated innervation. They felt that in stutterers the dominant (left) hemisphere had less of a margin of dominance over the non-dominant (right) hemisphere. As a result, it would be unable to impose its timing pattern over the right hemisphere, resulting in dyssynchronous impulses reaching the paired muscles, and stuttering behavior would occur.

The studies that followed were generally attempts to substantiate the Orton-Travis Theory. This research falls into two major categories. First were studies that investigated the relationship between handedness and stuttering behavior (Bryngelson and Rutherford, 1937; Lindsley, 1940). These studies attempted to verify the hypothesis that handedness is directly related to dominance for speech, and that a shift of preferred handedness or lack of hand preference would interfere with the margin of dominance between the left and right hemisphere and lead to stuttering. The results of these studies were mostly inconclusive as the presumed handedness shift initially thought to account for a reduced margin of dominance could not be corroborated (Daniels, 1940; Johnson and King, 1942).

The second group of studies attempted to identify abnormalities in the electroencephalographic (EEG) records of stutterers compared to normal speakers, as evidence for cortical asynchrony (Travis and Knott, 1936, 1937; Douglass, 1943; Knott and Tjossen, 1943; Freestone, 1942; Scarbrough, 1943; Rheinberger, Karlin and Berman, 1943). Although the studies were inconsistent and difficult to replicate, the small quantitative differences that were found in this research provided some support for the view that stuttering is the result of mixed or incomplete dominance.

Nevertheless, interest declined in the mixed dominance theory of stuttering after 1950, when the majority of the EEG studies focused on the relationship of stuttering behavior to measures of Autonomic Nervous System (ANS) functions such as emotionality and anxiety proneness which were thought to be causal factors (Murphy, 1953; Douglass, 1952; Knott, Correll and Shephard, 1959).

More recently, advances in the methodologies used to investigate the neurophysiological basis for language have lead to revived interest in the cerebral dominance theory and its relation to stuttering behavior. By using the Wada Test (Wada and Rasmussen, 1960), Jones (1966) was able to demonstrate bilateral control of speech in four stutterers prior to surgery for cerebral pathology. Administrations of the Wada Test to stutterers with no brain pathology have failed to replicate Jones'results (Andrews, Quinn and Sorby, 1972; Lussenhop, Boggs, LaBorwitt and Walle, 1973), suggesting that this phenomenon may be more related to aspects of the cerebral pathology than to the nature of stuttering.

Another approach to the study of hemispheric dominance in stutterers is the use of dichotic listening tasks. While it is generally found that subjects have a right ear advantage (REA) for dichotically presented verbal material (Kimura, 1961; Curry, 1967; Studdert-Kennedy and Shankweiler, 1970), Curry and Gregory (1969) reported that a group of stutterers showed no consistent REA compared to a control group of normal speakers who did have a significant REA on a dichotic task. Since that study, other comparisons of stutterers and normal speakers on dichotic tasks have produced inconsistent results. Although some studies lent support to a cerebral dominance theory (Mattingly, 1970; Perrin and Eisenson, 1970; Prins and Walton, 1971; Sommers, Brady and Moore, 1975), more do not (Quinn, 1972; Slorach and Roehr, 1973; Cerf and Prins, 1974; Dorman and Porter, 1975;

Sussman and MacNeilage, 1975). However, since dichotic tests evaluate aspects of speech perception, they may not be the proper mode of assessment of cerebral asymmetries preceding speech production in stutterers.

The approach used in the present study, the averaged electro-encephalographic response (AER) methodology, does provide a means of assessing cerebral asymmetry preceding speech production in stutterers. This technique involves the measurement of electrocortical activity generated at the surface of the scalp. Specific cortical potentials, evoked by a repeated stimulus, are identified by adding together those evoked potentials which are synchronized with the stimulus. This procedure has been used to measure cerebral asymmetries preceding the speech of normal speakers (Ertl and Schaefer, 1967, 1969; Schaefer, 1967; McAdam and Whitaker, 1971a; Morrell and Huntington, 1971, 1972; Gerbrandt, L.K., Goff, W.R., Smith, D.B., 1973; Grabow and Elliott, 1974; Szirtes and Vaughn, 1973). In addition, Low, Wada and Fox (1974) found AER results with normal speakers which compared favorably with Wada testing, making the procedure a viable one for evaluation of hemispheric relationships in stutterers.

The use of AER recording procedures in evaluation of stuttering behavior has taken two directions. Although the body of research to date is small, most studies have followed up theoretical contentions that anxiety or other negative emotion evokes stuttering behavior (Brutten and Shoemaker, 1968). These studies have used slow potential recording techniques in attempts to relate electrocortical factors to 'expectancy to stutter' (Knott and Irwin, 1973; Peters, Love, Otto, Wood and Bebignus, 1974; Love, Peters, Wood, Otto, 1974; Zimmerman and Knott, 1973, 1974). Zimmerman and Knott (1974) also evaluated the motor responses of a group of stutterers in an attempt to measure cerebral asymmetries preceding speech production.

The AER studies suggest that a re-evaluation of the relationship between interhemispheric responses and stuttering behavior is warranted. Modern electrophysical recording devices and methodologies make it possible to control some of the variability attributed in earlier studies to artifact contamination and behavior change (Fox, 1966). The findings of Zimmerman and Knott (1974) that stutterers differ in cortical asymmetry during fluent speech suggest that the further study of the evoked cortical response patterns of subgroups of stutterers may elucidate the neurophysiological factors associated with stuttering. Basic research to determine if differences exist between sub-groups of stutterers may provide information relevant to the nature of stuttering. The literature will be reviewed in terms of evaluation of those neurophysiological relationships which are relevant to cerebral dominance and disintegration of timing of the bilateral paired musculature, which seems to result in dysfluency.

Review of the Literature

Tests of the Orton-Travis Theory: Stuttering and Handedness

Most of the EEG studies of stuttered speech prior to 1950 were attempts to substantiate the cerebral dominance theory of Orton (1927) and Travis (1931) as discussed above. The research which attempted to support a theory of incomplete or mixed cerebral dominance in stutterers was divided among two main types of investigations: a) EEG differences related to handedness; b) EEG differences related to cerebral dominance.

According to Travis (1931), there was a relationship between laterality, or peripheral sidedness, and stuttering. If this were so, a higher incidence of stutterers would be left handed, ambidextrous, and/or have had a forced handedness shift. In an attempt to verify this assumption, Bryngelson and Rutherford (1937) compared a group of 74 stuttering children ranging from 4-16 years of age with a normal speaking control group. In the experimental group 34.3% of the children were ambidextrous and 71.6% had been shifted from left to right hand usage, as compared to only 8.3% and 9.5% for the control group. The authors interpreted this as support for the idea that in stutterers neither cerebral hemisphere has control over peripheral midline structures.

Based on the assumption that handedness was correlated with cerebral dominance for speech, Lindsley (1940) posited that ambidextrous or left handed persons would be more likely to have bilateral or right hemisphere representation for speech; and that stutterers would fall into this category. Lindsley compared the EEGs of 48 right handed, 8 left-handed and 9 ambidextrous children with those of two adult male stutterers. Electrodes were placed bilaterally over the occipital and motor areas and alpha wave recordings were made under speech and silent conditions. Alpha is a sinusoidal waveform with a frequency of about 10 cycles per second and a relatively high voltage which is affected by various physiological states including attention.

In general, the ambidextrous group showed significantly more asynchronous activity from recordings at occipital lobe sites than the right handed subjects. In both stutterers the amount of unilateral blocking, or the absence of alpha waves in one hemisphere while the alpha rhythm is present on the other side, was increased over the motor sites during speech. Just prior to each marked stuttering period there was an interval during which the two hemispheres were reversed in phase with frequent unilateral blocking of alpha rhythm accompanying most moments of stuttering in both occipital and motor areas. Lindsley suggested that these changes in the cortical activity may interfere with smooth bilateral muscle movement necessary for speech production, and that individuals lacking definite hand preference are more apt to be subject to this interference.

Although Lindsley's work presented experimental EEG evidence to support Bryngelson and Rutherford, other investigators (Daniels, 1940; Johnson and King, 1942) found no support for the posited relationship between handedness shift, ambidexterity and stuttering. Daniels (1940), using a large sample, found little support for a relationship between handedness and stuttering. In a survey of 1594 college freshmen, 77 students reported forced handedness shift; only one was a stutterer. In addition, Daniels' data does not indicate a higher incidence of left handedness and ambidexterity in stutterers. One hundred thirty-eight of the students were classified as ambidextrous, including only four stutterers. These findings are in opposition to those of Bryngelson and Rutherford (1937) where a high incidence of stuttering related to ambidexterity and handedness shift was reported. In contrasting the two studies it must be kept in mind that the handedness inventories, informants and age of subjects all differed. In Bryngelson and Rutherford's study the handedness task is not clearly defined and information regarding the stuttering group was taken from parents, teachers and clinical records rather than directly from the subject as in Daniels' study. This raises some speculation that the results of Lindsley's study may have been contaminated by the artifactual influence of uncontrolled visual impact and complicated verbal responses. Certainly the conclusions from two stutterers cannot be considered definitive.

It must be concluded that no clear trend in the literature links handedness patterns with stuttering behavior. Stutterers as a group do not appear to be similar in experimental terms to left-handed or ambidextrous persons. The large discrepancies between the Bryngelson and Rutherford study and that of Daniels, plus the questionable evidence produced from two stutterers in Lindsley's study, are not enough to support a theory of lack of clear hand preference as a causal factor. Although recent evidence (Levy, 1969) suggests that left-handed persons may have a greater incidence of bilateral representation for speech as a result of hemisphere competition, there is little support from these early handedness studies to imply that stutterers behave like left-handed persons.

Tests of the Orton-Travis Theory: Stuttering and Cerebral Dominance

Most of the EEG studies prior to 1950 were attempts to differentiate stutterers from nonstutterers on the basis of continuous alpha wave activity. Travis and Knott (1936) compared the EEGs from the left occipital and motor areas of stutterers and normal speakers during speech and silence. Electrode placement was bipolar (both electrodes over the cortex), and the amplitude and duration characteristics of the alpha wave were measured. They found that by visual inspection stutterers had larger and slower alpha waves during fluency when compared to normal speakers. These small differences were difficult to interpret as they were noted in fluent conditions, and resulted from a unilateral investigation.

In a second study, Travis and Knott (1937) evaluated the bilaterally recorded occipital and motor potentials from 17 stutterers and 15 normal speakers. As in the earlier study, electrode placement was bipolar and the cortical potentials were recorded in the standard manner of the time, using matched noninterfering amplifiers which fed a multi-element oscilloscope, providing permanent records on photographic film. Speech and silence were recorded with the subject's eyes closed. When a moment of stuttering occurred, a signal was incorporated in the EEG record by the experimenter. The data were visually analyzed for hemisphere synchronization and similarity. Dyssynchronization was defined as lack of a phasic relationship of 45 degrees or more between the hemispheres. Dissimilarity was defined in terms of differences in amplitude and duration of the waveform. The records were read continuously in 1-100th second intervals. Findings indicated that during speech (either fluent or stuttered) the stutterers' EEGs were more evenly matched from the two hemispheres than normal speakers, and in silence the stutterers were more likely than the normal speakers to have dyssynchronous hemispheric patterns. When the relationship between the relative amount of dyssynchrony in silence and the severity of stuttering were evaluated, it was found that during silence the severe stutterers had more amplitude similarity but more dyssynchrony. During fluency, the severe stutterers had more hemispheric similarity while during stuttering they had less similarity and less dyssynchrony than both the normal speakers and the less severe stutterers. It is difficult to interpret the results of this study, which are inconsistent with the authors' stated hypothesis that the hemispheres would be more dissimilar during stuttering. However, the results were provocative, since differences were noted in the hemispheric relationship as a function of severity of stuttering.

Several studies followed in an attempt to continue and expand this early work. The evidence in support of Orton and Travis' contentions was mixed, with some studies supporting a cerebral dominance theory (Douglass, 1943; Knott and Tjossen, 1943; Jones, 1949) and others failing to find differences between stutterers and non-stutterers (Freestone, 1942; Scarbrough, 1943; Rheinberger, Karlin and Berman, 1943; Fox, 1966).

Douglass (1943) supported Orton and Travis' contention that stutterers had a different cortical response pattern than non-stutterers. In his study, alpha waves from the bilateral occipital and motor areas of 20 stutterers and 20 control subjects were measured in silence and speech. Alpha was defined as the occurrence of three or more consecutive waves of five microvolts or more in amplitude with a frequency range of 8-12 Hz. Electrode placement was monopolar (one electrode at the cortex; the other at the ear). A baseline EEG was first recorded in silence, with the subject blindfolded and eyes closed. Following a silent reading of a paragraph, the EEG was recorded while the subject paraphrased what he had just read (blindfolded and with eyes closed). Analysis of variance and covariance failed to indicate a significant difference between the groups on the basis of mean percentage of time that unilateral blocking of alpha occurred either in speech or silence. However, in silence stutterers and non-stutterers tended to differ with respect to which half of the occipital lobe had more alpha activity. The stutterers had a higher percentage of alpha in the left occipital lobe, and the non-stutterers had a higher percentage in the right, and in speech the stutterers tended to have more alpha blocking in the occipital areas than non-stutterers.

Knott and Tjossen (1943) replicated Douglass' study for the silent condition, confirming his findings that stutterers and non-stutterers tend to differ with respect to which half of the occipital lobe has more alpha activity. This lent support to the Orton-Travis Theory by suggesting that stutterers have a different lateral hemispheric excitability than non-stutterers. Although differences noted under silent conditions are difficult to discuss, it is possible that the differences originally noted in Douglass' study during speech can be attributed to a greater attention value of speech for stutterers, rather than to neurophysiological differences between the two groups.

While the results of the above studies provide some rather tenuous support for a cerebral dominance theory, other results did not.

Freestone (1943) compared stuttering, fluency and silence and found no significant hemispheric differences in amplitude or similarity of alpha activity between stutterers and non-stutterers for bilateral, frontal, motor and occipital electrode placements. Although not significant, the stutterers did have a tendency toward greater alpha similarity than non-stutterers.

Scarbrough (1943) studied the mean alpha potentials per second of 20 stutterers and their normal controls during silence only. Monopolar electrode leads were placed over left occipital, motor and frontal areas, and two fifteen minute EEG recordings per subject were taken, one week apart. Based on thirty second samples from the first and last five minutes of each recording, no significant differences were noted between stutterers and non-stutterers for frequency or variability of frequency of cortical potentials although three stutterers and one control subject had qualitatively abnormal records.

Rheinberger, Karlin and Berman (1943) compared stutterers and non-stutterers and found no differences in alpha between groups, for a variety of measures in silent conditions only. Leads were bipolar and monopolar, placed bilaterally over frontal, central, occipital and intermastoid areas of the brain.

In 1949, Jones failed to find significant differences between stutterers and non-stutterers on a number of bilateral occipital lobe measures including amount of alpha blocking, out-of-phaseness and clinical abnormalities. Contrary to the findings of Scarbrough (1943) and Rheinberger _et al_ (1943), however, stutterers did exceed non-stutterers for amount of left hemisphere blocking in silent conditions.

More recently, Fox (1966) compared the EEG records of 13 stutterers and their normal speaking controls who were matched for sex, age, handedness and imitative simulation of stuttering behavior. The EEG alpha activity was recorded from bipolar electrodes placed bilaterally over occipital, motor, and temporal areas. Recordings were made during silence, stuttering, fluency and with eyes opened and closed. The controls simulated the stuttering patterns of their matched partners by imitation of the stuttering pattern, frequency and duration of stuttering blocks and general rate and rhythm of speech. There was no indication of neurophysiological differences between groups for any of the experimental conditions; however, when the verbal conditions simulating stuttering behavior were compared to actual stuttering, intergroup comparisons of the alpha wave characteristics of both stutterers and non-stutterers showed decreases in frequency and synchronization ratios. When stutterers simulated stuttering, hemispheric synchronization was less than in non-stutterers, and differences in frequency, amplitude and rhythm between two waves of a continuous pair was less in the stuttering group. Nevertheless, the lack of consistent differences between stutterers and non-stutterers across conditions led Fox to conclude that EEG differences noted between real stuttering, simulated stuttering, and fluency are probably a result of behavioral factors such as arousal, rather than hemispheric asymmetry based on neurophysiological characteristics, since both real and simulated stuttering was disruptive of the EEG display. One interfering variable was visual effect, as the data collected during stuttering and simulation of stuttering, with the eyes open were more disruptive of the EEG measurements than recordings made with eyes closed, during the same conditions. Other variables which could differentiate between the two groups might not have been apparent from visual inspection of the EEG records.

Stuttering and Emotionality

After 1950, the trend in EEG studies of stutterers was toward evaluation of the relationship between stuttering and emotionality, rather than toward confirmation of a cerebral dominance theory of stuttering onset. According to Travis (1931), the relationship between emotionality and cerebral dominance is unclear. It is not specified whether the stutterers' hemispheric margin of dominance would be lowered by increased stress or if stress interacts with an already low margin of dominance in order to precipitate stuttering behavior.

Douglass (1952) found that stutterers showed greater occipital activity in the dominant hemisphere in response to emotional stimuli such as words and pictures than did their normal speaking controls. Murphy (1953) studied the alterations of alpha in response to frustration. The bilateral occipital disruption during frustration was greater in a group of stutterers than in a group of normal speakers.

Knott, Correll and Shephard (1959) evaluated two groups of stutterers and a group of normal speakers (N = 63) for anxiety-proneness in a silent task. The method used was that which was described by Ulett, Glesser, Lawler and Winokur (1952) whereby a EEG response to photic stimulation is measured. The amount of voltage output or frequency of alpha in response to the flashing light differentiates between 'anxiety-prone' and non-anxious subjects. One group of stutterers behaved in the manner of Ulett's anxiety-prone group, while the other did not, suggesting a difference in the sampling techniques and methods of choosing the two groups of stutterers.

Although these studies are not essential to the current study they have some bearing on future trends in EEG evaluations of stuttering behavior and for that reason are worthwhile mentioning at this point.

Critique of Early EEG Studies

In reviewing the early EEG studies which compare stutterers to non-stutterers, although the results are not entirely supportive of a theory of cerebral dominance, a tendency toward a neurophysiological difference of unspecified nature between stutterers and non-stutterers can be seen in some of the studies reviewed here. Notable are the early work by Travis and Knott (1937) in which less hemispheric differences were found in a stuttering group under both silent and <u>fluent</u> verbal conditions, and those studies which found different hemispheric alpha blocking for stutterers (Jones, 1949; Douglass, 1943; Knott and Tjossen, 1943). Despite some provocative findings, the early EEG studies are methodologically inconsistent and results are often difficult to interpret. It is possible that trends noted between stutterers and non-stutterers would be significant if some of the methodological problems could be settled.

In the EEG studies reviewed above, crucial methodological procedures were often unspecified, making comparisons between studies difficult. Different features of the EEG record were chosen for study, including amplitude, duration, frequency of alpha blocking, percentage of time that alpha waves were present, and similarity of the waveform patterns between corresponding portions of the two hemispheres. Some studies used monopolar leads while others favored bipolar placement. Scarbrough (1943) and Jones (1949) evaluated alpha waves generated only in silent conditions. In addition, areas of the brain chosen to study often differed from one study to another.

Inconsistency in the results of previous studies is also related to the wide variability of individual differences of stutterers. Sussman and MacNeilage (1975), pointed out that one explanation for the inconsistencies in all stuttering research is the lack of a homogeneous population. Stutterers are generally described in terms of sex, age, and handedness characteristics, with only a broad statement about the nature or range of stuttering behavior. Where distinctions were made about the nature of stuttering behavior (Travis and Knott, 1937) there were differences between the clinically severe and milder groups. Although this was an indication that this distinction may be an important experimental one, the finding was not followed up in other studies.

The studies reviewed here were often vague in description of other procedures such as the criteria for defining a 'moment of stuttering'. For example, it is unclear if the subjects in some studies who were recorded in silence were told beforehand that they would not speak, as some of the differences noted in silence might be attributed to the subjects' 'expectancy' toward speaking. Secondly, data were not gathered immediately before, during and after single moments of stuttering. Rather, they were gathered before, during and after 'periods' of stuttering. Therefore, it is not known exactly what happened at the moment of stuttering. In addition, the criteria for defining a moment of stuttering did not specify whether stuttering was defined by frequency, duration, effort, type of dysfluency or other factors.

Few studies described the speaking task itself. The use of rapid connected polysyllabic words and/or propositional speech could have contaminated the physiological response by causing considerable movement artifact associated with the act of speaking, which might have been mistaken for cortical response. Furthermore, if connected speech was evaluated, fluent and stuttered episodes might occur in close temporal contiguity for some subjects, making the results more difficult to evaluate on an ongoing EEG record. Since the small differences observed in previous studies provided little evidence to support the view that the cortical potentials of stutterers are statistically different from those of non-stutterers under verbal or silent conditions, it is not difficult to see why interest in the Orton-Travis theory declined.

Recent Studies of Cerebral Dominance and Stuttering

In the last decade, contemporary theories of cerebral dominance and more sophisticated methods of recording and measuring electrocortical activity have led to renewed interest in the search for neurophysiological differences between stutterers and non-stutterers.

Jones (1966) reported a bilateral hemispheric control of the speech of four stutterers, using the Wada Test (Wada and Rasmussen, 1960). In this procedure, when sodium amytol is injected into the carotid artery serving the hemisphere dominant for speech, the patient will temporarily develop aphasic-like symptoms. By injecting each artery it can be determined which hemisphere is dominant for speech, or if speech is represented bilaterally. Jones was able to demonstrate bilateral control of speech in four stutterers prior to surgery for cerebral pathology. Following surgery, complete remission of stuttering and evidence for cerebral dominance in the non-operated hemisphere occurred in all cases. Subsequently, Jones' procedure was repeated on stutterers who had no brain pathology (Andrews, Quinn and Sorby, 1972; Lussenhop, Boggs, LaBorwitt, and Walle, 1973; Walle, 1972). A total of six right-handed subjects were tested. All showed clear left-hemisphere representation for speech, although one subject with pre-existing cerebral pathology did show bilateral aphasic symptoms with the Wada Test. It should be noted here that three of Jones' subjects were left-handed and thus more likely to have mixed dominance. The existence of unilateral cerebral pathology in Jones' subjects may also have altered the results by causing a change in pre-morbid speech control.

Other tests of the Wada technique where bilateral speech representation has been found did not report stuttering behavior among the subjects (Milner, Branch, and Rasmussen, 1964). The lack of support by other authors for Jones' work led to speculation that the important variable determining the results of Jones' study was the pre-existing cerebral pathology. However, interest was once again raised in the relationship between stuttering and cerebral dominance as a result. Because of the risks involved in the use of the Wada technique with normal speakers with no brain pathology, more feasible methods were needed for the evaluation of cerebral dominance for speech. The AER seems to provide such a technique, as discussed below.

Averaged Electroencephalographic Response Evaluation of Motor Behavior

Stromsta (1964) suggested that the inconclusive results of previous EEG studies involving stutterers might be related to the formidable task of visual interpretation of continuous EEG responses. He felt that AER techniques might control for some of the error-producing variables noted in earlier studies (stuttering and fluency in close temporal contiguity, visual impact), as it is possible with this technique to study and identify the small portion of the waveform which is related to a particular event. Since the AER can be measured in milliseconds, the motor potentials occurring up to 1000 msec. prior to the speech or motor activity can be studied in detail. A number of investigators have used AER techniques with normal speakers in attempting to document reliable non-random changes in the electrical activity occurring prior to and during speech production.

Normative studies. These studies attempted to provide evidence from AER's of normal speakers that there are cerebral events which characteristically precede speech. Ertl and Schaefer (1967) used AER methodology to summate the unilateral electrocortical activity occurring prior to speech and voluntary movement. Simultaneous activity was recorded from EEG electrodes placed at the right motor area and from EEG electrodes on the flexor musculature of the left forearm of five adults. Subjects spoke the word 'tea' at a self-paced rate of one every two seconds for 100 trials. Following the verbal condition, 100 contractions of the left fist were completed in a similar manner. Both responses were amplified, filtered with the same bandwidth of the EEG and recorded on audiotape. The subjects' responses triggered an oscilloscope, producing a pulse output for each sweep to indicate periods of analysis. The pulse was shaped, delayed by 150 milliseconds, and recorded on a third channel of the tape recorder with the EEG and EMG activity. Reliable non-random changes were detected in the EEG activity of all subjects preceding voice onset. The AER comprised a positive peak at 70-170 milliseconds prior to voice onset and a negative component occurred up to 50 milliseconds preceding voice onset. Waveforms obtained by Ertl and Schaefer for cortical command potentials and EMG prior to the speaking task showed only these two reliable components within the 250 millisecond pre-onset analysis period. As no EMG activity corresponded to this finding, it was considered evidence for cortical activity preceding vocalization.

Schaefer (1967) subsequently differentiated between AERs for the spoken phonemes /t/, /o/, and /p/, a phenomenon which he suggested indicates that electrical activity recorded from the brain maintains a degree of 'semantic specificity'. These potentials occurred as early as 310 milliseconds prior to voice onset, causing Schaefer to speculate that 'command' potential components with latencies of up to 200 milliseconds might correspond to the initiation of pyramidal neuronal firing controlling the articulatory musculature specific to a particular word.

In a further report, Ertl and Schaefer (1969) discussed the positive relationship between the lip-recorded EMG and the AER potentials preceding speech that they had identified in their earlier (1967) study. This early work also raised important methodological questions related to voice onset trigger, and artifactual contamination, variables which are relevant to any further comparisons of bilateral cortical sites. However, since these studies did not make bilateral comparisons of homotopic locations, they are difficult to compare to the bilateral studies which followed.

The most important bilateral AER study was McAdams and Whitaker's (1971a) attempt to document electrocortical localization for language by measuring the bilateral cortical response pattern associated with the production of two groups of polysyllabic words beginning with /p/ and /k/, and their analogous non-speech gestures (single segmental syllables $p^h\wedge$ and $k^h\wedge$). Electrodes were located bilaterally over the pre-central gyri and inferior frontal areas and referred to linked electrodes at the left and right mastoid. A forehead electrode served as ground. Vocalization of a specified stimulus triggered a 2000 milliseconds sweep by the signal averager allowing for on-line analysis of activity occurring for 1500 milliseconds prior to and 500 milliseconds during vocalization. Responses were produced at a self-paced rate of at least 4-6 seconds between stimuli.

Samples of 30 responses per subject were summated, with data from verbalization and analogous gestures pooled into two groups for purposes of statistical analysis. Left-right hemisphere differences were computed for pre-central and inferior frontal locations. Waveforms characterized by large, fast positive potentials occurring up to 500 milliseconds prior to the voice trigger were attributed to movement artifact. The readiness potentials for speech were slower, lower in amplitude and occurred prior to the faster shifts. It is not clear however, why the authors characterized these as readiness potentials rather than movement artifacts, as they also appear to occur within 500 milliseconds of the triggered onset.

The left-right hemisphere differences over inferior frontal sites were significantly greater ($p < .05$, one-tailed) than the differences between precentral motor areas for the polysyllabic word condition; while differences between hemispheres in syllable conditions were not statistically significant. The former differences, which distinguished /p/ and /k/ words from their analogous gestures, were characterized by greater negative asymmetry over left hemisphere recording sites prior to speech onset. The authors claimed that the potentials arising from the inferior frontal area and differing in the direction of larger negative potentials in the left hemisphere were evidence for within hemisphere localization of speech. This was the first published evidence for cortical asymmetry preceding speech production and, as a result, became the focus of considerable discussion.

The results of the McAdam and Whitaker study have been criticized for a wide range of problems in experimental design and the probable influence of artifacts on the waveforms (Morrell and Huntington, 1971; Grabow and Elliott, 1974). Morrell and Huntington (1971) criticized McAdam and Whitaker's use of an acoustic transient as a voice trigger. They pointed out that simultaneously recorded EMG from a variety of articulatory muscles is necessary in order to sort out the true EEG activity from the contaminating activity accompanying muscle action potentials. This was also suggested earlier by Ertl and Schaefer (1967, 1969). Morrell and Huntington had six subjects repeat 50 utterances for each of two words beginning with /p/. The average EEG amplitude of the 150 millisecond epoch prior to the phonation of /p/ and the 150 milliseconds preceding the lip EMG was measured at various loci over the left and right hemisphere. The results did not support McAdam and Whitaker's claim of intra-hemisphere localization for speech. In the majority of subjects the maximum activity occurred in areas posterior to those studied by McAdam and Whitaker (temporoparietal and central electrode placement), with no consistent hemispheric differences. This cannot be considered a direct replication of McAdam and Whitaker's study, however, as the analysis times were shorter and the trigger, behavioral task, scoring procedures and number of responses summated,all differed.

McAdam and Whitaker (1971b) responded to the criticism of Morrell and Huntington by stating that acoustic airburst is a preferable trigger, as it "leads to the least 'ambiguity in triggering onset' so that (one) can minimize the amount of temporal variability in the brain potential observations". McAdam and Whitaker also felt that recording with simultaneous EMG would not have added to their study. They argue that placement of the electrodes would be "arbitrary" and that the choice of a "simple, non-word gesture(s) involving the same musculature preparation as the /p/ and /k/ initial words" was a more appropriate control and that the lack of any significant hemispheric differences prior to their production was evidence of left hemisphere localization prior to speech production.

It appears, nevertheless, that McAdam and Whitaker's evidence for left hemisphere localization for language may have been confused with artifact contamination. Morrell and Huntington (1971) observed AER activity similar to that described by McAdam and Whitaker from electrodes placed near the canthus of the eye, suggesting that this artifact might also have caused some of the wave form differences found by McAdam and Whitaker. More recently, Grabow and Elliott (1974) criticized McAdam and Whitaker for paying insufficient attention to artifact contamination caused by the glosso-kinetic potential. The glossokinetic potential, first described by Klass and Bickford (1960), is characterized by waves with a frequency of 1-6 cycles per second and amplitude of up to 100 millivolts. This artifact is maximal in the frontal, temporal and occipital regions and can be large enough to distort EEG tracings during word production. Grabow and Elliott duplicated the major elements of McAdam and Whitaker with simple sounds such as 'ba' and 'da' and added 'lilt', a word shown by Klass and Bickford to elicit a prominant glossokinetic response. In addition, four three-syllable /p/ and /k/ words were repeated in random sequence for 32 trials. The subject's voice activated a special purpose computer by means of a carotid-dynamic microphone connected to the amplifier system (an improvement in the amplification used by McAdam and Whitaker, according to the authors). Visual inspection of single and summed responses showed wide variability both between and within subjects, dependent upon their particular response. While no hemispheric asymmetry was noted before, during, or after speech, hemispheric asymmetries could be produced during word production by purposeful lateralization of the tongue. Grabow and Elliott concluded that the differences between hemispheres noted prior to voice onset by McAdam and Whitaker were merely movement artifacts caused by changes in tongue posture and then summated with the other cortical activity.

Some discrepancies between Grabow and Elliott's and McAdam and Whitaker's studies should be considered here. First, the experimental task differed, as McAdam and Whitaker used various self-initiated words as stimuli, while Grabow and Elliott required their subjects to repeat words. Secondly, some of the asymmetry found by McAdam and Whitaker may have been produced by electrode characteristics such as drift and

and impedance, and variance of gain evidenced by unequal calibration artifacts, all of which were controlled by Grabow and Elliott. Finally, eye movement, tongue movement and other muscle potentials preparatory to speech may be additive or disruptive in the generated AERs. Since McAdam and Whitaker did not adequately control for these artifacts their data might reflect uncontrolled visual and glossokinetic movement as well as cerebral activity. It should be noted, however, that Grabow and Elliott maximized the occurrence of extracerebral artifact by having subjects purposefully lateralize tongue movements. Their failure to replicate McAdam and Whitaker's study is not conclusive due to these methodological differences.

The findings of McAdam and Whitaker have been supported by studies which used similar recording techniques (Morrell and Huntington, 1972; Szirtes and Vaughan, 1973; Grözinger, Kornhuber, Kriebel, 1973; Grözinger, Kornhuber, Kriebel and Murata, 1974), and additional support has come from work using slow potential techniques based on the CNV paradigm (Low, Wada and Fox, 1974; Zimmerman and Knott, 1973, 1974), wherein the averaging of the slow potentials takes place between fixed S1-S2 intervals. This is a reaction time paradigm with S1 being the alerting stimulus. The subject must respond as quickly as possible after the occurrence. It should be noted that in the Zimmerman and Knott studies (1973, 1974), stutterers formed the experimental group. Typically, a negative shift occurs between the

S1 and S2. This has been related to expectancy (Walter, W.G., Cooper, R., Aldridge, V.J., McCallum, W.G. and Winter, A.L. (1964)).

Morrell and Huntington (1972) examined the cortical potentials from a variety of bilateral electrode sites. Electrocortical potentials were time-locked to speech production and were compared to EMG recordings from the lower lip, larynx and jaw. All electrode sites were linked to earlobe references. Speech conditions included spontaneous self-paced repetition of a given stimulus and speech production cued by a tone or repeated from a taped stimulus. Electrodes were placed bilaterally at frontal, temporo-parietal, rolandic, anterior temporal, and vertex, parietal and occipital midline sites. Subjects characteristically produced a slow negative shift, beginning several hundred milliseconds before speech, and maximal over posterior electrode sites. Although a similar course of activity was often found for articulatory activity from EMG electrodes, the speech related potentials had a distinct pattern of timing and distribution which is compatible with a cerebral origin. Hemispheric asymmetries were also noted by visual inspection, with left hemisphere potentials being larger than their homologous right sites.

Using a back averaging technique as in McAdam and Whitaker (1971a) Szirtes and Vaughan (1973) supported their work, finding a left hemisphere negativity beginning 500 milliseconds before speech production. The speech related potentials were maximal over fronto-temporal sites. A slight cortical asymmetry was also noted over the precentral motor cortex. However, the authors felt this was due to muscle innervation rather than neural activity related to speech production.

As much of the controversy regarding McAdam and Whitaker's claim of localization of language centers on contamination of the cortical response by interfering artifacts, discussion of these artifacts and possible controls may enhance understanding of studies of cerebral activity during motor production. Grözinger, Kornhuber, and Kriebel (1975) examined the artifact contamination from a variety of sources during cortical recording. To maximize control of artifacts, head movement was minimized by immobilization. During responses, subjects used a fixation point to minimize eye movements. Interference of tongue movement with brain potentials preceding speech was avoided by self-paced voluntary repetition with the tongue resting in a neutral position during an 8 second interstimulus interval. Artifact contamination which might be noted from position of the reference electrode and time constant were also evaluated, as was the muscle potential measured by Galvanic Skin Response (GSR) and Electromyography (EMG). Motor and speech activity included production of phonemes, sentences, articulation placement without phonation, and phonation without articulation (e.g., humming). Speech onset was marked by the beginning of the phonogram via a throat microphone (a back averaging technique was used, with a delay of 500 milliseconds between the trigger and the averaging). Trials with artifacts were marked on line by negative impulses generated by the experimenter on the recording tape, and were eliminated from summation. Differences in reference electrode sites resulted in amplitude differences, but no latency changes in the AER.

The cortical potentials preceding speech and humming was variable while large shifts of potentials following articulation movements were stable; however, a slow brain potential preceding speech and correlated with respiratory waves was supported as cortical in origin by the exclusion of the various sources of artifact from the record. Grözinger et al interpreted this as supportive of other studies which found evidence for cerebral asymmetries preceding language production (Grözinger, Kornhuber, Kriebel and Murata, 1974; Morrell and Huntington, 1971; Ertl and Schaefer, 1972).

Grözinger et al concluded that because such invarient activities as the sharp increment in lip activity prior to phonation of some plosives, the glossokinetic potential associated with speech production, and head and eye movements might influence the EEG recording, the control of these artifacts is both essential and feasible prior to attempting studies which hope to confirm the presence of lateralized hemispheric activity prior to speech production. It should be noted that in other studies such as Grabow and Elliott (1974), which have been critical of studies resulting in possible artifact contamination, periodic potentials caused by tongue movements all occurred after activity onset.

Low et al (1973) reported hemispheric asymmetries in contingent negative variation findings which correlated with the Wada Test. In their study, 39 subjects (16 left-handed, 23 right-handed) were evaluated in a traditional CNV paradigm with electrode placement at the inferior and posterior frontal areas of both hemispheres. Potentials were summated from the epoch following stimulus presentation and prior to the motor response, resulting in cortical asymmetries which were comprised of a greater negative shift on the dominant hemisphere prior to phonation. This hemispheric asymmetry, correlated with the results of the Wada Test in ten of the eleven subjects who had been evaluated with the Wada Test.

A recent report which was not published at the time the present study was conceived also supports McAdam and Whitaker's findings. In a study which replicated the conditions of McAdam and Whitaker and evaluated the cerebral asymmetries preceding several different speech tasks, Levy (1977) found reliable differences characterized by more negative activity in the left hemisphere prior to the articulation of the more complex utterances. It is interesting to note that those utterances which were sequentially more complex, involving greater fluency of movement resulted in greater left hemisphere differences over frontal lobe sites regardless of their semantic, syntactic or lexical value. Levy (1977) concluded that interhemispheric asymmetries may be seen prior to articulation and may vary for different articulations. These findings were in agreement with similar findings of McAdam and Whitaker for English polysyllabic words, although Levy also reported reliable cerebral asymmetries for 'multiple puffs and huffs' between left and right frontal areas (e.g., p^{h}ʌ , p^{h}ʌ , p^{h}ʌ). This is in contrast to McAdam and Whitaker, who found no hemispheric asymmetries using similar stimuli.

The above studies have contributed to the methodological information which is necessary to improve the recording and documentation of cortical motor potentials preceding speech production. Since McAdam and Whitaker (1971a) and subsequent investigators have suggested what a normative response pattern might look like, stutterers could be compared to a group of normal speakers. In addition, the data of Low *et al* (1973; 1974) which compare to the Wada Test, suggest that the AER technique may serve as a non-traumatic substitute for Wada Testing in evaluation of cerebral dominance in stutterers.

AER Studies of Stuttering. To date, there have been few attempts to compare stutterers with normal speakers using AER recording techniques. These studies fall into two groups: a) evaluation of slow potentials in a CNV 'expectancy' paradigm (Peters, Love, Otto, Wood and Bebignus, 1974; Love, Peters, Wood,Otto, 1974; Zimmerman and Knott, 1973) and b) assessment of cortical asymmetries preceding speech (Zimmerman and Knott, 1974).

As the CNV is hypothesized to be stress related (Knott and Irwin, 1973), it is a useful mode for evaluation of the proposed relationship between stuttering and negative emotion (Brutten and Shoemaker, 1968). Peters et al (1974) evaluated the relationship between slow brain potentials (CNV) and expectancy to stutter, positing that cortical activity prior to stuttering might reflect anticipation of stuttering behavior. Words which had previously been rated 'frequently stutter' and 'never stutter' by each subject were flashed on a screen followed after 1000 milliseconds by a light signal to say each word. This condition was compared to a control task which consisted of button pushing in response to one frequency combination from a series of tone combinations. Electrode placement was at the vertex and left and right parietal areas. Data were recorded on analog tape with a 5000 millisecond time constant. Electrophysiological responses were digitized in 4000 millisecond epochs and averaged in groups of 20 on a PDP-12 computer. Eye movement was minimized by subtracting the ocular muscle potentials (EOG) from the vertex EEG with a compensating devise which, according to the authors, was 90% effective in eliminating eye movement artifact. The data from each group of subjects were pooled and the AERs were summated from three conditions (non-speech, frequently stutter, never stutter).

Results indicated that the amplitude of the CNV was smaller for stutterers than non-stutterers before a signal to speak. Among stutterers the CNV was significantly smaller before words rated frequently stuttered upon than rarely stuttered upon; however, difference between groups in terms of negative amplitude were not significant even though visual inspection showed a larger CNV in the normal speaking group. No differences were noted between groups on the non-speech task. The authors felt that the non-significant differences between groups which occurred in speaking tasks might be related to specific word or sound expectancies. This conclusion is supported by a study by Knott and Irwin (1973), who showed that anxiety-prone normal speakers had smaller CNVs under stressful conditions; and can be seen as tenuous evidence for theoretical contentions that anxiety or negative emotion evokes stuttering behavior (Brutten and Shoemaker, 1968). A study by Love et al (1974) was a continuation of analysis of the same data as Peters et al and confirms these conclusions.

Two studies by Zimmerman and Knott (1973, 1974) are noteworthy as they compared the CNV at the vertex with bilateral frontal sites for a group of stutterers and normal speakers. In their 1973 study, a typical CNV paradigm was used, in which subjects responded verbally following a 250 millisecond interstimulus interval. Results showed that stutterers were different from normal speakers when responding either dysfluently or fluently. With normal speakers, a CNV response characterized by a negative shift was observed at the vertex placement in the 250 millisecond interval prior to the verbal response, followed in time by a negative shift at the left inferior frontal area. The stuttering group, when responding fluently, also showed a negative CNV at the vertex, but no evidence of a left or right inferior frontal shift. Conversely, during stuttered responses, no CNV was noted at the vertex, but at the inferior frontal sites, a negative shift was noted in the left hemisphere and a positive shift in the right hemisphere. This is in contrast to Peters et al who found decreased CNVs prior to a signal to speak, whether the response was stuttered or fluent. These data, although analyzed by visual inspection only, implied a neurophysiological difference between stutterers and non-stutterers which Zimmerman and Knott related to an interaction between an affective stimulus (i.e., a stressful speaking situation) and a motor response.

A later study (1974) by Zimmerman and Knott is the only one directly relevant to the present study. In this study, 9 male stutterers and 5 non-stutterers were compared to the results of McAdam and Whitaker (1971a) for a normal speaking group. Electrode placement was consistent with McAdam and Whitaker over bilateral inferior frontal areas, as well as vertex sites. Subjects were recorded in four conditions which included a speech and non-speech vocal task and a non-vocal manual task. The two non-vocal control conditions involved the subject's differential reaction to a high or low frequency tone, expressed by a key pressing response. In the vocal non-speech condition, words were flashed on a screen for 250 milliseconds and the subjects responded 1500 milliseconds later by pressing a key to indicate their 'expectancy' to stutter. In the verbal condition the same words were shown, and the subjects responded verbally. In this condition the monosyllabic and polysyllabic words appeared on the screen for a 250 millisecond latency period before a light signaled the subjects to respond. These conditions conform to what is called a traditional CNV paradigm. Electrical activity was recorded on-line and artifact-free trials were fed into a PDP-12 computer and averaged over a four second epoch. From 6 to 12 trials per subject were averaged for each condition.

The results indicated no statistical significance in the vertex evoked CNV in any of the four experimental conditions. However, visual inspection of the data recorded from frontal areas support the findings of McAdam and Whitaker. Four of the five normal speakers had larger negative amplitude shifts over left inferior frontal sites prior to both the verbal and non-verbal 'expectancy' task, indicating that verbal processing alone was sufficient to create hemispheric asymmetries. In contrast, seven of nine stutterers showed no clear hemispheric asymmetries during either the verbal or the non-verbal 'expectancy' task. It is important to note that in the verbal task all responses were <u>fluent</u>.

Although their results were not statistically confirmed, the visual analysis of Zimmerman and Knott's normal group's data conformed to the interhemispheric asymmetries produced by McAdam and Whitaker's subjects, and their stuttering group did not provide any consistent left hemisphere asymmetry,according to the authors. If one speculates that the findings for the normal speaking group reflect specialized activity of the left hemisphere for speech, then Zimmerman and Knott's study suggest a difference in cerebral dominance between stutterers and non-stutterers represented by a lack of consistent asymmetry over frontal sites, between left and right hemispheres in the stuttering group.

Those studies which found support for differences in the cortical motor responses of stutterers and non-stutterers agree with studies which found differences between the two groups using sensory tasks (Sussman, MacNeilage, 1974) and lend further support to a concept of differences in aspects of cerebral dominance between stutterers and normal speakers.

Curry and Gregory (1969) found that stutterers showed less of a REA on a dichotic listening task while Sussman and MacNeilage found that a significantly larger number of stutterers showed a REA for an 'articulation tracking task', implying that stutterers may be less attentive to auditory cues when processing verbal material, and may be more dependent upon visual-spatial cues.

A recent study (Moore and Lang, 1977) concurs with Sussman and MacNeilage, finding that prior to a reading task, significantly greater alpha duration was recorded at left hemisphere temporal sites for stutterers than non-stutterers suggesting that stutterers may be processing linguistic stimuli in the right hemisphere, a more specialized area for visual-spatial processing.

The studies discussed here imply that AER methodology can be informative with regard to the measurement of event-related brain behavior associated with anticipation of stuttering, and also in the evaluation of cortical asymmetries preceding a motor response such as speech production. The work of Peters et al (1974) and Love et al (1974) are related to earlier EEG attempts to compare stuttering onset with autonomic arousal (Douglass, 1952; Murphy, 1953; Knott, Correll and Shephard, 1959), while the work of Zimmerman and Knott (1973, 1974) is an extension of the early work of Travis and Knott's (1936, 1937) attempts to relate stuttering and cerebral dominance.

Statement of the Problem

Zimmerman and Knott (1974) have reported that, under fluent conditions, the cortically evoked potentials of stutterers and non-stutterers differ. Their study suggests that investigation of the variables involved in this phenomenon might be informative in determining the nature of stuttering.

Orton and Travis hypothesized that stuttering results from a lack of "motor lead control". According to modern cerebral dominance theory, left hemisphere dominance for speech would be displayed as an asymmetry in the amplitude of left dominant hemispheric AER patterns in normal right handed speakers. If the left hemisphere is dominant for speech in non-stuttering subjects, and if stutterers do not have the same form of dominance, as Zimmerman and Knott (1974) contended, then further AER studies comparing stutterers to non-stutterers may help clarify the nature and basis of this theoretical interhemispheric conflict.

According to the literature, non-stutterers' AERs should show a pattern of asymmetry, perhaps in terms of amplitude or latency, favoring their left hemispheres. On the other hand, the AERs of stutterers may have two different patterns:

1) their AERs may show a pattern of asymmetry reflecting a right hemisphere dominance or;
2) their AERs might be more symmetrical or similar in nature.

Both these AER patterns seem possible, and data from studies reviewed here support both suppositions.

In addition, the literature reviewed here suggests that the AER patterns of stutterers are influenced by other subject and task variables. Stutterers do not constitute a homogeneous population. Severity of stuttering is a subject variable which has been cited from the early work of Travis and Knott (1937) to the present (Zimmerman and Knott,1974) as a possibly important classification of stuttering behavior.

If cortical differences exist between stutterers and normal speakers, what differences exist between clinically mild and severe stutterers? If differences do exist between groups of stutterers differentiated according to severity, what interactions exist between severity of stuttering and different speaking conditions? Do severe and mild stutterers exhibit different AER patterns during fluency? What are the articulatory and linguistic factors which are related to fluency?

Analysis of the studies reviewed here suggest that further use of the averaged electroencephalographic response technique might lead to new information and further clarification of the nature of the relationships between stuttering behavior and neurophysiological events as well as further understanding of the overt nature of stuttering and its causal relationships. The present study was an attempt to use the AER technique to obtain further information about cerebral dominance in stutterers.

The experimental hypotheses were:

1. In a speech production task, normal speakers' AERs will be characterized by greater left hemisphere amplitude prior to and during phonation.
2. Conversely, stutterers will have less asymmetry in amplitude between the left and right hemisphere than non-stutterers; or will demonstrate a right hemisphere dominance prior to and during a speech task.
3. Among a sample of stutterers, the more severe the stutterer, the more different will be his AERs from those of normal speakers. This difference will be reflected in one of two ways:
    a) there will be less asymmetry in the severe stutterers' AERs or,

b) there will be a more pronounced right hemisphere dominance in the severe stutterers' AERs.

METHOD

Subjects

Subjects were 24 right-handed males aged between 19 and 49 years. Edinburgh Handedness Inventory scores greater than 70% right-handed (Oldfield, 1971) were required to verify hand preference (see Appendix A). Subjects were assigned in equal numbers to one of three groups; severe stutterers, mild stutterers and normal speakers. The 16 stutterers were placed in the mild or severe group on the basis of a pre-experimental assessment of stuttering. Responses on the Thematic Apperception Test (TAT) task (Johnson, Darley, Spriestersbach, 1963) provided the speech sample used for stuttering assessment. Each stutterer spoke for three minutes about TAT card number 10, and his responses were recorded on one channel of a Sony 654-4 four-track tape recorder. Using Van Riper's interpretation of the Iowa Test of Severity of Stuttering (1971), those subjects who stuttered on 5% or fewer of the total words spoken were assigned to the group of mild stutterers, while those who stuttered on 10% or more of the total words were classified as severe stutterers. Degree of severity was verified by a second examiner, trained in these assessment procedures, prior to the assignment of subjects to groups.

In addition to the preselection criteria of strong right-handedness and severity of stuttering assessment, subjects were required to demonstrate a low level of body movement during pretest in order to participate in the experiment. This latter criteria was used to eliminate subjects whose excessive movements might severely contaminate the EEG record and to provide more homogeneous experimental groups. Subjects were eliminated during the pre-experimental assessment if they exhibited excessive body movements such as head and jaw jerks, or if their stuttering patterns consisted mainly of non-vocalized blocks. Non-vocalized blocks, such as laryngeal blocking, were characterized by suspension of vocalization and frequent struggle reaction, in contrast to vocalized blocks, such as clonic blocks which were characterized by excessive repetitive or prolonged phonation of speech sounds. The first eight severe stutterers and the first eight mild stutterers who fulfilled the above criteria were chosen as subjects. Ages ranged from 19 to 49 years in the group of severe stutterers, 19 to 37 years in the group of mild stutterers, and 20 to 34 years in the group of normal subjects.

Stimulus Materials

There were six experimental conditions in this study. Conditions 1, 2, and 3 utilized linguistically meaningful monosyllabic words as stimuli, while conditions 4, 5, and 6 were comprised of three consonant-vowel (CV) syllables with the same initial consonants as the words used in the first task. All stimuli began with one of the three unvoiced plosive consonants /p/, /t/, or /k/. These consonants were selected since they represent all plosive manners of articulation as well as bilabial, alveolar, and velar phonetic placements.

In conditions 1, 2, and 3 each of the three consonants served respectively as the initial consonant in 25 different monosyllabic words which were formed in combination with the vowels / æ /, /i/, /a/, /u/, or / ʌ/. The 75 words were selected from the Thorndike Lorge List of 30,000 Words (1944) and from One Syllable Words (Moser, 1969) (see Appendix B).

Monosyllables were selected as the experimental stimuli because they tend to produce less variability in the EEG record than polysyllabic words (Grözinger, Kornhuber, Kriebel, 1975). The consonants /p/, /t/, and /k/ were also selected as initial phonemes because these plosives have been used in the majority of the previous AER studies of normal speakers (McAdam and Whitaker, 1971a;Grabow and Elliott, 1974) and therefore provide a comparative baseline. These plosives have the additional advantage in that they provide the most sharply delineated and reliable transient for triggering the onset of the electroencephalographic response (McAdam and Whitaker, 1971a).

The stimuli in conditions 4, 5, and 6 consisted of 25 single repetitions each of three unvoiced consonant-vowel syllables beginning with the phonemes /p/, /t/, and /k/ (i.e., 'pʰʌ', 'tʰʌ', and 'kʰʌ') for a total of 75 utterances. Consonant-vowel syllables were included in the present study to permit the comparison of speech sounds which are analogous to those in the word conditions, but which lack semantic value. Stutterers, for example, may in fact demonstrate considerable differences in their normal responses to the production of speech sounds as a function of presence or absence of stimulus meaning.

Each of the 75 stimulus words was printed with a black felt-tipped marker pen on a 12.7 cm X 17.78 cm index card. All words were printed in lower-case letters, 3 cm in height, for easy legibility. The cards were randomly ordered and attached to a ring binder for presentation. A response sheet with the test stimuli printed in the order of stimulus presentation, was used by _E_ to monitor _S_'s responses and to indicate any stuttered or other responses to be eliminated from AER summation due to excessive artifact (see Appendix C).

Apparatus and Test Procedures

After successful completion of the handedness inventory, assessment of stuttering severity, and screening for predisposition to movement artifact, each subject was scheduled for the experimental test session. At the beginning of the test session the procedures involved in the experiment were described to the subject. He then signed a permission form indicating that he understood the task, was participating voluntarily, and was aware that he was free to withdraw at any time (see Appendix D).

EEG recordings were obtained via silver-silver chloride surface electrodes 1 cm in diameter with 121.92 cm shielded cables and standard pin-type connectors. The electrodes were supplied by the EEG laboratory of the Montreal Neurological Institute. Two electrodes were placed symmetrically left and right over the cortical regions corresponding to the inferior frontal area for each hemisphere. These placements were made 11 cm laterally from the vertex along the inter-aural line and 4 cm anterior to that point. According to McAdam and Whitaker (1971a) and Zimmerman and Knott (1973) these placements lie over the presumed Broca's area (iF'_3) and its contralateral homologue (iF'_4). The recording from the left-hemisphere site was referred to an electrode over the left mastoid, and that from the right hemisphere site was referred to the right mastoid. The ground electrode was connected to the forehead. These five electrodes were secured to the subject with gauze and collodion adhesive. After the electrodes were attached, each was filled with EEG jelly by means of a blunt hypodermic syringe. Electrode contact resistance was monitored with a Fluke 8000A digital multimeter until the contact resistance was stabilized at less than 2000 ohms by blunt needle abrasion of the scalp surface through the opening in the electrode. Following electrode placement there was a twenty-minute delay to permit stabilization of the electrode potentials prior to recording the EEG signal.

The subject was then seated in a comfortable chair inside a double-walled, sound-shielded room (IAC Model 1203-A), and the scalp electrodes were connected to the EEG recording system (see Appendix E). This system included a custom junction box with a separate 2 milliampere fuse for each electrode to protect the subject from electric shock in the event of amplifier malfunction during recording.

The EEG signals from the left hemisphere and the electrical activity from the left mastoid were connected to the non-invert and invert inputs of an Ortec 4660 differential amplifier with high common-mode rejection. The gain of this amplifier was set at 1K, with the bandpass adjusted to 0.1 to 100 Hz. Signals from the right hemisphere and mastoid electrodes were connected similarly to a second Ortec 4660 differential amplifier with the same gain and bandpass settings. The ground electrode was connected to the coaxial shielding of the left-hemisphere amplifier invert input connector. The Ortec amplifiers were situated behind the subject inside the test booth. The EEG signals were further amplified by a factor of 20, using a specially-designed 2 channel amplifier located outside the test booth. The amplified EEG activity from left and right hemispheres was recorded on channels 1 and 4 of the Sony 654-4 four-track tape recorder, using a Vetter 2D FM adaptor. An Ampex 900 omnidirectional microphone was used to record the acoustic airburst which would trigger the EEG responses to be summated. It was placed 10 centimeters above and just lateral to the subject's mouth. In addition, the ongoing electroencephalographic activity from each hemisphere of the subject was monitored by simultaneously routing to an Advance OS 1000A 2 channel Oscilloscope set at 1 volt per centimeter. The record level of Channel 2 of the Sony 654-4 four track tape recorder was set to peak the VU meter at OdB during speech.

Before each subject was tested, a custom calibration pulse generator was connected to the electrode pinjacks for each hemisphere and 20 microvolt calibration pulses were recorded onto the left and right hemisphere channels of the Sony 654-4 tape recorder. These calibration pulses provided a check on the stability of the recording system, enabled the selection of appropriate playback levels for subsequent signal averaging, and permitted accurate quantification of the AER amplitude in microvolts. At this time, the electrode resistance was verified a second time and the test session was begun.

The subjects were seated opposite one experimenter (E_1) who could be seen by the second experimenter (E_2), through a window in the IAC booth. Subjects were instructed to make themselves comfortable, to try to keep all physical movements including blinking and swallowing to a minimum and to fixate on the 4 cm diameter black circle which was placed at eye level before them when responding. Subjects were instructed to return to a neutral mouth position following each response (i.e., keeping the lips lightly together and the tongue resting gently on the floor of the mouth).

According to Grözinger, Kornhuber and Kriebel (1975), use of this position avoids much of the artifact in the EEG record associated with tongue movement.

The responsibilities of E_1, who remained with the subject,were to present the experimental stimuli and to tabulate stuttered responses accompanied by excessive movement and responses made prior to focusing on the fixation dot. Subjects were asked to repeat trials which were rejected on the basis of these three criteria.

The second experimenter (E_2) was positioned outside the IAC booth at the control panel during the test session and was responsible for: (a) instructing the subjects prior to the test session; (b) observing the EEG signals via the Advance OS 1000A 2-channel oscilloscope to verify amplifier operation and to monitor peaking or other disturbances in the EEG signal; (c) timing the 10 second inter-stimulus interval; and (d) signalling presentation of each stimulus by a light which was visible only to E_1. In addition to these duties, E_2 monitored the subject's response via earphones, and noted those responses which were stuttered or otherwise misarticulated on a response form identical to that used by E_1. The order of word (i.e., 1, 2, and 3) and CV (i.e., 4, 5, 6) conditions was counterbalanced across subjects such that half of the subjects in each group received conditions in the order 1, 2, 3; 4, 5, 6, while the remainder were tested in the order 4, 5, 6; 1, 2, 3.

Conditions 1, 2, and 3 (Words)

Each of the 24 subjects was told that he would be asked to say a series of words, one at a time. Owing to the nature of artifactual electrical changes in EEG activity during extraneous motor responses, the subjects were instructed to remain stationary while responding. They were free to move and change position during the 10 second interstimulus interval. The interstimulus interval was intended to minimize the effects of muscle potential artifacts on the EEG response prior to vocalization and to provide a silent period around each response for the purpose of AER computation. Subjects were cautioned to avoid responding until signaled by E_1 to do so, and were told that if they responded prematurely they would be asked to repeat the response.

The stimuli were presented at eye level approximately 0.6 meters from the subject. Each word was presented by E_1 following the light signal from E_2. After a 3 second interval to enable the subject to read the word, E_1 covered the word with the fixation point. This gesture signaled the subject to respond. Following each response E_1 continued to hold the fixation point in place until signaled with the light by E_2 to present the next stimulus.

During the interstimulus interval both experimenters marked their respective response forms when necessary to indicate aberrant responses. Stuttered responses were marked "S", and responses contaminated by movement or other artifact which rendered them negative were checked. All responses considered to be fluent remained unmarked. The incidence of fluent responses on the two response sheets were compared prior to AER computation. Following presentation of the 75 monosyllabic words the subjects were given a five minute rest. The monosyllabic words were presented in the same order for all subjects.

Conditions 4, 5, and 6 (Consonant-vowel syllables)

All 24 subjects were told that they would be asked to say a series of CV syllables one at a time. Subjects were instructed once more about the importance of minimizing movement during all responses. The subjects were given instructions on the production of each consonant-vowel syllable, both by verbal explanation and by demonstration. Each syllable was carefully rehearsed by the subject with particular attention given to minimizing the preparatory movements such as taking a breath, lip pursing and jaw lowering. Subjects were asked to return to the neutral mouth position following each response.

During the rehearsal, the record volume of the Sony 654-4 tape recorder was regulated to peak at OdB for each gesture. While responding, subjects were asked to fixate on the fixation point. Following satisfactory rehearsal, each gesture was produced 25 times in succession, with a five second inter-trial interval. The stimuli for gestural responses were presented in the same order for all subjects.

The inter-trial interval was timed by E_2 who also indicated each new trial to E_1 with the light signal, whereupon E_1 signaled the subject to respond with a head nod. This procedure was repeated until each of the three gestures had been satisfactorily produced 25 times each for a total of 75 responses. As before, during production of each stimulus, E_2 monitored the oscilloscope for evidence of negative responses which were later eliminated from the experimental sample.

Post Test Procedures

After the experiment was completed, the electrodes were removed with acetone. The magnetic tape (Scotch Brand .63 cm) which contained the subject's verbal and cortical responses to both tasks was removed from the response tape recorder and labeled with the subject's name, group assignment and order of test conditions. The duplicate response forms were labeled in the same manner and placed with the response tape in a separate folder for each subject. The entire experimental procedure including electrode placement, was always completed in less than three hours.

Analysis of the Data

Reliability

After all 24 subjects had been tested, the responses appropriate for AER computation were selected. Although it was anticipated that the entire 150 responses for the six conditions would be suitable for AER computation, post-test comparisons of the duplicate response sheets necessitated elimination of a number of trials for the reasons described earlier. Responses involving stuttered words and responses judged by either E_1 or E_2 to be negative due to movement artifact were not used in signal averaging. Only those responses which were considered to be fluent speech by both experimenters were selected for AER analysis. Each of these were viewed on an Advance OS 1000A 2-channel oscilloscope and any responses which were disrupted by peaking of the electrocortical activity were eliminated. This procedure was followed for all subjects prior to AER analysis resulting in a set of 15 acceptable responses being selected from the original 25 recorded for each subject under each of the six conditions. When more than 15 of the recorded word responses in any one condition were acceptable, the set of 15 was chosen in such a way as to maximize the number of words in common across subjects.

Signal Averaging

The recording equipment used in the present experiment was dismantled and reassembled for AER computation (see Appendix F). Each of the six groups of 15 trials was averaged separately, resulting in six pairs of AERs for each subject. Prior to signal averaging, the analogue tape-recorded signals were converted to digital signals by the LINC-8 computer and stored on LINC-tape. The plosive airburst was used to trigger the computer, which digitized 512 separate voltage values separated by 3.906 millisecond intervals for each AER epoch of 2000 milliseconds. The LINC-8 was programmed in such a manner so as to permit pre-triggering, such that 1000 milliseconds of the AER epoch occurred before speech onset; 1000 milliseconds of the epoch followed speech onset. Initiation of vocalization was defined by the triggered plosive burst and will hereafter be referred to as speech onset.

Prior to signal averaging for each subject, the playback gains on the 2-channel Vetter FM adaptor DC output levels were adjusted using the 20 microvolt calibration pulses recorded on the response tape,and the voltages of the calibration pulses for each EEG channel were displayed on the teletype. The amplitudes of the calibration pulses on the left and right hemisphere EEG channels were noted, and the DC levels were adjusted until the calibration pulses on each channel equalled 20 microvolts. These values were maintained at the same level for all AER computations for that particular subject. Permanent records of each pair of averaged calibration pulses or AERs were obtained using a Hewlett Packard Model 7044A X-Y recorder, which was connected to the LINC-8 computer.

A total of 6 pairs of AERs were computed for each subject in this manner. The left and right hemisphere AERs were computed at the same time and were displayed with two moveable cursors on a Tektronix Model 613 storage display. Cursor 1 was then set to the position corresponding to 500 milliseconds prior to speech onset and Cursor 2 was adjusted to 500 milliseconds following speech onset. The latency for each cursor position and the voltage change in each AER between these cursor positions were then displayed on the teletype.

AER Measurement

Several manipulations of the AER data were necessary to arrive at a sampling method which would be feasible for statistical analysis by providing both a low sampling error and a fair representation of the major aspects of the waveform. In this way, a sampling of the 512 possible samples per 2000 millisecond sweep would be arrived at without "peak clipping" or sacrifice of neural information. To accomplish this, the wave form with the sharpest vertical rise (i.e., the fastest voltage change) was selected from the plotted individual records of all the AERs. This waveform was used to determine the highest frequency component of all the waveforms, which was 1.19 Hz. This frequency was used as the basis for determining the sampling rate. By this procedure all the waveforms of a slower voltage change (less sharp vertical rise) would also be sampled, assuring a low sampling error.

The above computation demonstrated that a 16 Hz sampling rate would adequately represent the data. To obtain this rate, the 512 possible samples per 2000 millisecond sweep were compressed to 32 samples per sweep, per hemisphere, yielding a sample point every 62.5 milliseconds along the 2000 millisecond sweep or 16 samples per 1000 milliseconds.

The voltage generated at each of the 32 sample points for each AER was printed on the teletype, and simultaneously punched onto teletype paper tape. This paper tape was then read into the IBM 360 computer MUSIC system, where it was transferred to magnetic tape to make it accessible to the IBM 370 OS system for subsequent statistical analysis of AER amplitude changes between sampling points at various latencies.

Analysis of Variance

Visual inspection of the computer generated data indicated that 8 sample points per hemisphere would provide sufficient quantification of the main features of the AER record. These sample points corresponded to the points of maximum electrical activity for pooled data along the 2000 millisecond continuum, and consisted of four points prior to speech onset (250 millisecond, 187.5 millisecond, 125 millisecond, and 62.5 millisecond), the point of speech onset (0 millisecond) and the three points following speech onset (62.5 millisecond, 125 millisecond, 187.5 millisecond). A four way analysis of variance was performed on the eight samples per hemisphere, using the BMD 08V computer program from the Biomedical Computer Program Manual (Dixon, 1975). In this analysis the factors were Groups (normal speakers, mild and severe stutterers), Hemispheres (left and right), *Conditions* (monosyllabic words beginning with /p/, /t/, and /k/ and consonant-vowel syllables beginning with /p/, /t/, and /k/), and *Time* (250, 187.5, 125, and 62.5 milliseconds preceding triggered speech onset; speech onset; and 62.5, 125 and 187.5 milliseconds following speech onset). The dependent variable was response amplitude measured in microvolts.

RESULTS

The signal averaging procedures in the present study resulted in six pairs of averaged electroencephalographic responses (AERs) per subject. Representative examples for each subject in the normal speaking, mild stutterers, and severe stutterer groups are presented in Figures 1, 2, and 3 respectively, and representative examples of group AERs, pooled across subjects, are presented in Figure 4. The AERs in these four figures correspond to those generated under the /p/ word condition but as can be seen by comparison to those presented in Appendices G-I, are exemplary of the AERs obtained in this experiment.

The mean response amplitudes obtained for normal subjects, mild stutterers, and severe stutterers for each hemisphere under each condition and time period are presented in Tables 1, 2, and 3 respectively. Table 4 shows this information for the three groups combined.

Analysis of Variance

The AER amplitude scores for each subject were subjected to the following four-way analysis of variance: GROUP (Normal speakers, mild stutterers, severe stutterers) X HEMISPHERE (right and left) X CONDITION (/p/ words, /t/ words, /k/ words, /p/ syllables, /t/ syllables, /k/ syllables) X TIME (-250 msec., -187.5 msec., -125 msec.,

Figure 1

Normal Speakers
(p) words

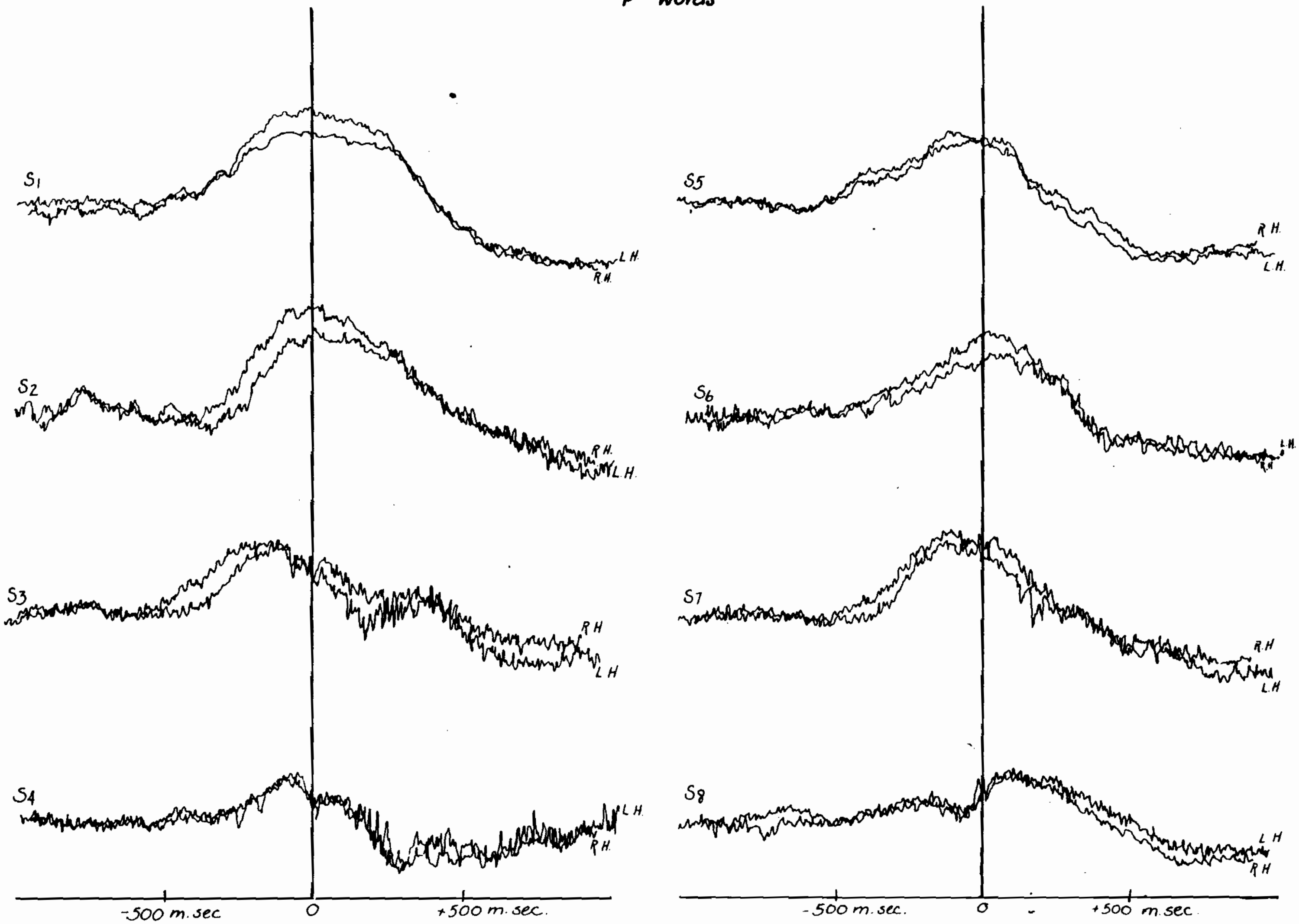


Figure 2

Mild Stutterers
(p) words

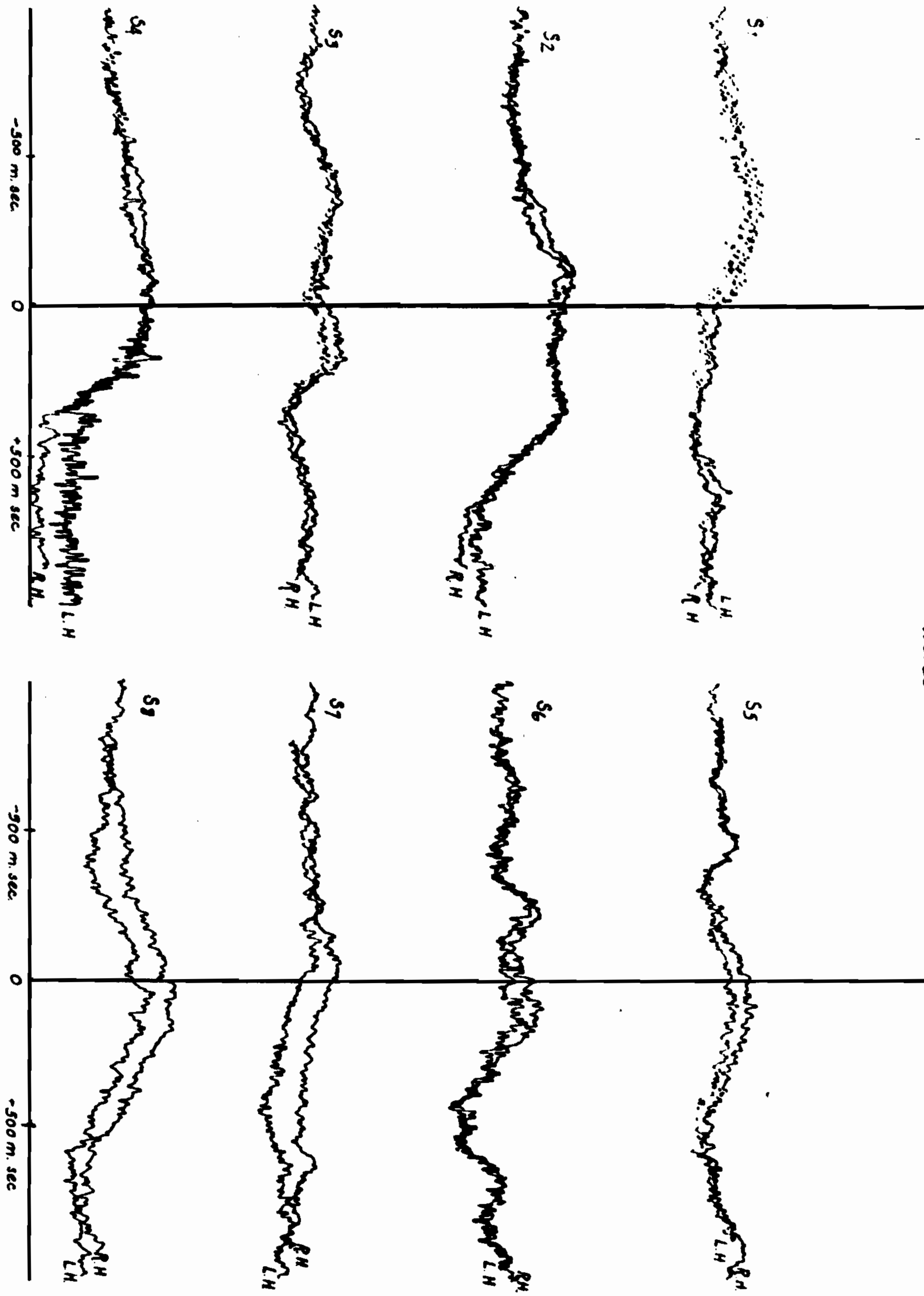
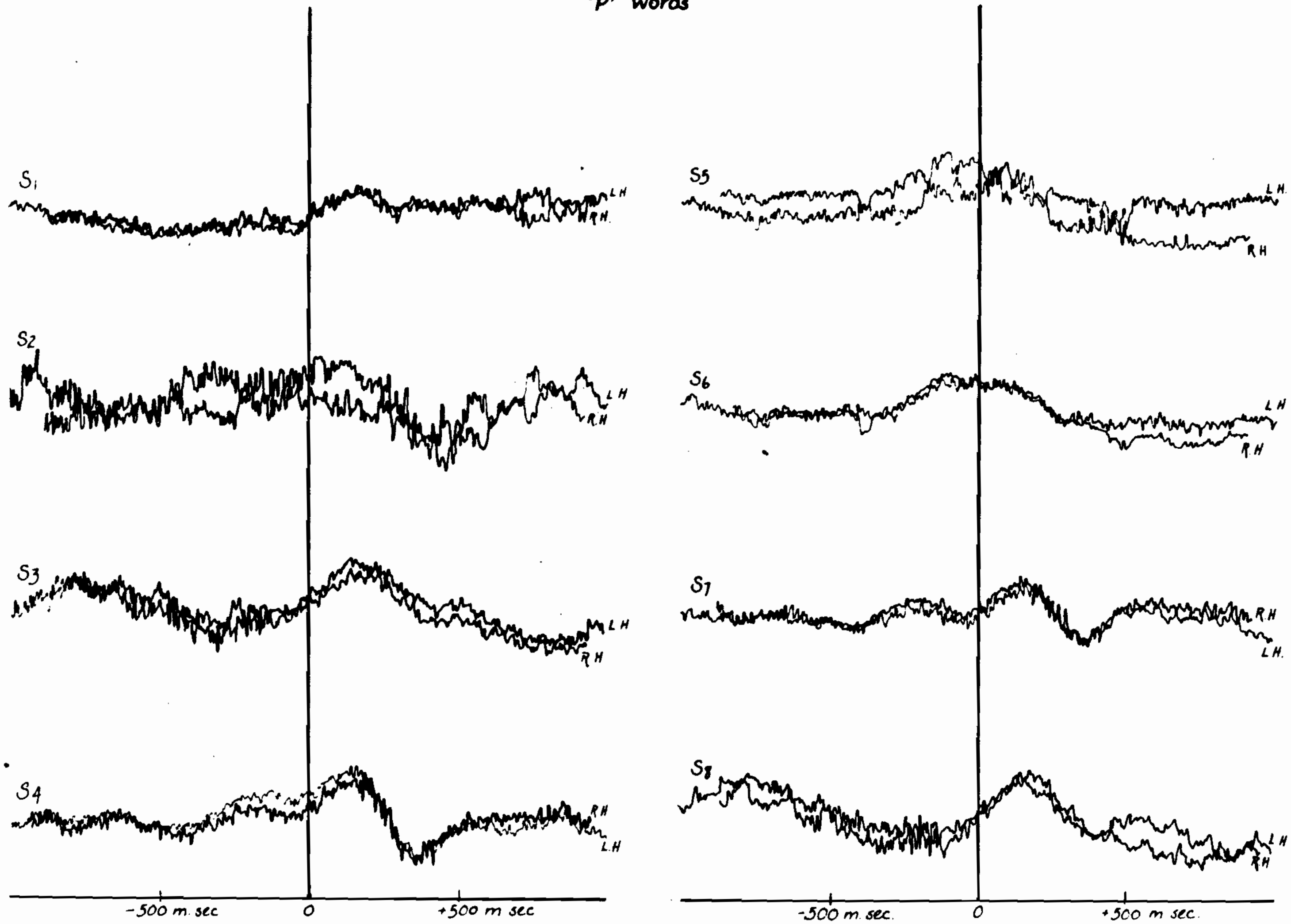


Figure 3

Severe Stutterers
'p' words



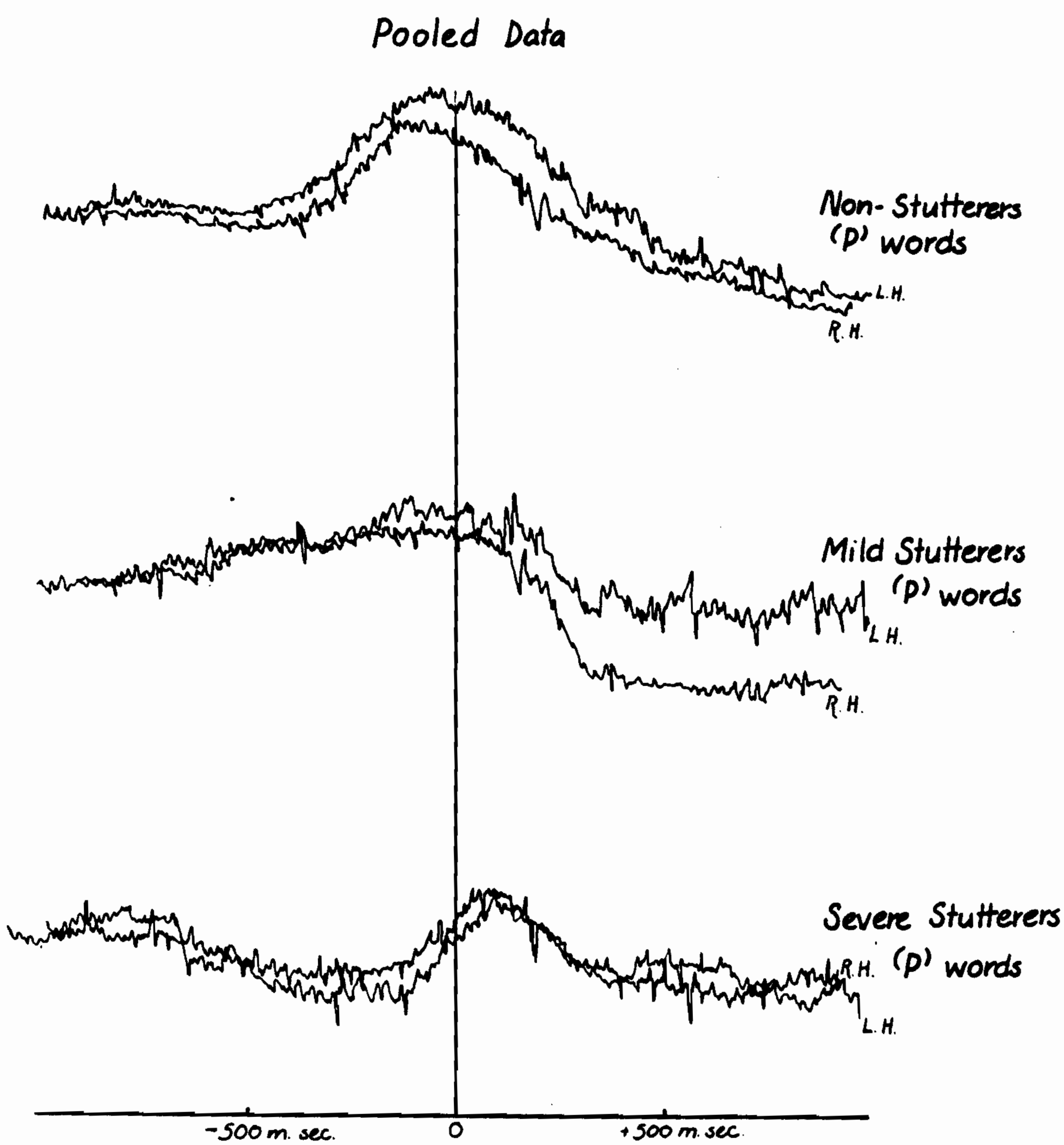

Pooled Data
Non- Stutterers
(p) words
L.H.
R.H.
Mild Stutterers
(p) words
L.H.
R.H.
Severe Stutterers
(p) words
R.H.
L.H.
-500 m. sec.
0
+500 m. sec.

Figure 4

TABLE 1—NORMAL SPEAKERS

Mean Responses in Microvolts for each Hemisphere, under each Condition for each Time Period.

Conditions	H	-250	-187.5	-125	-62.5	0	62.5	125	187.5	Total Time
'p'words	R	11.17	12.71	12.08	8.73	12.13	14.33	12.89	8.78	11.60
	L	12.91	13.55	13.50	11.47	17.10	19.30	17.62	12.88	13.54
't' words	R	6.92	7.98	7.21	2.52	3.32	9.37	10.43	9.08	7.10
	L	8.03	10.76	10.60	5.26	5.68	13.02	14.05	12.91	10.38
'k' words	R	11.90	11.86	11.65	10.96	10.96	10.73	12.01	11.70	11.47
	L	12.71	14.68	14.62	13.88	15.25	16.92	16.31	14.13	14.81
'p'syllables	R	9.83	13.08	14.15	11.23	10.45	10.25	10.45	8.32	10.97
	L	14.07	16.92	19.02	18.56	20.45	20.87	19.90	14.00	17.97
't'syllables	R	6.36	6.67	6.16	7.12	9.40	10.85	12.03	10.03	8.64
	L	7.97	10.30	11.03	12.15	13.71	16.06	16.38	13.02	12.57
'k'syllables	R	9.68	13.47	12.90	11.30	11.80	13.45	15.67	14.26	12.81
	L	16.00	19.42	18.43	20.32	22.71	24.75	24.58	19.86	20.75
Total R+L		10.59	12.61	12.61	11.12	12.74	14.99	15.19	12.41	12.71
Total Cond.	R	9.31	10.96	10.69	8.65	9.67	11.50	12.25	10.36	10.43
	L	11.94	14.27	14.53	13.61	15.81	18.48	18.14	14.47	15.15

TABLE 2

Mean Responses in Microvolts for each Hemisphere under each Condition for each Time Period.

Results for group 2 - Mild Stutterers

Conditions	H	-250	-187.5	-125	-62.5	0	62.5	125	187.5	Total Time
'p' words	R	1.35	2.12	3.83	2.03	2.90	1.43	0.11	-1.35	1.89
	L	5.17	7.53	10.38	10.86	12.28	12.12	11.98	10.55	10.10
't' words	R	2.02	1.26	-0.53	-1.17	2.36	4.63	4.33	1.15	1.75
	L	1.23	1.85	-0.31	-1.46	3.77	8.13	10.96	8.46	4.07
'k' words	R	3.20	3.22	0.63	-0.43	3.33	4.57	4.56	2.47	2.69
	L	2.67	3.43	1.48	2.33	6.35	8.28	8.51	7.52	5.07
'p' syllables	R	6.20	8.40	9.60	8.80	9.10	8.51	6.56	4.97	7.76
	L	5.53	8.52	9.91	8.28	7.95	6.63	5.00	3.00	6.85
't' syllables	R	2.51	3.01	1.64	3.55	5.81	7.73	8.30	9.53	5.26
	L	5.00	5.00	2.62	2.72	5.38	6.28	7.86	8.33	5.39
'k' syllables	R	-1.46	-1.95	-3.15	-2.57	3.72	7.68	9.28	8.95	2.56
	L	0.62	-1.78	-3.10	-2.50	4.28	8.50	11.01	11.93	3.62
Total R+L		2.83	3.38	2.75	2.53	5.60	7.04	7.37	6.29	4.72
Total Cond.	R	2.30	2.67	2.01	1.70	4.53	5.76	5.52	4.28	3.59
	L	3.37	4.09	3.50	3.37	6.67	8.32	9.22	8.30	5.85

TABLE 3

Mean Responses in Microvolts for each Hemisphere under each Condition for each Time Period.

Results for group 3 - Severe Stutterers

Conditions	H	-250	-187.5	-125	-62.5	0	62.5	125	187.5	Total Time
'p' words	R	6.27	7.20	6.93	6.73	8.31	10.22	11.71	10.27	8.45
	L	3.40	4.20	4.35	4.65	5.78	8.61	11.41	11.36	6.72
't' words	R	2.40	0.55	-0.6	0.23	7.40	15.63	19.58	16.88	7.74
	L	2.17	2.40	3.90	4.37	12.78	19.75	22.11	19.12	10.82
'k' words	R	2.07	0.87	-1.66	-0.80	8.90	15.82	16.48	14.87	7.06
	L	1.31	0.73	-1.30	-1.41	4.61	9.17	10.86	10.28	4.28
'p' syllables	R	8.60	10.61	9.46	7.02	10.17	11.77	12.12	8.07	9.72
	L	8.13	10.70	8.95	8.35	11.43	13.53	11.26	6.88	9.90
't' syllables	R	1.93	1.18	-0.61	-1.27	5.78	10.71	11.13	10.02	4.85
	L	3.71	1.12	-0.51	-1.18	4.87	10.42	12.66	9.61	5.08
'k' syllables	R	-1.32	-1.36	-0.78	-0.53	7.12	12.46	16.01	16.11	5.96
	L	-1.37	-1.21	-2.27	-2.55	4.91	8.71	11.57	10.35	3.51
Total R+L		3.10	3.08	2.15	1.96	7.67	12.23	13.90	11.23	7.00
Total Cond.	R	3.32	3.17	2.12	1.89	7.95	12.77	14.51	12.70	7.29
	L	2.89	2.99	2.18	2.03	7.40	11.70	13.31	11.27	6.71

TABLE 4

Mean Responses in Microvolts for each Hemisphere, under each Condition, for each Time Period.

Results for Combined Groups.

Conditions	H	-250	-187.5	-125	-62.5	0	62.5	125	187.5	Total Time
'p' words	R	6.26	7.34	7.61	5.84	7.78	8.66	8.02	5.90	7.17
	L	7.16	8.42	9.41	8.99	11.29	13.35	13.67	11.59	10.51
't' words	R	3.78	3.26	2.02	0.52	4.36	9.87	11.44	9.03	5.53
	L	3.81	5.00	4.73	2.72	7.41	13.63	15.70	13.49	8.31
'k' words	R	5.72	5.31	3.54	3.24	7.73	10.37	11.04	9.68	7.07
	L	5.56	6.28	4.93	4.93	8.73	11.25	11.89	10.64	8.02
'p' syllables	R	8.21	10.69	11.07	9.01	9.90	10.17	9.71	7.12	9.48
	L	9.26	12.04	12.62	11.73	13.27	13.67	12.05	7.96	11.57
't' syllables	R	3.60	3.62	2.40	3.13	6.99	9.76	10.48	9.86	6.23
	L	5.56	5.47	4,38	4.56	7.98	10.92	12.30	10.32	7.68
'k' syllables	R	2.30	3.38	2.99	2.73	7.54	11.19	13.65	13.10	7.11
	L	5.08	5.47	4.35	8.45	10.63	14.98	15.72	14.04	9.84
Total R+L		5.52	6.35	5.83	5.40	8.67	11.42	12.20	10.22	8.17
Total Cond.	R	4.97	5.60	4.94	4.08	7.38	10.01	10.76	9.11	7.10
	L	6.07	7.11	6.73	6.33	9.96	12.83	13.64	11.34	9.25

-62.5 msec., 0 msec., +62.5 msec., +125 msec., +187.5 msec., with respect to speech onset). The results of this analysis of variance are summarized in Table 5, and the mean values for each comparison can be found in Tables 1-4.

Main Effects

Although the main effects for GROUP and CONDITION were not statistically significant, the main effects for HEMISPHERE and TIME were significant at the .01 and .001 levels respectively.

Hemisphere. (H: $F(11,21) = 8.0$, $p < .01$) Left hemisphere responses ($\bar{X} = 9.24$ microvolts) were larger in amplitude than right hemisphere responses ($\bar{X} = 7.41$ microvolts). This result is represented in Figure 5.

Time. The second significant main effect was that for Time (T: $F(7,147) = 8.3$, $p < .001$). Inspection of this effect which is depicted in Figure 6, suggests that the greatest change in response voltage occurred between Time 4 (62.5 milliseconds prior to speech onset) and Time 6 (62.5 milliseconds following speech onset). This was confirmed by an a posteriori Newman Keuls Test (Winer, 1962) of this main effect (Table 6) which indicated that response amplitudes measured at points before speech onset were significantly smaller than the responses measured at three points following speech onset.

TABLE 5

Analysis of Variance for response amplitude under each condition at time periods from 250 milliseconds prior to speech onset 187.5 milliseconds after speech onset.

GROUP (G) X HEMISPHERE (H) X CONDITIONS (C) X TIME (T)

	Source	df	Mean Square	F	P
1.	Groups (G)	2	13267.0	1.8	n.s.
2.	Hemispheres (H)	1	2628.7	8.0	.01
3.	Conditions (C)	5	725.8	1.0	n.s.
4.	Times (T)	7	2281.5	8.3	.001
5.	S (G)	21	7101.5		
6.	GH	2	1359.3	4.1	.05
7.	GC	10	676.9	1.0	n.s.
8.	HC	5	70.0	0.6	n.s.
9.	GT	14	420.7	1.5	n.s.
10.	HT	7	27.9	2.3	.05
11.	CT	35	208.1	2.7	.001
12.	SH (G)	21	327.1		
13.	SC (G)	105	668.9		
14.	ST (G)	147	247.7		
15.	GHC	10	295.9	2.8	.01
16.	GHT	14	31.9	2.6	.01
17.	GCT	70	48.8	0.6	n.s.
18.	HCT	35	13.6	1.5	.05
19.	SHC (G)	105	104.1		
20.	SHT (G)	147	12.1		
21.	SCT (G)	735	74.5		
22.	GHCT	70	11.0	1.2	n.s.
23.	SHCT (G)	735	8.9		

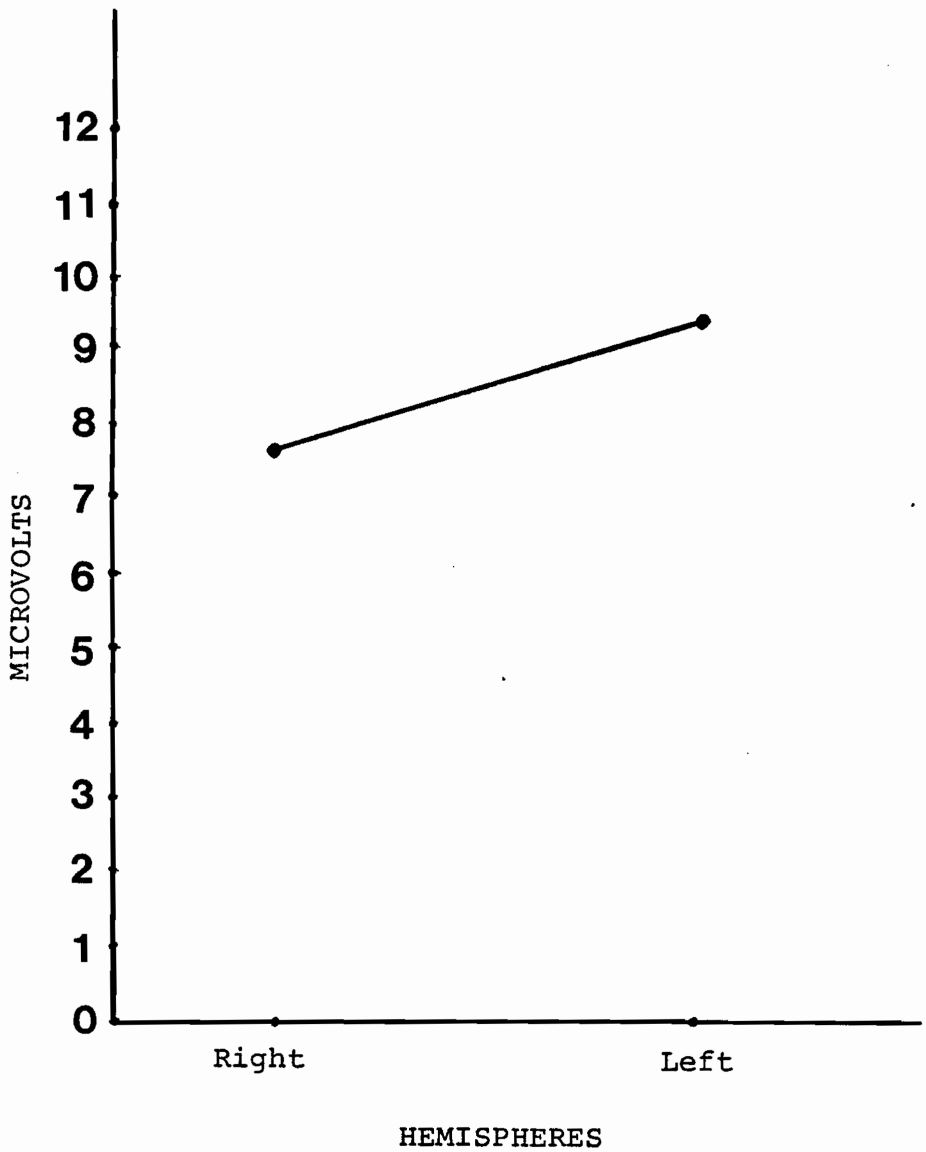


FIGURE 5

Main Effect for Hemispheres

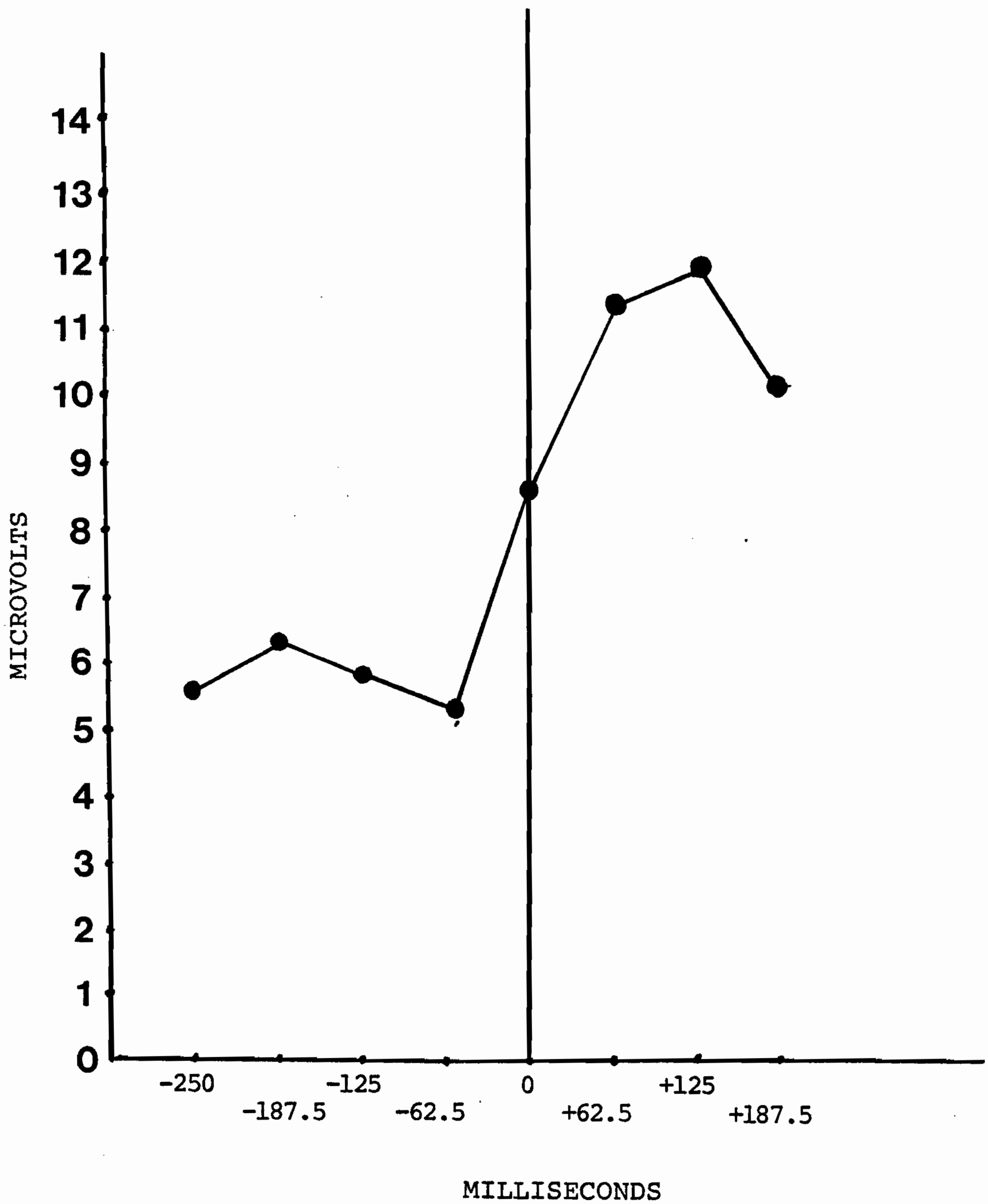


FIGURE 6

Main Effect for Time

TABLE 6

Newman-Keuls Test of TIME as a Main Effect

Time T1 250 milliseconds prior to speech onset (SO)
Time T2 187.5 milliseconds prior to (SO)
Time T3 125 milliseconds prior to (SO)
Time T4 62.5 milliseconds prior to (SO)
Time T5 (SO)
Time T6 62.5 milliseconds following (SO)
Time T7 125 milliseconds following (SO)
Time T8 187.5 milliseconds following (SO)

ORDER	1	2	3	4	5	6	7	8
TIMES	T4	T1	T3	T2	T5	T8	T6	T7
MEAN	5.212	5.529	5.841	6.363	8.677	10.234	11.426	12.161
	T4	T1	T3	T2	T5	T8	T6	T7
T4	---	0.324ns	0.643ns	1.178ns	3.546ns	5.141*	6.361*	7.067*
T1		----	0.319ns	0.853ns	3.333ns	4.817*	6.337*	6.7433*
T3			----	0.534ns	2.103ns	4.497*	5.717*	6.424*
T2				----	2.368ns	3.963*	5.183*	5.889*
T5					----	1.594ns	2.814ns	3.521*
T8						----	1.220ns	1.926ns
T6							----	0.7062ns
T7								----

* .05
** .01

Two-Way Interactions

Although the interactions of GROUP X CONDITION, HEMISPHERE X CONDITION, and GROUP X TIME were not statistically significant, GROUP X HEMISPHERE, CONDITION X TIME, and HEMISPHERE X TIME were significant at the .05, .05 and .01 levels respectively.

Group X Hemisphere. As predicted, this interaction was significant (GH: $F(2,21) = 4.1$, $p < .05$). The interaction is depicted in Figure 7 which suggests that the left hemisphere response was much larger than the right hemisphere response for the normal speaking group, with a similar but smaller difference for the mild stutterers, and a very small difference in the opposite direction for severe stutterers. An a posteriori test of Simple Effects (Keppel, 1973) shown in Table 7, was carried out to test the significance of the differences between groups for each hemisphere and between hemispheres for each group. The only significant difference found was the difference between hemispheres for the normal speaking group. No differences between groups for the separate hemispheres were statistically significant.

Hemisphere X Time. This interaction (HT: $F(7,147) = 2.3$ $p < .05$), as shown in Figure 8 indicates that although the change in amplitude over time appears to be the same for the two hemispheres, the trends were sufficiently different to

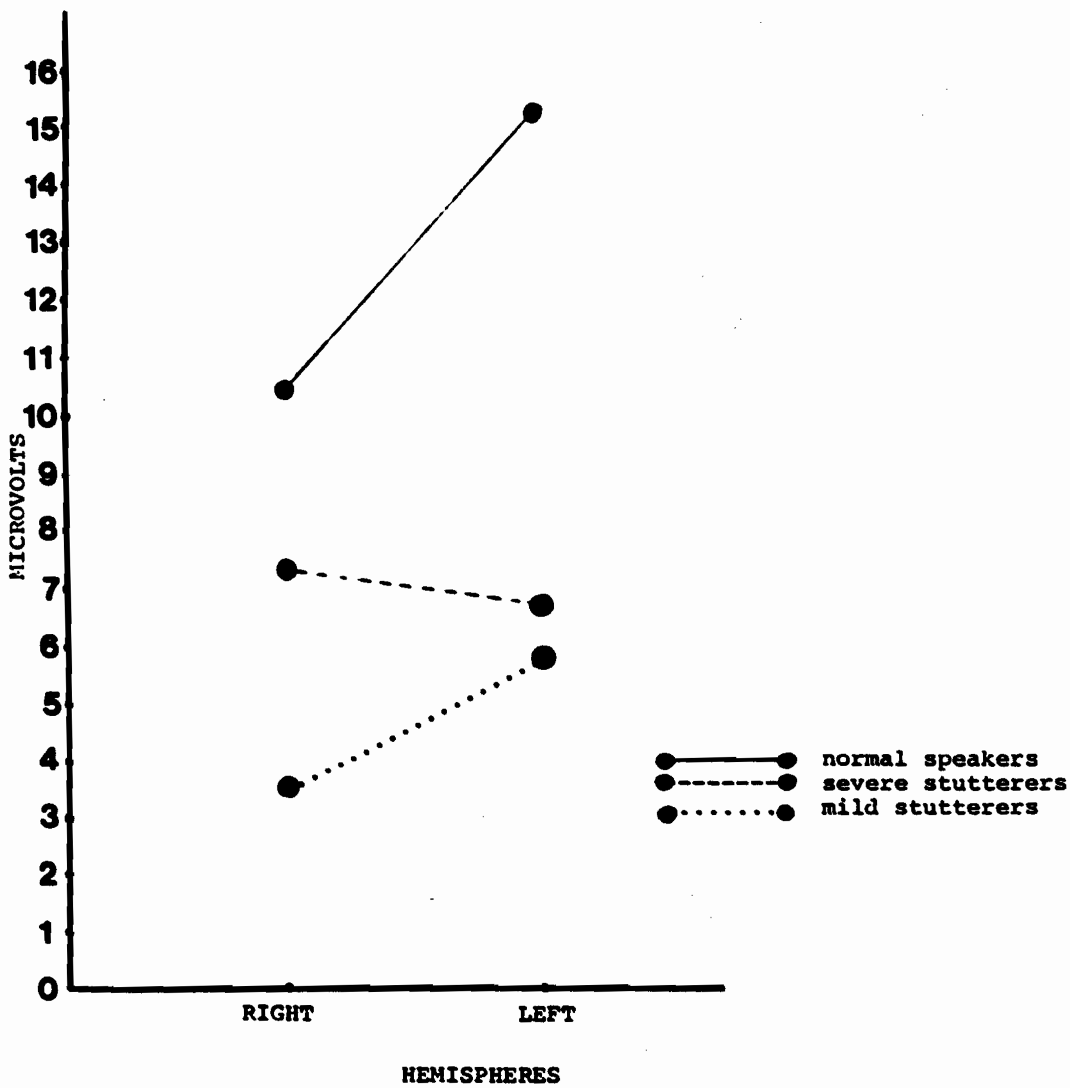


FIGURE 7

Interaction of Groups and Hemispheres

TABLE 7

Test of Simple Effects for a GROUP X HEMISPHERE interaction

	Normal Speakers	Severe St.	Mild St.
Left Hemisphere	15.16	6.72	5.86
	*		
Right Hemisphere	10.43	7.31	3.60

* .01, $F_{2,23} = 6.44$ (Column effect, Group 1)

Differences are expressed in microvolts

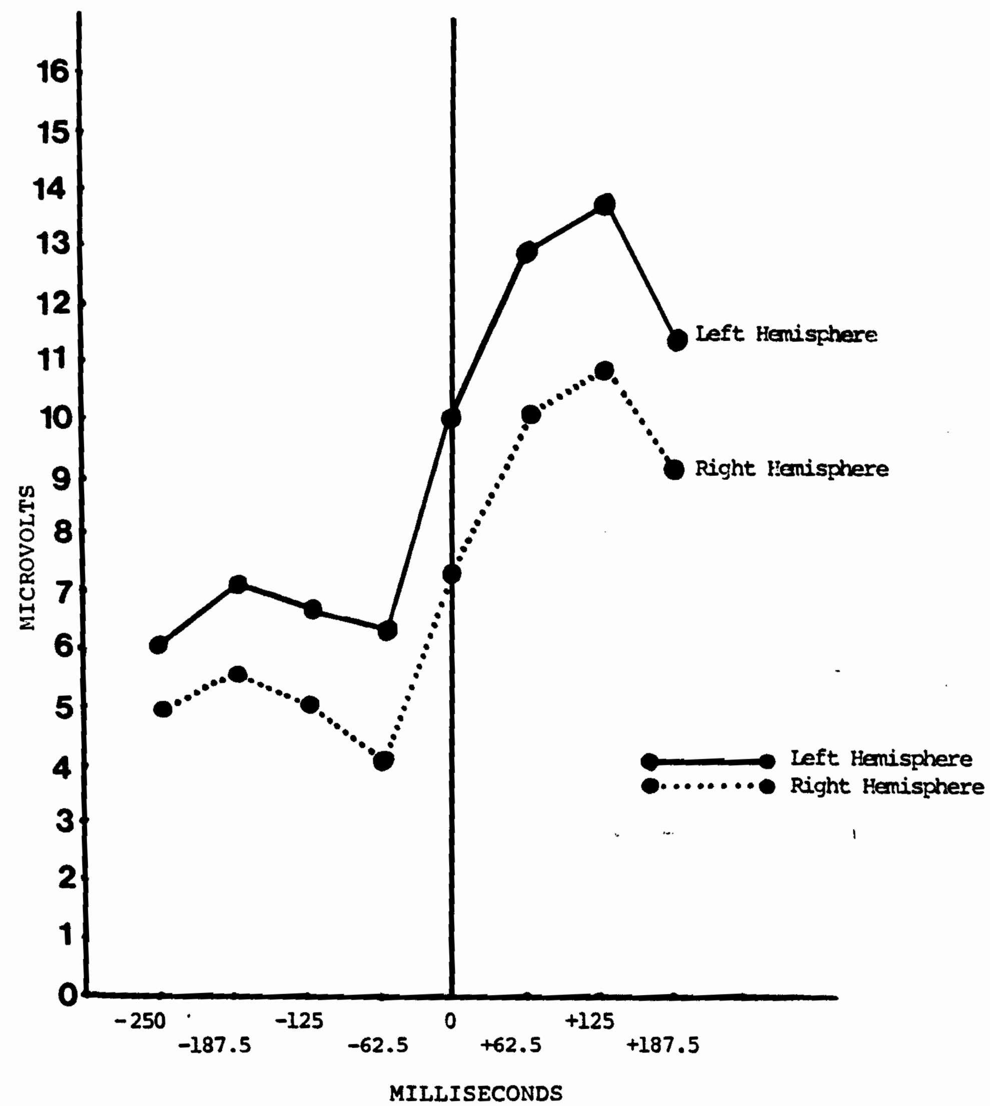


FIGURE 8

Interaction of Hemispheres and Time

produce a significant Hemisphere X Time interaction. An a posteriori test of Simple Effects (Table 8) revealed, as expected, significant changes for each hemisphere over time. However, the differences between hemispheres were significant only for Time 5 (speech onset), Time 6 (+62.5 milliseconds), Time 7 (+125 milliseconds), and Time 8 (+187.5 milliseconds).

Condition X Time. This interaction (CT: $F_{35,735} = 2.79$, $p < .01$) shown in Figure 9, suggests quite different trends over Time for /p/ words and /p/ syllables as compared with the remaining conditions. No further analysis of this interaction was carried out, as the relationship between Conditions and Time was not central to understanding comparisons between groups, which is the central focus of this study.

Three-way Interactions

The Group X Condition X Time interaction was not statistically significant. The three remaining three-way interactions, Group X Hemisphere X Condition; Group X Hemisphere X Time; and Hemisphere X Condition X Time were significant at the .01, .01, and .05 levels, respectively.

Group X Hemisphere X Condition. This interaction (GHC: $F(10,105) = 2.8$, $p < .01$) which is depicted in Figure 10a-f suggests that only the normal speaking group demonstrates hemisphere effects over conditions. Hemisphere effects

TABLE 8

Test of Simple Effects for the Hemisphere X Time Interaction

TIME	-250	-187.5	-125	-62.5	0	62.5	125	187.5
←*→ LEFT HEMIS.	6.0	7.1	6.7	6.3	9.9	12.8	13.5	11.3
					↕ *	↕ *	↕ *	↕ *
←**→ RIGHT HEMIS.	4.9	5.6	4.9	4.0	7.3	10.0	10.7	9.1

Left Hemisphere F = 9.09 ** .01

Right Hemisphere F = 2.27 * .05

T5 F = 2.70 .05

T6 F = 3.13 .05

T7 F = 3.13 .05

T8 F = 2.37 .05

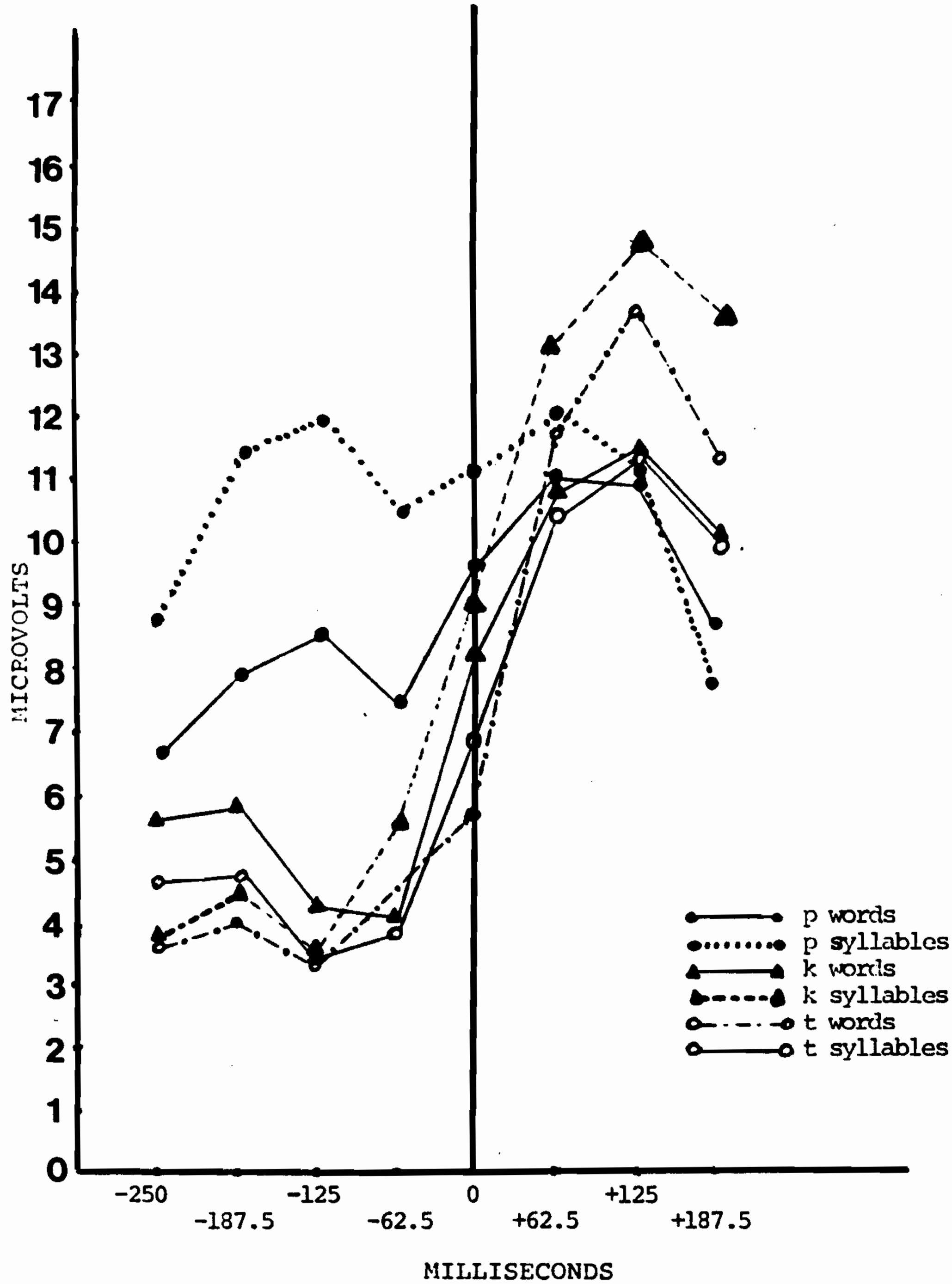


FIGURE 9

Interaction of Conditions and Time

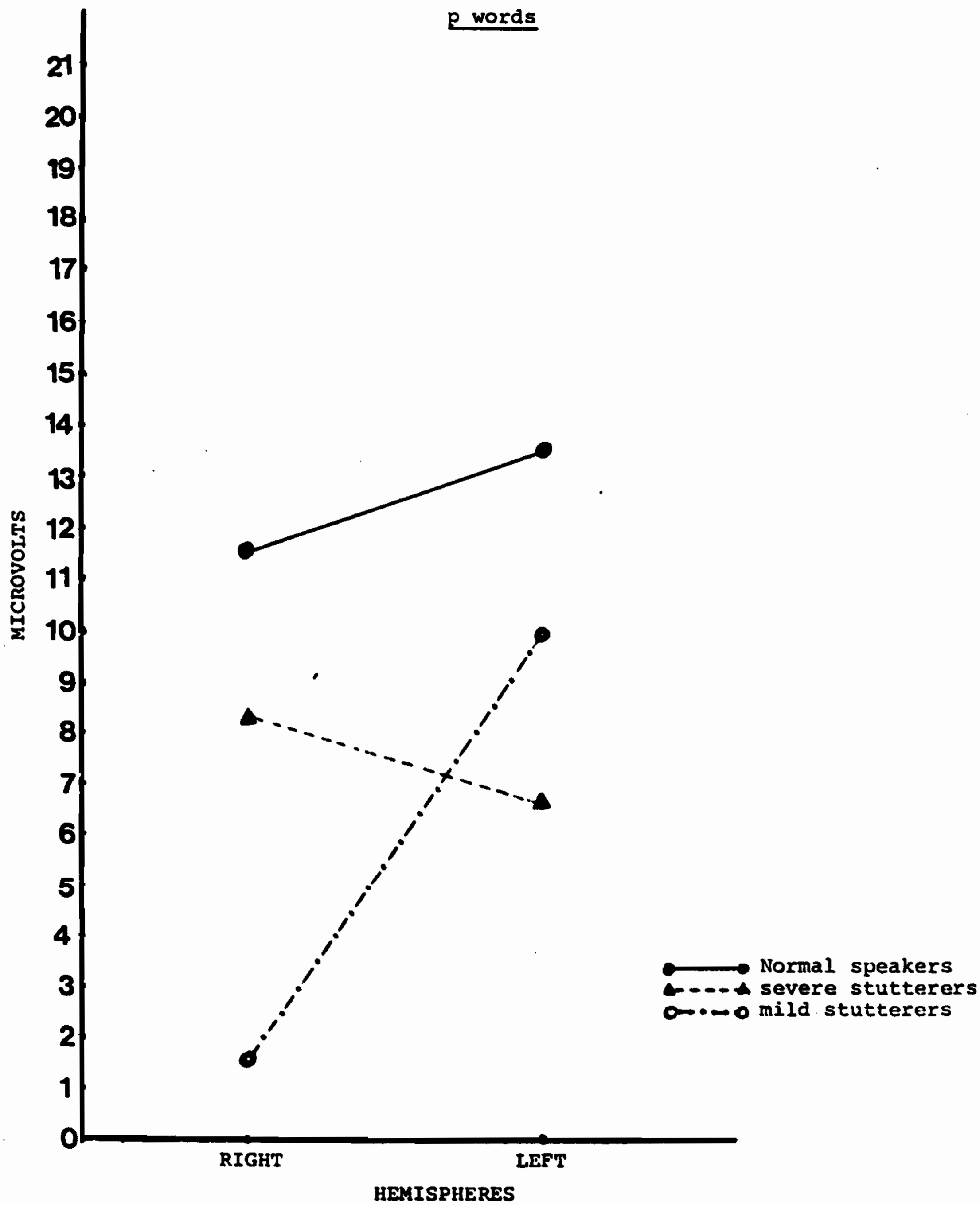


FIGURE 10A

Group, Hemisphere, Condition Interaction for 'p' words

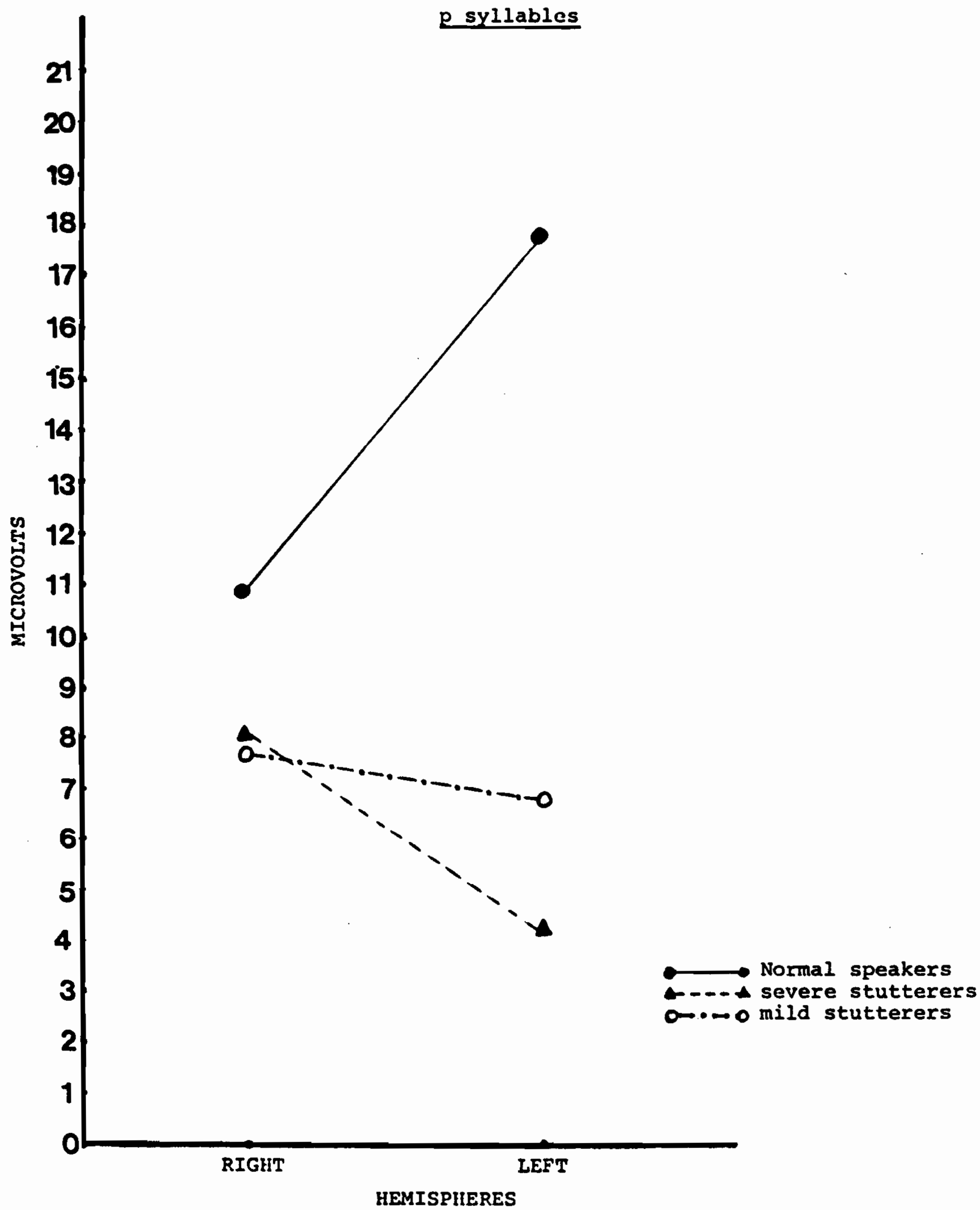


FIGURE 10B

Group, Hemisphere, Condition Interaction for 'p' syllables

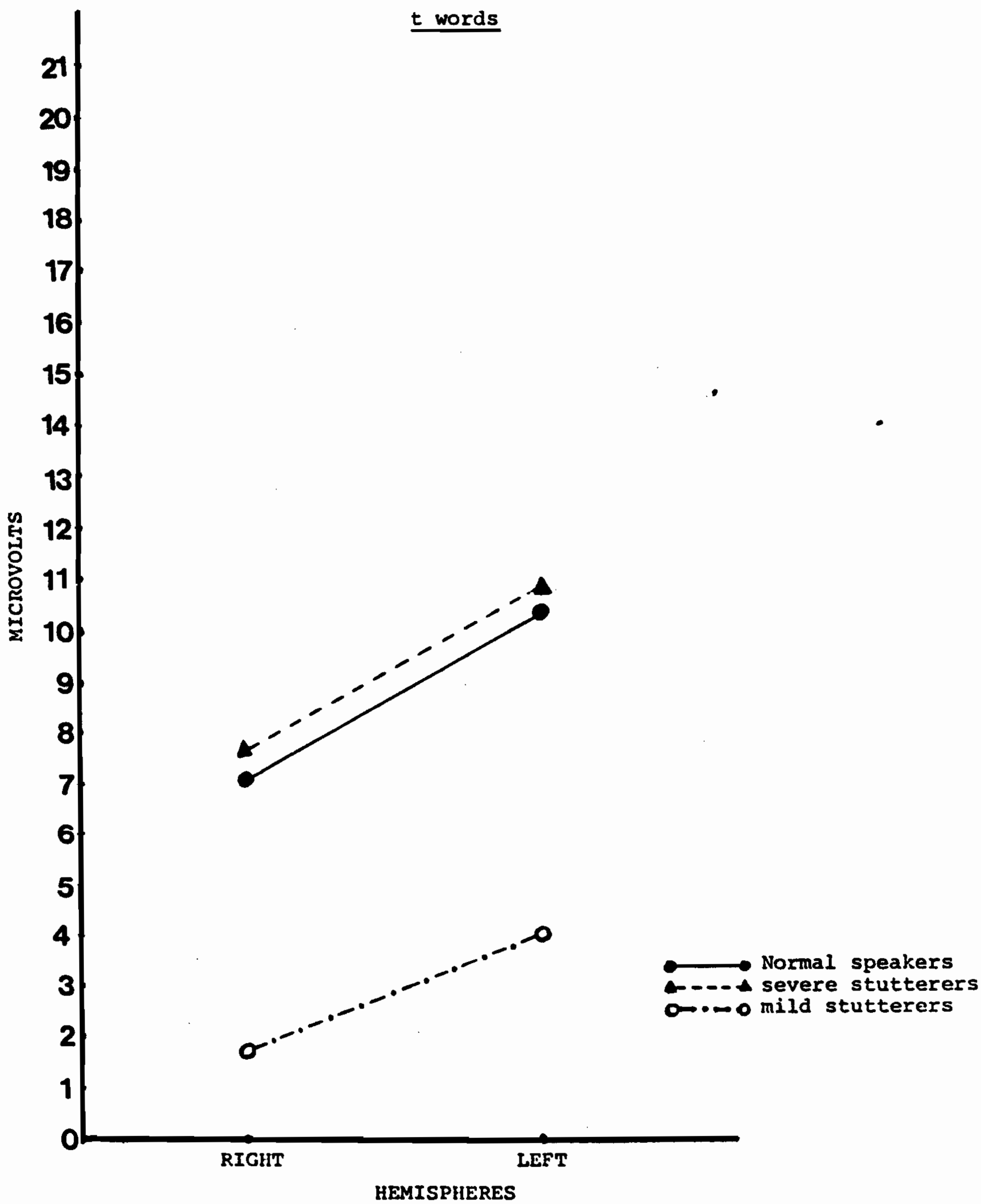


FIGURE 10C

Group, Hemisphere, Condition Interaction for 't' words

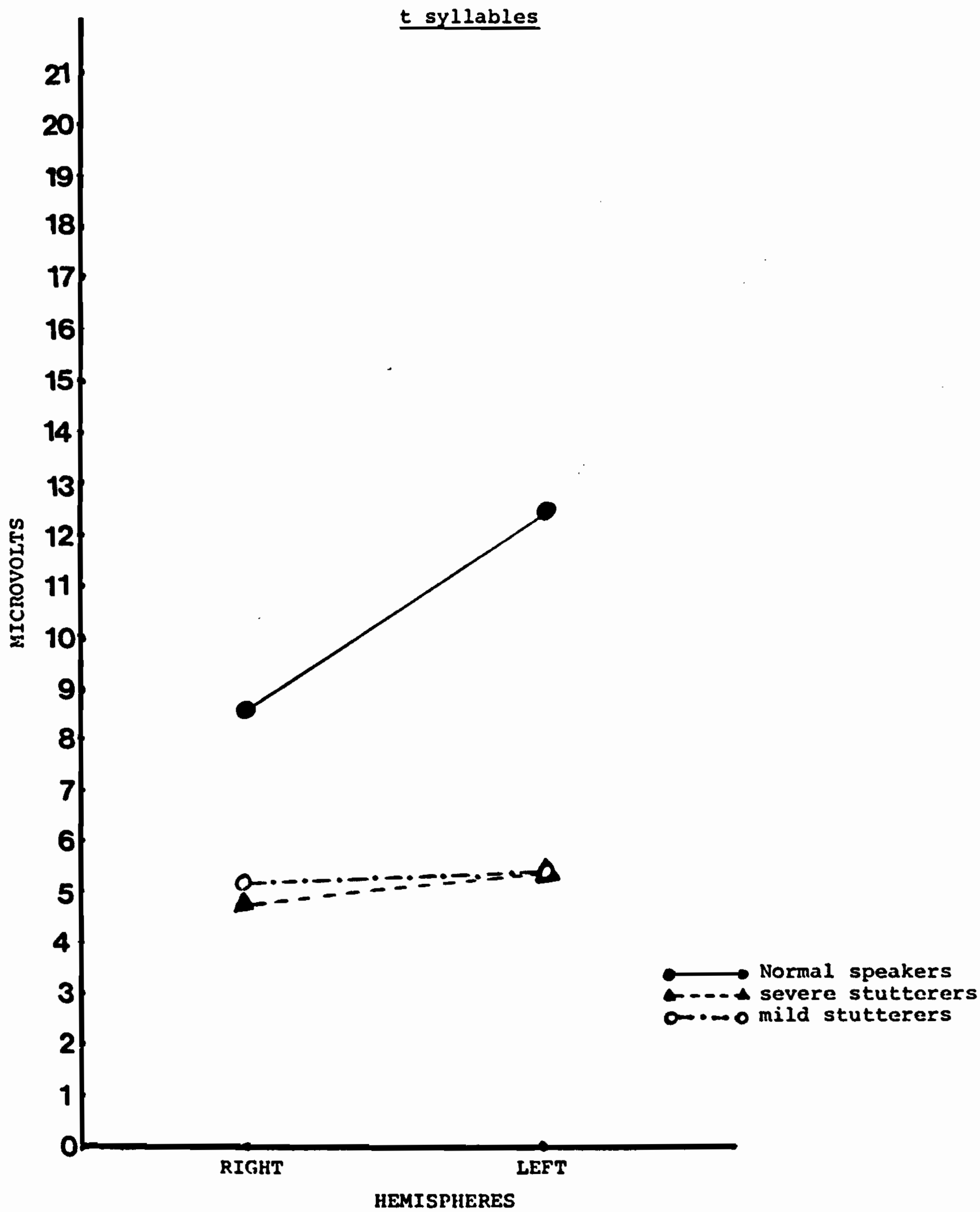


FIGURE 10D

Group, Hemisphere, Condition Interaction for 't' syllables

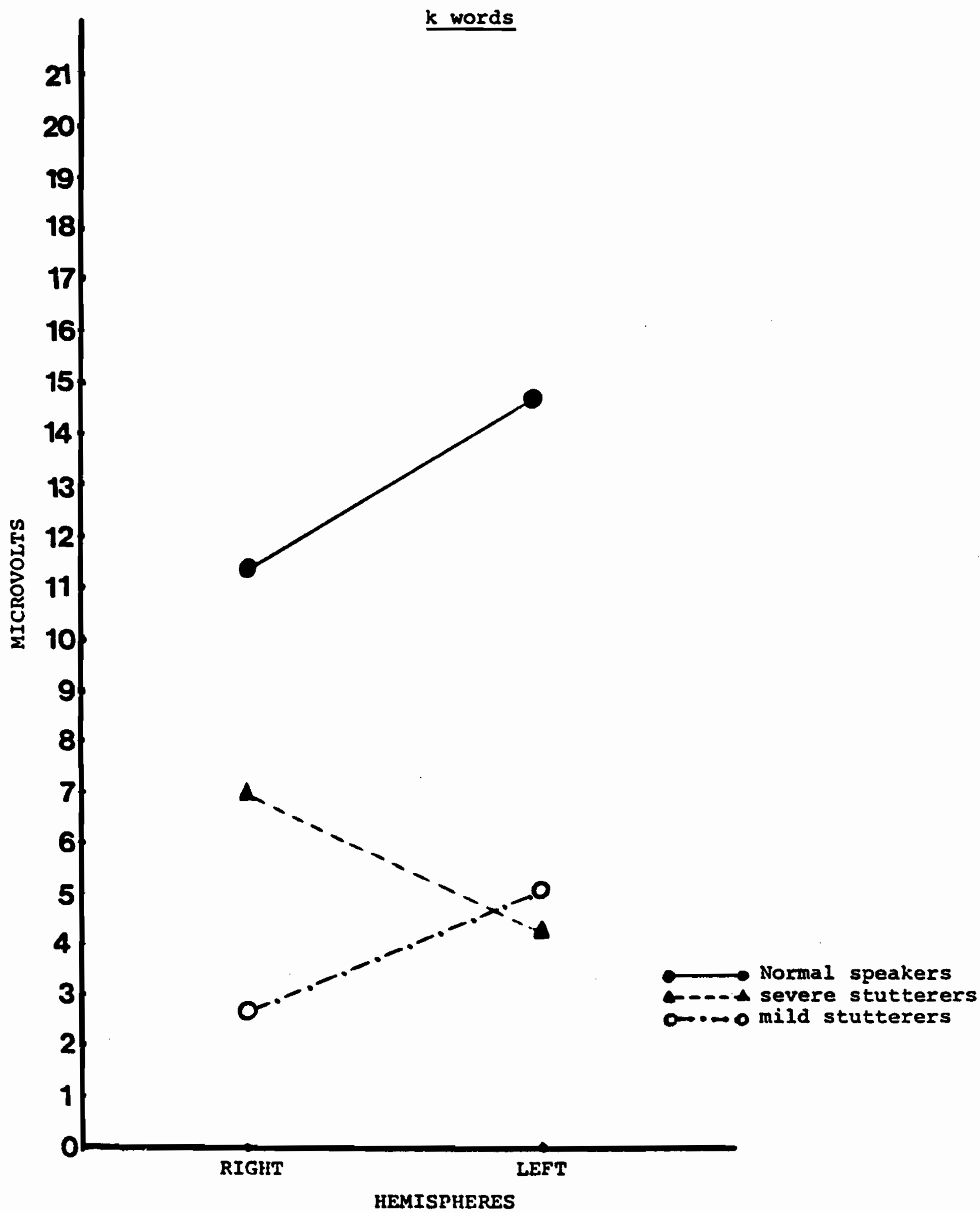


FIGURE 10E

Group, Hemisphere, Condition Interaction for 'k' words

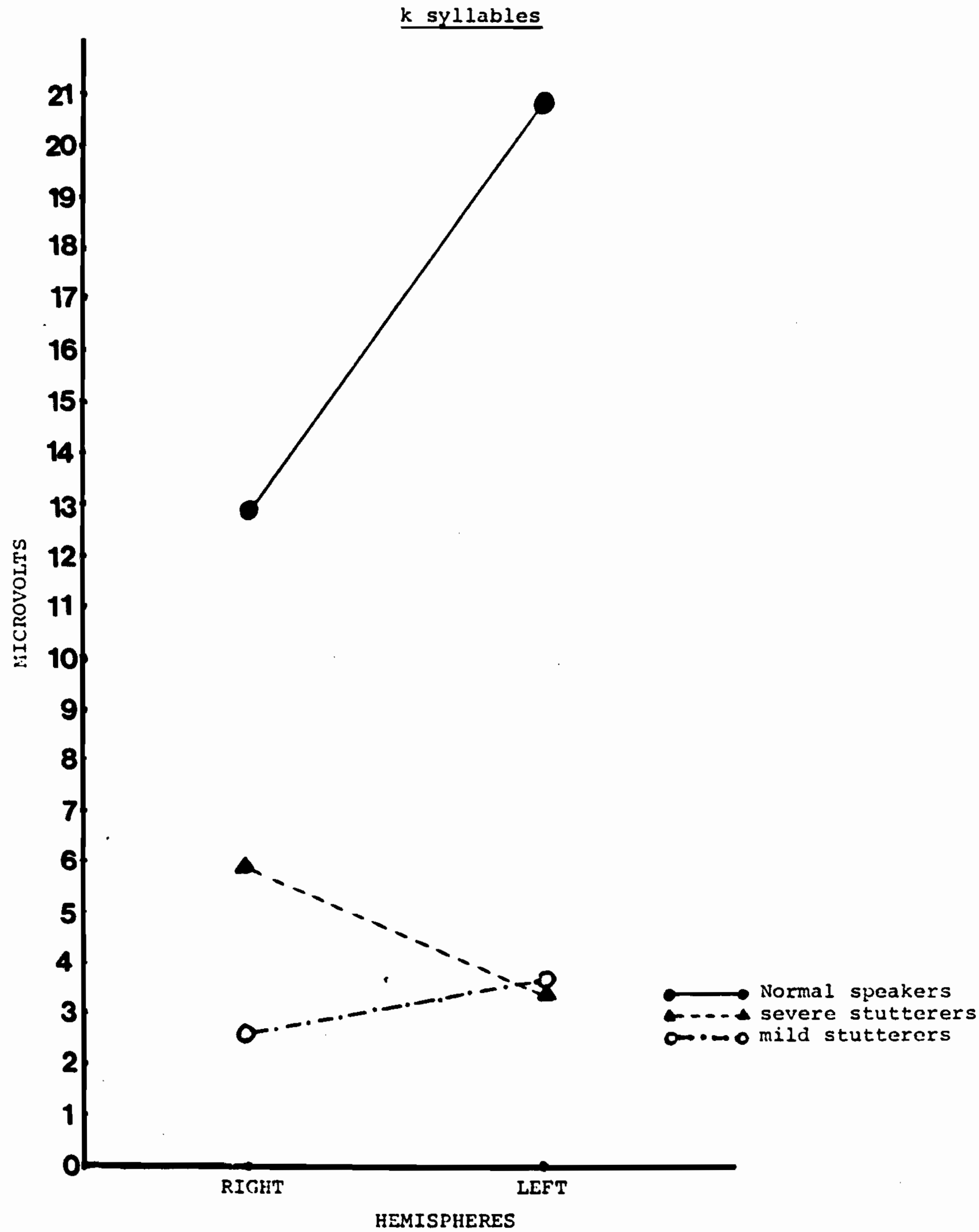


FIGURE 10F

Group, Hemisphere, Condition Interaction for 'k' syllables appear to have varied for both groups of stutterers from one condition to another. A test of Simple Effects (Table 9) showed, however, a significant left-hemisphere superiority only in two conditions for the normal speaking group (i.e., /p/ syllables and /k/ syllables). A significant left hemisphere asymmetry was also noted for the mild stuttering group in the /p/ word condition. According to Table 9, the normal speaking group was significantly different from both groups of stutterers only in Condition 6 (/k/ syllables).

Group X Hemisphere X Time. This interaction (GHT: $F(14, 147) = 2.6$ $p < .01$) as shown in Figure 11, appears to be largely attributable to a smaller change over time in the differences between hemispheres for the normal speaking group than for the stutterers. However, the a posteriori test for Simple Effects (Table 10) indicates instead that the only significant differences between hemispheres occurred for the normal speaking group at speech onset (Time 5) and for the three times following speech onset (62.5 milliseconds, 125 milliseconds, and 187.5 milliseconds). According to Table 10, the differences between hemispheres for normal speaking subjects prior to speech onset were not significantly different.

Hemisphere X Condition X Time. This interaction (HC T: F 35, 105 = 1.5 $p < .05$) is shown in Figure 12 a-c. A test of simple effects indicated that a significant Condition effect

TABLE 9

Test of Simple Effects for Condition X Hemisphere X Group Interaction

	P. WORDS			P SYLLABLES		
Groups	Normal	Severe	Mild	Normal	Severe	Mild
Left H.	14.79	6.72	10.11 ↑ **	17.98 ↑ *	9.90	6.86
Right H.	11.61	8.46	1.56 ↓	10.97 ↓	9.73	7.77
	T WORDS			T SYLLABLES		
Left H.	10.4	10.82	4.0	12.58	5.0	5.4
Right H.	7.0	7.76	1.7	8.58	4.8	5.2
	K WORDS			K SYLLABLES		
				←	*	→
Left H.	14.81	7.78	5.0	↑ ** 20.76	3.51	3.62
Right H.	11.47	7.39	2.6	↓ 12.81	2.4	2.56

* .05
** .01

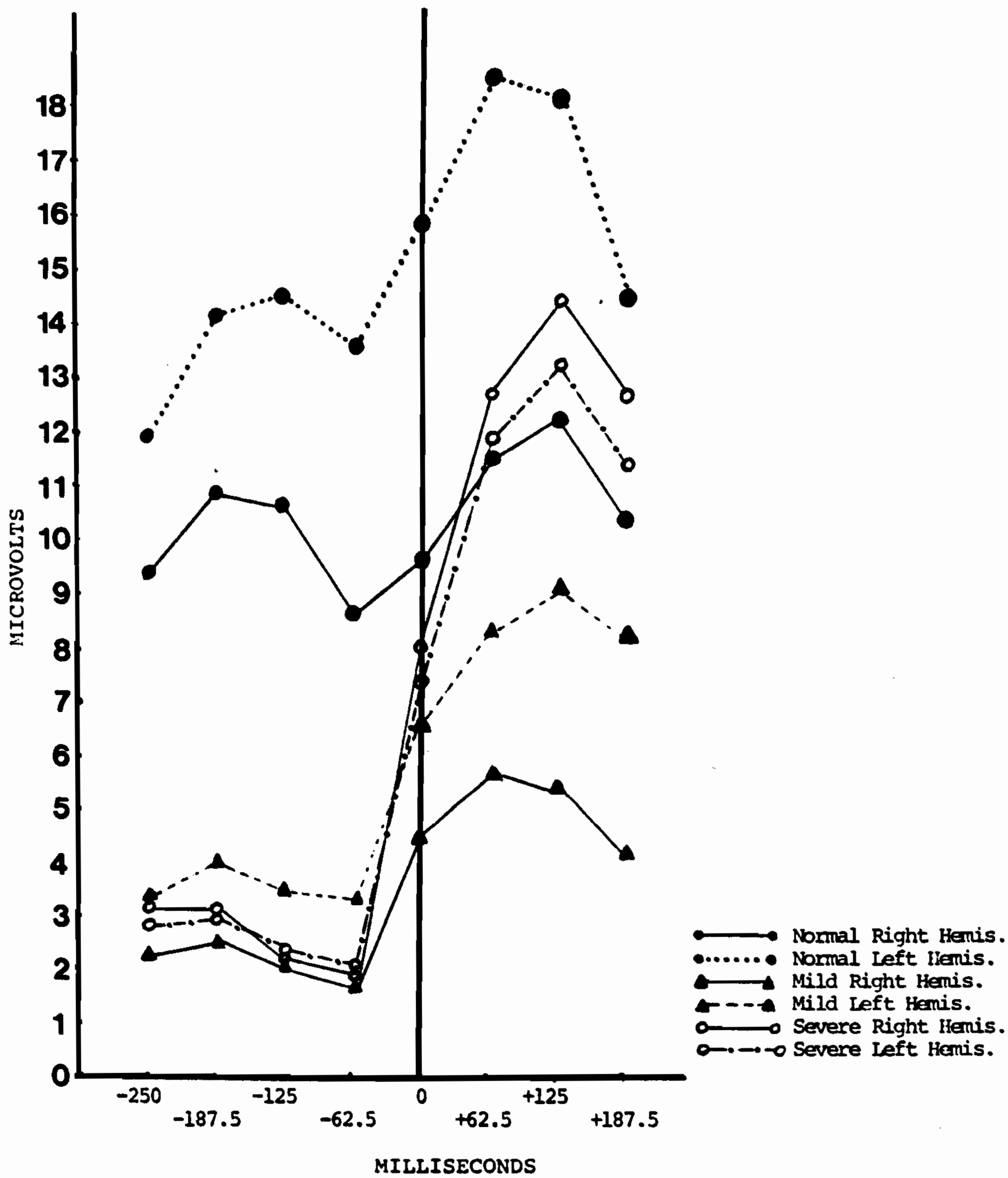


FIGURE 11

Group, Hemisphere and Time Interaction

TABLE 10

Test of Simple Effects for Group X Hemisphere X Time Interaction

TIME	1			5		
Groups	Normal	Severe	Mild	Normal	Severe	Mild
Hemis. L Hemis. R	11.95 9.31	2.89 3.32	3.38 2.30	15.82 ** 9.68	7.40 7.95	6.67 4.53
TIME	2			6		
Hemis. L Hemis. R	14.27 10.96	2.99 3.17	4.09 2.67	18.99 ** 11.50	11.70 12.77	8.33 5.76
TIME	3			7		
Hemis. L Hemis. R	14.53 10.69	2.18 2.12	3.50 2.0	18.14 ** 12.25	13.31 14.51	9.22 5.22
TIME	4			8		
Hemis. L Hemis. R	13.61 8.65	2.030 1.89	3.37 1.70	14.47 * 10.36	11.27 12.70	8.30 4.20

* .05
** .01

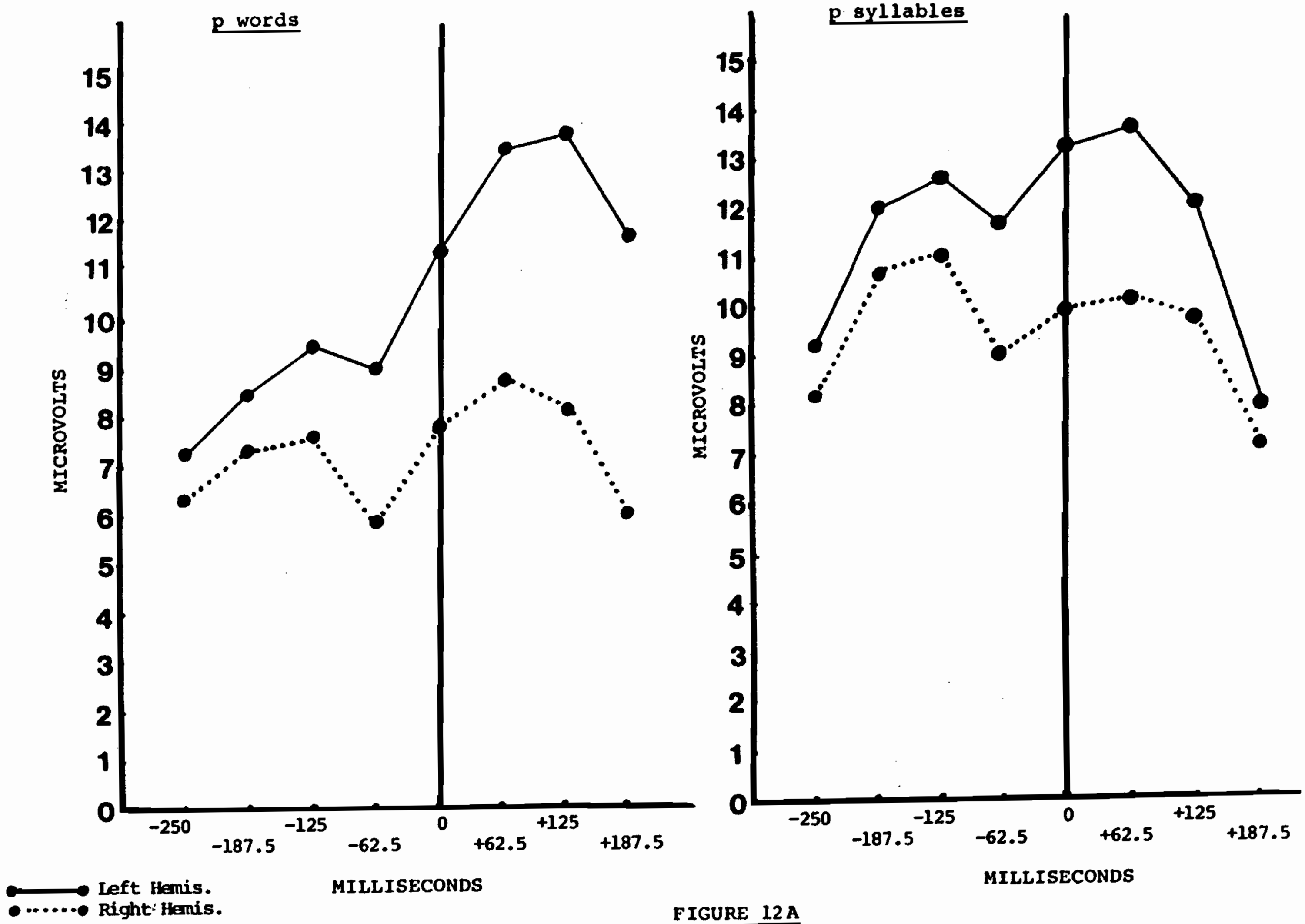


FIGURE 12A

Hemisphere, Condition, Time interaction for 'p' words and 'p' syllables

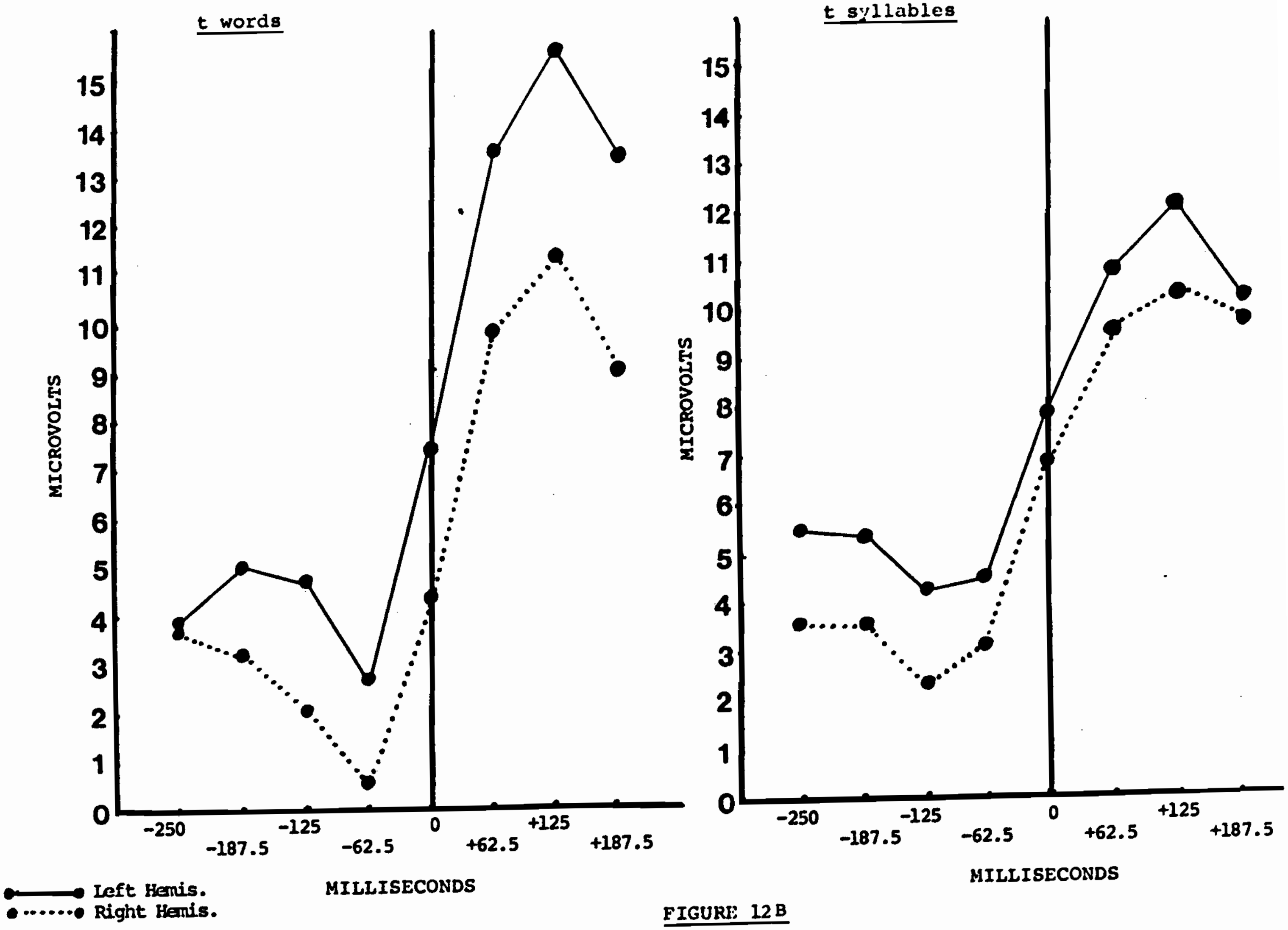


FIGURE 12B

Hemisphere, Condition, Time interaction for 't' words and 't' syllables

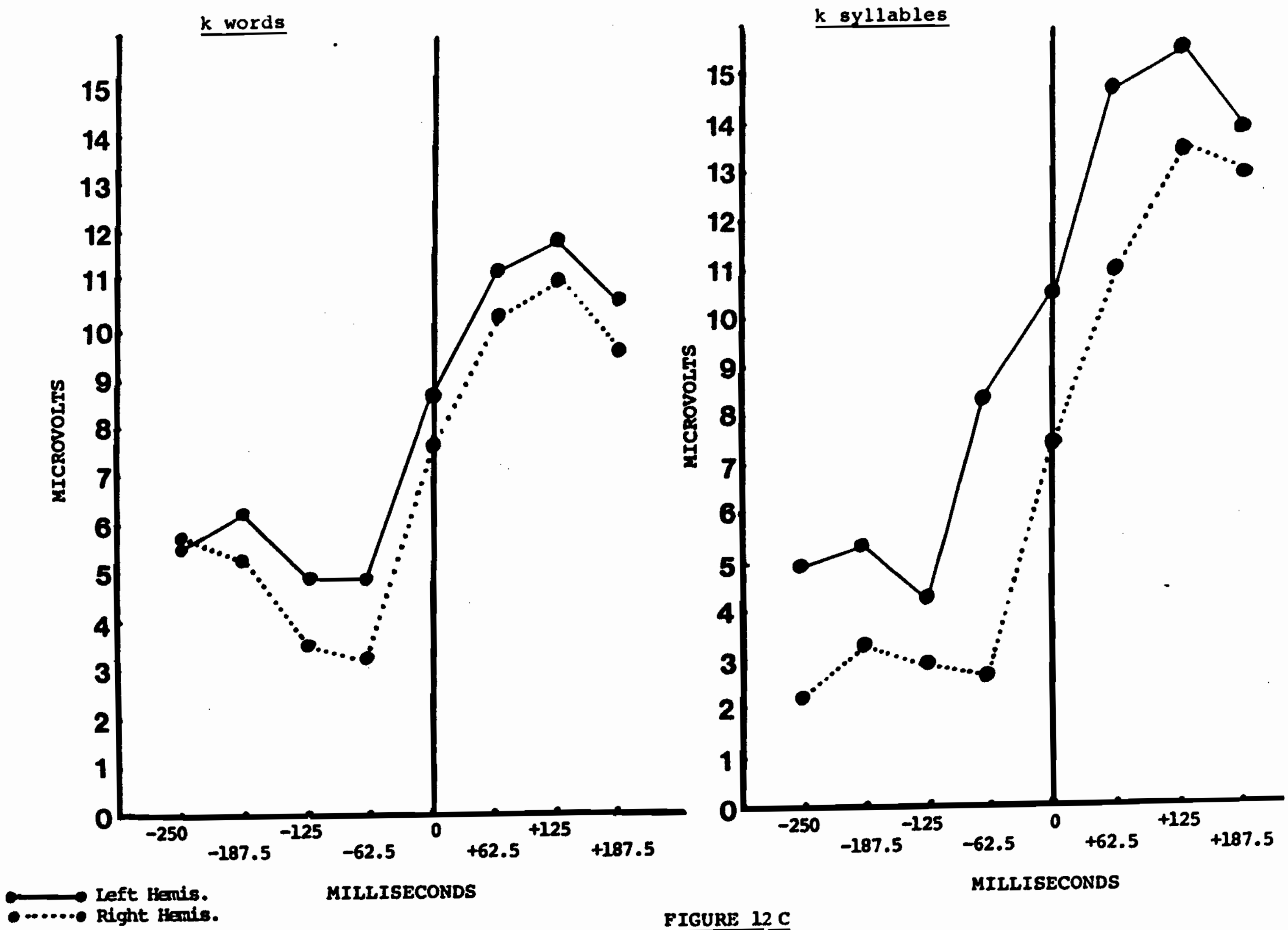


FIGURE 12 C

Hemisphere, Condition, Time interaction for 'k' words and 'k' syllables occurred at Time 5 (speech onset), Time 7 (+ 125 milliseconds), and Time 8 (+ 187.5 milliseconds) for the left hemisphere only. In addition, the left hemisphere response is significantly larger than the right for Times 5, 7 and 8 under certain conditions. At Time 5 (speech onset) the left hemisphere response is significantly larger than the right for /p/ words and /p/ syllables. At Time 7 (125 milliseconds) the left hemisphere response is significantly larger than the right for /t/ words and at Time 8 (187.5 milliseconds the left hemisphere response is significantly larger than the right for /p/ words and /t/ words only, (see Table 11). As this interaction does not include group comparisons it is not of primary interest in interpretation of this study and will not be considered further.

TABLE 11

Test of Simple Effects for Conditions X Hemispheres X Times

Condition	1	2	3	4	5	6
Time 1 - 250 milliseconds						
Left Hemis.	7.1	3.8	5.5	9.2	5.5	5.0
Right Hemis.	6.2	3.7	5.7	8.2	3.6	2.3
Time 2 - 187.5 milliseconds						
Left Hemis.	8.4	5.0	6.2	12.0	5.4	5.4
Right Hemis.	7.3	3.2	5.3	10.7	3.6	3.3
Time 3 - 125 milliseconds						
Left Hemis.	9.4	4.7	4.9	12.6	4.3	4.3
Right Hemis.	7.6	2.0	3.5	11.0	2.4	2.9
Time 4 - 62.5 milliseconds						
Left Hemis.	8.9	2.7	4.9	11.7	4.5	5.0
Right Hemis.	5.8	0.5	3.2	9.0	3.1	2.7
Time 5 - Speech Onset						
Left Hemis.	* .01 11.7	7.4	8.7	13.2	7.9	10.6
Right Hemis.	7.7**	4.3	7.7	9.9**	7.0	7.5
Time 6 + 62.5 milliseconds						
Left Hemis.	13.3	13.6	13.2	13.6	10.9	13.9
Right Hemis.	8.6	9.8	10.3	10.1	9.7	9.4
Time 7 + 125 milliseconds						
Left Hemis.	** .01 13.6	15.7	13.4	12.0	12.3	15.7
Right Hemis.	12.8	10.5**	12.0	10.4	12.0	15.6
Time 8 + 187.5 milliseconds						
Left Hemis.	* .01 11.6	13.5	11.8	7.9	10.3	14.0
Right Hemis.	5.9**	9.0**	9.6	7.1	9.8	11.8

* .01 ** .05

DISCUSSION

Recent studies (Zimmerman and Knott, 1973, 1974) have utilized the averaged electroencephalographic response (AER) technique to re-investigate the claim of Orton and Travis (1927, 1931) that stuttering results from "aberrant inter-hemispheric relationships" (Travis, 1978, p. 278). The purpose of the present study was to use the AER method to gain further information about the nature of hemispheric relationships during speaking in mild and severe stutterers as compared with normal speakers.

This study was intended to test the hypothesis that the normal speakers' AERs would be characterized by greater mean amplitude over the dominant hemisphere prior to and during a speaking task, while stutterers would show either less amplitude asymmetry between hemispheres, or even right hemisphere dominance under the same conditions. It was further hypothesized that the group of severe stutterers would have a smaller margin of dominance than either mild stutterers or normal speakers.

The results confirmed the hypothesis of different degrees of dominance in stutterers on a verbal task, thus providing support for the Orton-Travis Theory. The normal speakers showed a significant left hemisphere dominance just at the time of speech onset and during speech production. Neither the mild nor severe group of stutterers showed any significant left hemisphere dominance before or during fluent speech production.

The present study provided new information about hemispheric dominance in stutterers, since it differed from previous studies with respect to the method of subject selection, the choice of stimuli, and the method of data collection and analysis. In the present study, stutterers were classified as mild or severe on the basis of a pre-experimental frequency of stuttering index, in order to create more homogeneous groups of stutterers and to evaluate Orton and Travis' speculation that severity of stuttering might be related to differences in the hemispheric margin of dominance. Other studies which compared stutterers to non-stutterers have not attempted to group stutterers according to overt stuttering characteristics (Zimmerman and Knott, 1973, 1974; Peters et al, 1974).

The experimental stimuli were monosyllabic words and consonant-vowel syllables. These two types of stimuli represented linguistically meaningful and meaningless materials of similar length. Previous studies either did not use a non-meaningful control condition (Zimmerman and Knott, 1974; Low et al, 1974), compared a series of verbal responses to a non-verbal motor task (Peters et al, 1974), or paired stimuli of varying lengths (McAdam and Whitaker, 1971a).

In the present study, data were collected and analyzed for time periods prior to speech onset as well as during the motor response, while previous studies have analyzed only the data which preceded speech onset. In addition, data were statistically analyzed using analysis of variance, whereas the conclusions of most of the previous studies were based on visual inspection of the data. Although visual inspection of the data in this study indicated that the left hemisphere amplitude was larger than the right prior to speech onset, as previous studies had reported (McAdam and Whitaker, 1971a, etc.), subsequent statistical analysis revealed that these differences did not become significant until speech onset.

The results of the present study confirm the prediction derived from previous research and theory that greater left hemisphere asymmetry will occur during speech production by normal speakers. Specifically, this study supports the early (1927, 1931) predictions of Orton and Travis regarding the relationship between cerebral dominance and stuttering, and contributes new evidence to more recent findings which indicate that stuttering is in some way related to disorders involving the hemispheric balance (Zimmerman and Knott, 1973, 1974). The following discussion will point out the discrepancies between specific predictions, methods, and findings of this study and those of previous studies, as well as the implications for a theory of stuttering.

Relationship of Findings to Previous Studies

It was predicted that normal speakers' AERs would be characterized by greater left hemisphere amplitude prior to and during a speaking task. Significant amplitude differences favoring the left hemisphere in normal right-handed speakers occurred at speech onset and during speech, but not prior to speech. This difference took the form of significantly greater localized activity over the left inferior frontal site than over the corresponding right hemisphere site. The present results for normal speakers will be discussed relative to studies which found left hemisphere asymmetries by analyzing a similar motor response (McAdam and Whitaker, 1971a; Morrell and Huntington, 1972; Szirtes and Vaughan, 1973; Grözinger et al, 1975; Levy, 1977) and also to studies which evaluated the CNV slow potential waveform (Low et al, 1974; Zimmerman and Knott, 1973, 1974). The salient characteristics of these studies are summarized in Table 12, which also includes the present study. As shown by Table 12, the experimental procedures and methods of data analysis varied considerably from study to study.

The subjects of previous studies differed in both sex and handedness. The experimental stimuli differed in length of utterance, initial consonant, and linguistic characteristics related to meaning. Furthermore, some studies compared a verbal stimulus with a non verbal-vocal gesture, others compared a verbal response to a non-verbal motor activity, and in some instances, the response consisted of the multiple repetition of the same stimulus with no corresponding vocal control. The method of response to stimuli presented either auditorily or visually also varied. The responses were either subject-initiated, tape recorded, or experimenter cued. In some studies the subjects formulated

TABLE 12

Studies where left hemisphere asymmetries were found for a motor response.

STUDY	SUBJECTS	STIMULI	RESPONSE	ELECTRODE PLACEMENT	TIME PERIOD MEASUREMENT	METHODS OF DATA ANALYSIS	RESULTS FOR NON STUTTERERS	RESULTS FOR STUTTERERS
McAdam and Whitaker 1971	8 female right-handed	Polysyllabic words and syllables	Self-paced spontaneous initiation of different stimuli	bilateral pre-central Gyri bilateral inferior frontal	1500 msec. prior to and 500 msec. following speech onset	t-test of amplitude asymmetry	greater negative activity at left inferior frontal site for 150 msec. preceding speech onset	
Morrell and Huntington 1972	12 subjects sex not specified, right-handed	Polysyllabic words and syllables	Self-paced spontaneous repetition of the same stimulus; speech responses cued by tape recorded stimuli	bilateral temporo-parietal bil. rolandic bil. frontal bil. anterior temporal central vertex, parietal, occipital; EMG from lower lip, larynx, jaw.	512 or 1024 msec. prior to and 512 or 1024 msec. following speech onset	visual inspection of amplitude asymmetry	slow negative shift beginning 200-500 msec. prior to speech onset, maximal over left posterior cortex	
Szirtes and Vaughan 1973	Sex not specified; Right and left handed	Phonemes and monosyllabic words	Not specified	bilateral inferior frontal bil. temporo-parietal bil. pre-central Gyri nose, cheek, cranial sites for isopotential mapping of amplitude	1000 msec. prior to and 1000 msec. following speech onset	topographic analysis of amplitude characteristics	small, consistent negative shift at dominant hemisphere, depending upon subject's handedness Speech related potentials are maximal over fronto-temporal sites	
Zimmerman and Knott 1973	6 non stutterers 8 stutterers right-handed	Monosyllables Polysyllables	CNV paradigm	Vertex bil. inferior frontal	1500 msec. after presentation of stimulus	visual inspection	negative shift at vertex between presentation of stimulus and signal to respond followed by a negative shift at left inferior frontal site.	During fluency: CNV neg. shift at vertex no left hemisphere neg. shift. During stuttering: No CNV neg. shift at vertex, negative shift at left inferior frontal, positive shift at right inferior frontal.

TABLE 12 (cont'd)

STUDY	SUBJECTS	STIMULI	RESPONSE	ELECTRODE PLACEMENT	TIME PERIOD MEASUREMENT	METHODS OF DATA ANALYSIS	RESULTS FOR NON-STUTTERERS	RESULTS FOR STUTTERERS
Grözinger et al 1974	17; sex not specified, right-handed	phonemes, mono-syllables, arti-culation movements without phonation, humming	self-paced, spontaneous repetition of stimuli	vertex bilateral inferior frontal EOG, respiration, EMG, GSR	3500 msec. prior to and 1000 msec. following speech onset	visual inspection of amplitude asymmetry	Potentials for 100 msec. prior to speech may include muscle potential. Stable differences in brain potentials for artic and phonation following speech onset.	
Zimmerman and Knott, 1974	9 male stut. 5 non stut. all right-handed	monosyllables; poly-syllables; not controlled for initial consonant	CNV paradigm	vertex, bilateral inferior frontal	1500 msec. period bet-ween presentation of stimuli and response signal	Mann-Whitney U test for vertex data; Judges rating of polarity of amplitude shift for frontal site data	Larger negative slow potential shift at left hemisphere frontal site prior to a signal to speak.	No difference from normal group for vertex data; no significant left hemisphere shift; More individual subject variability.
Low et al, 1974	40 normal Ss 16 left-handed 23 right-handed 11 epileptics	same monosyllable repeated	CNV paradigm	vertex; bilateral inferior frontal, bilateral posterior frontal	1500 msec. period bet-ween presentation of stimuli and response signal	visual inspection of amplitude asymmetry	Interhemispheric asymmetry allowed accurate prediction of results of Wada Test in 10/11 epileptic Ss; significantly correlated with handedness in normal Ss; greatest negative shift in dominant hemis. just prior to signal to speak	
Peters et al, 1974	7 stutterers 9 non-stutterers	words rated freq. or never stuttered; 1 moth not specified; manual response to a frequency com-bination	CNV paradigm	vertex; bilateral parietal	4000 msec. prior to speech onset	Wilcoxon, 1 tailed test	amplitude of CNV prior to speech onset greater for non-stutterers. amplitude of negativity larger for manual than verbal task < .02	CNV smaller preceding frequently stuttered words

TABLE 12 (cont'd)

STUDY	SUBJECTS	STIMULI	RESPONSE	ELECTRODE PLACEMENT	TIME PERIOD MEASUREMENT	METHODS OF DATA ANALYSIS	RESULTS FOR NON-STUTTERERS	RESULTS FOR STUTTERERS
Levy, 1977	8 female right-handed	single sounds, syllables, polysyllabic non-sense words	self paced within a 10-15 second interstimulus interval	bilateral inferior frontal; bilateral pre-central gyri, EMG, EOG	2500 msec. 1250 msec. preceding speech onset for analysis	statistical correction of the covariance of EOG and EMG	reliable hemispheric differ. in slow potential act. Left sites were more neg. before articulation of multiple utterances. Most evident over frontal area.	
Shanker, 1979	8 normal speakers; 8 severe stutterers; 8 mild stutterers; all right-handed males	monosyllables and syllables	experimenter timed verbal response following 8-10 second interstimulus interval	bilateral inferior frontal	250 msec. preceding speech onset and 187.5 msec. following speech onset	analysis of variance of amplitude asymmetry	left hemisphere significantly larger than right at speech onset and during speech	no significant hemisphere asymmetry for any of the measured time periods

their own responses after being given the initial consonant, while in other studies the stimuli were completely defined by the experimenter and remained the same for all subjects. The interstimulus interval was either self-paced or timed by the experimenter. In addition, some studies used a CNV paradigm where 'expectancy' can influence the subject's response. Electrode placements varied as to location on the cortex. While most studies chose bilateral inferior frontal locations, other more posterior sites were often added. In addition, some studies monitored various sources of muscle potential. The time period of analysis ranged from 4000 msec. prior to speech onset to 1000 msec. following initiation of verbal response. Finally, the methods of data analysis varied, with most of the previous studies relying upon visual inspection of hemispheric asymmetries, whereas the present study used quantitative measures to compare mean hemisphere amplitudes.

The wide range of experimental procedures makes comparison between studies difficult. The following sections will discuss the implications of these methodological variations with respect to the findings of the current study.

Subjects. According to Table 12, this study and that of Zimmerman and Knott (1974) evaluated only right-handed males, while McAdam and Whitaker (1971a) and Levy's (1977) subjects were all female and other studies do not specify subjects' sex (Szirtes and Vaughan, 1973; Grözinger, et al, 1974). As the relationship of sex to differences in cerebral asymmetry specific to speech is unknown, more attention to subject selection is recommended.

In addition, the present study grouped stutterers according to frequency of stuttering as a measure of severity, while other studies which compared a single group of stutterers to normal speakers (Zimmerman and Knott, 1973, 1974; Peters *et al*, 1974) made no attempt to classify stutterers into subgroups. Since the relationship of stuttering severity and cerebral dominance remains unknown, it seems advisable to reduce the amount of within-group variability by dividing stutterers into subgroups.

Stimuli. Inconsistencies between the results of the various studies may also reflect the differences between the verbal conditions. As can be seen in Table 12, the length of stimuli varied among studies. The subjects in the present study repeated monosyllabic words; whereas McAdam and Whitaker (1971a), Morrell and Huntington (1972), and Zimmerman and Knott (1974) used polysyllabic words. Levy evaluated six different types of motor responses, including single syllable, polysyllabic and multiple single utterances (e.g., 'pppp'). In addition, while the present study used words which began with either /p/, /t/, or /k/, Zimmerman and Knott (1973, 1974) did not control for initial phoneme and McAdam and Whitaker (1971a) specified the initial consonant but obtained diverse responses, as subjects were told to think of a different word for each stimulus and to avoid repetition. As a result, the responses generated for each subject were similar in initial consonant and in length, but differed in meaning.

More theoretically relevant to the current study are the implications of differences in cerebral dominance as a function of linguistic meaningfulness. Of the studies listed in Table 12, only the present study and McAdam and Whitaker (1971a) compared meaningful words and CV syllables. While no consistent differences between these stimuli were found in the present study, and the significant interactions involving conditions bore no direct relevance to the predicted asymmetry effects, McAdam and Whitaker noted significant condition effects when comparing polysyllabic words with CV syllables having the same control consonant. However, it is possible that their results reflect differences in stimulus length, rather than in meaningfulness per se, since their meaningful words were always longer than their nonmeaningful stimuli which consisted of syllables. This interpretation is supported by the absence of significant differences between meaningful and nonmeaningful stimuli in the present study where the monosyllabic words and CV syllables were more similar in length. Furthermore, Levy (1977) found greater hemispheric differences preceding the articulation of more sequentially complex utterances regardless of the length of utterance, or semantic value.

It is concluded that variations in type of stimuli could cause differences in cerebral asymmetries associated with speech production. While it is apparent from the findings of previous studies that the left hemisphere appears to hold the margin of dominance over the right in normal speakers, the specific nature of the linguistic variables related to the left hemisphere dominance remains unspecified by previous studies.

Response Modes. Other methodological differences between the studies shown in Table 12 concern the mode of response. In the present study, the stimuli were visually presented and responses were experimenter cued. An 8-10 second interstimulus interval followed each response. In McAdam and Whitaker's study (1971a), responses were self-paced by each subject, after instructions to allow a 4-6 second interval. while Levy's (1977) subjects responded once every 10-15 seconds, Morrell and Huntington (1972) and Grözinger et al (1975) evaluated the spontaneous self-paced repetition of the same stimuli and Morrell and Huntington included a condition where subjects repeated tape-recorded stimuli which were cued by a taped tone. Zimmerman and Knott (1973, 1974) and Low et al (1974) used a traditional CNV paradigm, which has been described earlier (p. 28).

The variety of methods used to elicit responses combined with differences in the nature of the stimuli may account for the discrepancies between the results of these studies. An inappropriate task may fail to reveal hemisphere dominance, while inappropriate selection of different verbal stimuli may fail to reveal condition effects. In addition, certain types of stimuli and methods of eliciting responses may be necessary in order to control the artifact which may accompany a motor response. While it is impossible to demonstrate that extra-cerebral artifacts from lip muscles, tongue, palatal or eye movements are not reflected in the findings of this study, both Grözinger et al (1974) and McAdam and Whitaker (1971a) agree that experimental controls lessen the possibility that bilateral articulatory movement is responsible for asymmetrical scalp activity. Levy (1977) recorded the EEG, as well as the simultaneous eye and 'mouth EMG' in order to observe the occurance of extra-cerebral artifact associated with motor responses. After the EEG record was corrected for EOG and EMG values, reliable left hemisphere asymmetries similar to those found by McAdam and Whitaker (1971a) were noted preceding speech onset. In the present study, several precautions were taken to control movement responses which could have contaminated the waveform. They included initiation of utterances from a neutral starting point, oscilloscope monitoring of all responses for peak clipping or other distortions, the simple nature of the task, the analysis of only fluent responses, and the lengthy interstimulus interval. It is unlikely that any artifact related to muscle potential, palatal, or other type of movement was responsible for the noted asymmetry in the normal speaker's AERs in this study, as those movements would result in bilateral changes in the electrocortical potential.

Because the above factors were carefully controlled it seems highly improbable that the asymmetry recorded in the present study simply reflects muscle potential. Rather, they represent a bioelectric correlate of hemispheric dominance. This interpretation is consistent with the contention that Broca's area participates in the programming of the movements needed for speech, and with other evidence in favor of a left hemisphere dominance for speech in normal right handed males. Thereby, a greater left hemisphere asymmetry is significant in indicating control of speech by the left hemisphere.

Electrodes. Because of the limits of instrumentation the present study evaluated the electrical activity only from electrodes located at bilateral inferior frontal areas. McAdam and Whitaker (1971a) and Levy (1977) measured differences between bilateral inferior frontal and pre-central gyri, with significant differences between hemispheres at frontal placements. Morrell and Huntington (1972) found left hemisphere responses to be maximal over the left posterior cortex, while Szirtes and Vaughan (1973) found maximum negativity at fronto-temporal sites. Low et al (1974), and Zimmerman and Knott (1973, 1974) evaluated the difference between a central vertex and frontal lobe site for changes in the CNV slow potential.

Regardless of specific site, hemispheric asymmetries related to speech production seem to be in the direction of larger amplitudes over the left cerebral cortex.

Time Period of Measurement. The current study found significant differences between left and right hemisphere just at speech onset and during speech production, whereas the maximum hemisphere differences reported by other investigators were observed in time periods preceding speech onset. McAdam and Whitaker (1971a) found that maximum negative activity was significantly greater over the left inferior frontal area within the 150 milliseconds prior to speech onset, while Morrell and Huntington (1972) noted greater negative activity over the posterior cortex in the 200-500 millisecond period preceding speech onset. Zimmerman and Knott and Low _et al_ (1974) evaluated only the slow potential shift in the interval between the presentation of the stimuli and the signal to speak and found that the greatest negative shift occurred just prior to the signal to speak.

Unlike previous studies which restricted data analysis to time periods prior to speech onset, the present study continued to analyze data through speech onset for 187.5 milliseconds of speech production. Thus, the time period for which data were analyzed in this study differs from previous studies. Since, in the current study, maximum hemispheric differences occur during speech production, the possibility exists that these differences were exaggerated by movement artifact. However, as discussed above, the procedural controls used make this conclusion unlikely.

Methods of Data Analysis. It has already been noted that discrepancies between the present study and others regarding the time of greatest left hemisphere asymmetry relative to speech onset may be related to methods of analysis. While the present study compared mean hemisphere amplitude by analysis of variance, most other studies employed only visual inspection of hemisphere amplitude differences. Levy (1977) used a special computer program to compare hemisphere amplitude asymmetry by correcting for sources of EMG and EOG artifact and then computing the means and 95% confidence intervals for the six successive 125 millisecond periods prior to speech onset. Others felt that statistical analysis might camouflage individual variability or involve specific assumptions about the nature of complex waveforms (Zimmerman and Knott, 1974). Consistent with previous studies, visual inspection of the data from the current study shows left hemisphere asymmetries prior to speech onset, which increase to become statistically significant at the moment of speech onset. Thus, differences in the time period analyzed and in method of data analysis may be jointly responsible for differences in the time of maximum hemispheric asymmetries.

In addition, visual inspection of individual data (Figure 1) and pooled data (Figure 4) showed the predicted trends toward a smaller margin of dominance in severe, compared to mild, stutterers. However, when compared statistically these differences were nonsignificant. This suggests that where asymmetries have been visually inferred, evaluation by quantitative measures may alter the conclusions. Therefore, it would seem that those differences which appear on visual inspection and are subsequently confirmed by statistical procedures provide the most definite proof of hemispheric asymmetry.

Comparison of Stutterers and Non-Stutterers

It was predicted that when the evoked potentials of stutterers were compared to those of non-stutterers, the stutterers' averaged potentials would show a lower margin of left hemisphere dominance, indicated by either a lack of hemispheric differences or perhaps by greater right hemisphere amplitude prior to and during speech production. This prediction was confirmed to the extent that neither mild nor severe stutterers showed a significant left-right hemisphere difference in contrast to normal speakers who exhibited significantly larger left hemisphere responses both at speech onset and during speech.

As indicated in Table 12, Zimmerman and Knott (1974) also found stutterers to be more variable by visual inspection than non-stutterers with respect to left-hemisphere asymmetry; however, these differences occurred prior to speech onset. In an earlier study (Zimmerman and Knott, 1973) no hemispheric asymmetry was noted when stutterers were fluent, while prior to stuttered responses a negative shift was noted at the left inferior frontal site and a positive shift at the right inferior frontal site. In addition, a CNV vertex response occurred prior to fluent responses but not preceding stuttering, suggesting the interaction of emotional arousal with the hemispheric relationship that was not supported by the later (1974) study.

Another study which found differences between stutterers and non-stutterers (Peters et al, 1974) is more difficult to compare to the present study, since these investigators compared verbal responses to manual activity, and active electrode sites were over central vertex and bilateral parietal lobes, rather than frontal areas. A standard CNV paradigm was used and responses were only analyzed for the 4000 msec. epoch preceding speech onset. Within this period the amplitude of the CNV was greater for non-stutterers than stutterers. Because of differences in active electrode site, direct comparisons to the present study cannot be made. However, the findings of Peters et al (1974) are consistent with those of the present study in the sense that both indicated a greater margin of cerebral dominance in normal speakers by the use of AER methods and a statistical analysis of the data.

The findings of Zimmerman and Knott (1973, 1974) are somewhat easier to compare with those of the present study, because of similar electrode placement, although other discrepancies in procedure exist (see Table 12). These differences, which have been discussed earlier, include lack of sub-grouping of subjects, and monosyllabic and polysyllabic stimuli not controlled for initial consonant. The method of response was a CNV paradigm in which words were rated for subjects' expectancy to stutter prior to responding. The period of analysis was the interval between presentation of the stimuli and the response. Cerebral asymmetries were verified by judges rating of polarity of amplitude shifts, rather than by more quantitative methods. In spite of these differences, both the results of Zimmerman and Knott (1974) and those of the present study indicate that stutterers and non-stutterers differ in cerebral dominance during fluency.

Although Zimmerman and Knott's results were not statistically analyzed, it would appear that differences between stutterers and non-stutterers in cerebral dominance related to fluent speech are sufficiently robust to be manifested under a variety of experimental procedures.

Theoretical Implications

Orton and Travis (1927, 1931) postulated that stutterers have a lower than normal margin of dominance between left and right hemispheres, and that the left hemisphere is, therefore, unable to impose its cortical timing pattern on the right, resulting in the dyssynchronous impulses which can ultimately lead to stuttering. According to this theory, increased emotional arousal interacts with the margin of dominance to result in stuttering. According to Travis (1931) an increase in stress would either reduce the hemispheric margin of dominance or add to the already lower margin of dominance to act as a precipitating factor in stuttering. The degree of emotional arousal which would precipitate stuttering would vary among stutterers depending on an individual's habitual margin of dominance. Fluent speech would be maintained in situations which contain low levels of stress, or in individuals whose margin of dominance is large. Stuttering behavior would be precipitated when a low margin of dominance interacts with stress. The results of Zimmerman and Knott (1973) for stuttered speech suggest that the hemispheric relationship is affected by changes in the CNV amplitude at the vertex. Therefore, in order to support the theory proposed by Orton and Travis, stutterers must be shown to have differences in hemispheric dominance when compared to non-stutterers under non-stressful conditions in which speech is fluent. Thus, the findings of this study, in which significant differences were noted between stutterers and non-stutterers during fluency, do support the Orton-Travis Theory.

If the greater left hemisphere amplitude at speech onset for normal speakers indicates cerebral specialization for speech, stutterers can be considered different in their patterns of cerebral dominance even when no stuttering takes place. This finding also agrees with that of Zimmerman and Knott (1974), who found that differences exist between stutterers and non-stutterers preceding fluent speech, and even when stutterers have to make decisions about their expectancy to stutter.

The present study found no statistically significant differences in cerebral dominance between severe and mild stutterers. According to modern cerebral dominance theory, severe stutterers may have a lower threshold for certain kinds of stress than milder stutterers, causing stimuli of lesser emotional intensity to decrease the margin of hemispheric dominance sufficiently to precipitate stuttering. However, the nature of the stimuli and experimental task in the present study may have constituted a condition in which the stress threshold was not exceeded for either group of stutterers, thus resulting in no dysfluency for either group. It is also possible that severe stutterers do have smaller margin of cerebral dominance than mild stutterers, and that further research with larger groups of subjects will demonstrate a relationship between severity of stuttering and amount of hemispheric asymmetry even during fluent speech.

The present results demonstrate that a smaller margin of cerebral dominance exists for stutterers even when experimental conditions are optimum for fluency. These conditions include maintenance of the timing of motor sequencing, rate and rhythm, all factors which seem to contribute to fluency. Had the present study included more stressing stimuli or tasks, the stress threshold might have been exceeded in the severe stutterers, resulting in significantly different amounts of stuttering between the two groups of stutterers. In addition, the speaking conditions of the present study included lengthy pauses before and after each response. As a result, subjects were able to compensate for dysynchronous timing by organization and planning of motor responses.

Specific manipulations of linguistic conditions could result in higher levels of stress in future studies. For example, verbal tasks which require rapid articulatory shifting might increase stress thresholds in stutterers. If stutterers lack the motor coordinations which are necessary for the timing of bilateral motor responses and synchrony of movement needed for verbal sequencing, then a lengthier, more complex, or rapidly produced articulatory sequence might require changes in the cortical processing demands for motor production, sufficient to decrease the margin of hemispheric dominance and to precipitate stuttering. Other experimental manipulations which might result in increased stress for stutterers could include increased pressure for response time, use of emotionally connotative words, alterations in the listener's reaction, or use of frequently stuttered upon words as stimuli. The response to stimuli which incorporate these variables could be measured by AER methods.

In summary, it is concluded that the inconsistent results of early attempts to evaluate the Orton-Travis Theory were a consequence of the unavailability of adequate procedures for the measurement of cerebral dominance. The results of the present study, using averaged electrocortical responses, provide new evidence relating reduced left hemisphere dominance and stuttering, and suggest the utility of the AER procedure for further investigations.

Other Methodological Considerations

The literature raises a number of procedural questions about factors which might influence evoked potentials during a motor response and which should be taken into consideration when planning a study of this nature. The possibilities of muscle potential influencing recorded motor responses have already been discussed. Other factors which were considered in the design of this study will be discussed briefly.

Choice of Trigger. This study utilized the back averaging technique recommended by McAdam and Whitaker (1971b), even though Zimmerman and Knott (1974) recommended time-locking of the averaged waveform to a constant pre-voice trigger. They felt that this would avoid a smoothing of the waveform which might be caused by variability between the trigger and the response resulting in lack of visually perceived hemispheric differences. Although this type of trigger might be more appropriate when analyzing stuttering, it is felt that when fluent responses were analyzed, the 10 second interstimulus interval and experimenter-cued response compensated for the variability which might have occurred if subjects had self-paced their responses. Therefore, when responding in this fashion, back averaging seemed an appropriate trigger choice.

Other AER Measures. Measures of differences in the mean hemispheric amplitude made the results of this study more easily comparable to other studies of a similar nature. Measurement of the latency of the phasic relationships between hemispheres did not seem indicated when investigating the margin of hemispheric difference. However, in future studies of dysfluency,latency measurements might contribute information regarding alterations in phase prior to the moment of stuttering.

Implications for Treatment

The assumptions of the Orton-Travis Theory imply that the goal of treatment should be either to increase the margin of hemispheric dominance or to help the stutterer compensate for inadequate dominance by increasing tolerance for the stress which triggers stuttering.

Early therapies which were specifically devoted to changing hemispheric dominance by shifting handedness as described by Travis (1978) have been abandoned, as it seems unlikely that one can alter a primary mode of cerebral organization which predisposes stuttering. The therapies which alter the rate of speech, and impose more regularity and motor planning on the timing of speech onset seem to help the stutterer to increase his ability to coordinate the bilateral movements necessary for fluency and to prepare for difficult speaking situations by alternating the onset of speech. Although this type of treatment does not change dominance, it may help the stutterer to verbally compensate for an altered hemispheric relationship.

A second mode of therapy has as its goal the reduction of stress by desensitizing the stutterer to his expectancy to stutter and building a tolerance for specific stressful situations.

Although these types of treatments have not developed from Orton and Travis' theory they are consistent with a treatment protocol which would help stutterers to keep the margin of dominance sufficiently wide by the internalization of a strategy for coping with the stressors which ultimately lead to a decreased cerebral margin of dominance dysfluency.

CONCLUSIONS

While other studies have used AER methodology to compare stutterers to normal speakers, this study is unique in that it is the first to attempt to statistically evaluate lateralized motor potentials during speech, relative to severity of stuttering. The finding of smaller left hemisphere dominance in stutterers than in non-stutterers supports the theory of Orton and Travis that in stutterers the dominant hemisphere has a smaller margin of dominance over the nondominant hemisphere. Since this difference occurred during fluent speech, it appears to reflect a primary pre-disposing condition for stuttering rather than a secondary condition involving an interaction with stress.

Some of the specific predictions of the study were not confirmed. Further research is needed to determine the nature of the differences in left hemisphere asymmetries between stutterers and non-stutterers with respect to the period preceding vocalization, type and severity of stuttering, effects of treatment, and type of speaking task. The AER technique seems to be an appropriate technique for evaluation of these aspects of cerebral dominance and stuttering.

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APPENDIX A

Edinburgh Handedness Inventory

Medical Research Council Speech and Communication Unit

EDINBURGH HANDEDNESS INVENTORY

Surname .... Given Names ....

Date of Birth .... Sex ....

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. If in any case you are really indifferent put + in both columns.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand-preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

	LEFT	RIGHT
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broom (upper hand)		
9. Striking Match (match)		
10. Opening Box (lid)		
i. Which foot do you prefer to kick with?		
ii. Which eye do you use when using only one?		

L.Q.		Leave these spaces blank	DECILE	

APPENDIX B

Experimental Word List

EXPERIMENTAL WORD LIST

1. taal
2. coop
3. key
4. tax
5. cans
6. tab
7. task
8. pass
9. peep
10. calf
11. cooed
12. cooled
13. kiel
14. Pam
15. pad
16. peach
17. keep
18. team
19. posh
20. coot
21. pop
22. pants
23. cool
24. patch
25. cob
26. cab
27. copped
28. pock
29. keys
30. tock
31. tack
32. tash
33. camp
34. pan
35. tat
36. teach
37. teem
38. peace
39. Tonk
40. cusp
41. pont
42. cod
43. tot
44. cache
45. keats
46. tart
47. teen
48. cad
49. cam
50. tease
51. kook
52. tap
53. pot
54. past
55. peaked
56. pack
57. Tom
58. keen
59. teas
60. pads
61. palm
62. cub
63. teeth
64. cop
65. ton
66. tours
67. teal
68. pond
69. pal
70. peele
71. peak
72. tan
73. pons
74. pomp
75. tod

APPENDIX C

Response Sheet

Response Sheet

Name ____________________ Age ______ Date ____________

Group ____________________ Condition Order ____________

1.	taal (t)	____	39.	Tonk (t)	____
2.	coop (k)	____	40.	cusp (k)	____
3.	key (k)	____	41.	pont (p)	____
4.	tax (t)	____	42.	cod (k)	____
5.	cans (k)	____	43.	tot (t)	____
6.	tab (t)	____	44.	cache (k)	____
7.	task (t)	____	45.	keats (k)	____
8.	pass (p)	____	46.	tart (t)	____
9.	peep (p)	____	47.	teen (t)	____
10.	calf (k)	____	48.	cad (k)	____
11.	cooed (k)	____	49.	cam (k)	____
12.	cooled (k)	____	50.	tease (t)	____
13.	kiel (k)	____	51.	kook (k)	____
14.	Pam (p)	____	52.	tap (t)	____
15.	pad (p)	____	53.	pot (p)	____
16.	peach (p)	____	54.	past (p)	____
17.	keep (k)	____	55.	peaked (p)	____
18.	team (T)	____	56.	pack (p)	____
19.	posh (p)	____	57.	Tom (t)	____
20.	coot (k)	____	58.	keen (k)	____
21.	pop (p)	____	59.	teas (t)	____
22.	pants (p)	____	60.	pads (p)	____
23.	cook (k)	____	61.	palm (p)	____
24.	patch (p)	____	62.	cub (k)	____
25.	cob (k)	____	63.	teeth (t)	____
26.	cab (k)	____	64.	cop (k)	____
27.	cooped (k)	____	65.	ton (t)	____
28.	pock (p)	____	66.	tours (t)	____
29.	keys (k)	____	67.	teal (t)	____
30.	tock (t)	____	68.	pond (p)	____
31.	tack (t)	____	69.	pal (p)	____
32.	tash (t)	____	70.	peele (p)	____
33.	camp (k)	____	71.	peak (p)	____
34.	pan (p)	____	72.	tan (t)	____
35.	tat (t)	____	73.	pons (p)	____
36.	teach (t)	____	74.	pomp (p)	____
37.	teem (t)	____	75.	tod (t)	
38.	peace (p)	____			

APPENDIX D

Subject Permission Form

SUBJECT PERMISSION FORM

Date ________________

The purpose of this study is to record your EEG activity during three different tasks. Two tasks involve speaking, and one involves listening to a set of stimuli in order to see how well you can process speech. While you are performing these tasks, your ongoing EEG activity will be recorded via seven (7) surface electrodes which will be attached to your head by a water soluable paste. Four electrodes will be attached to your scalp, one will be behind each ear, and one electrode will be attached to your forehead.

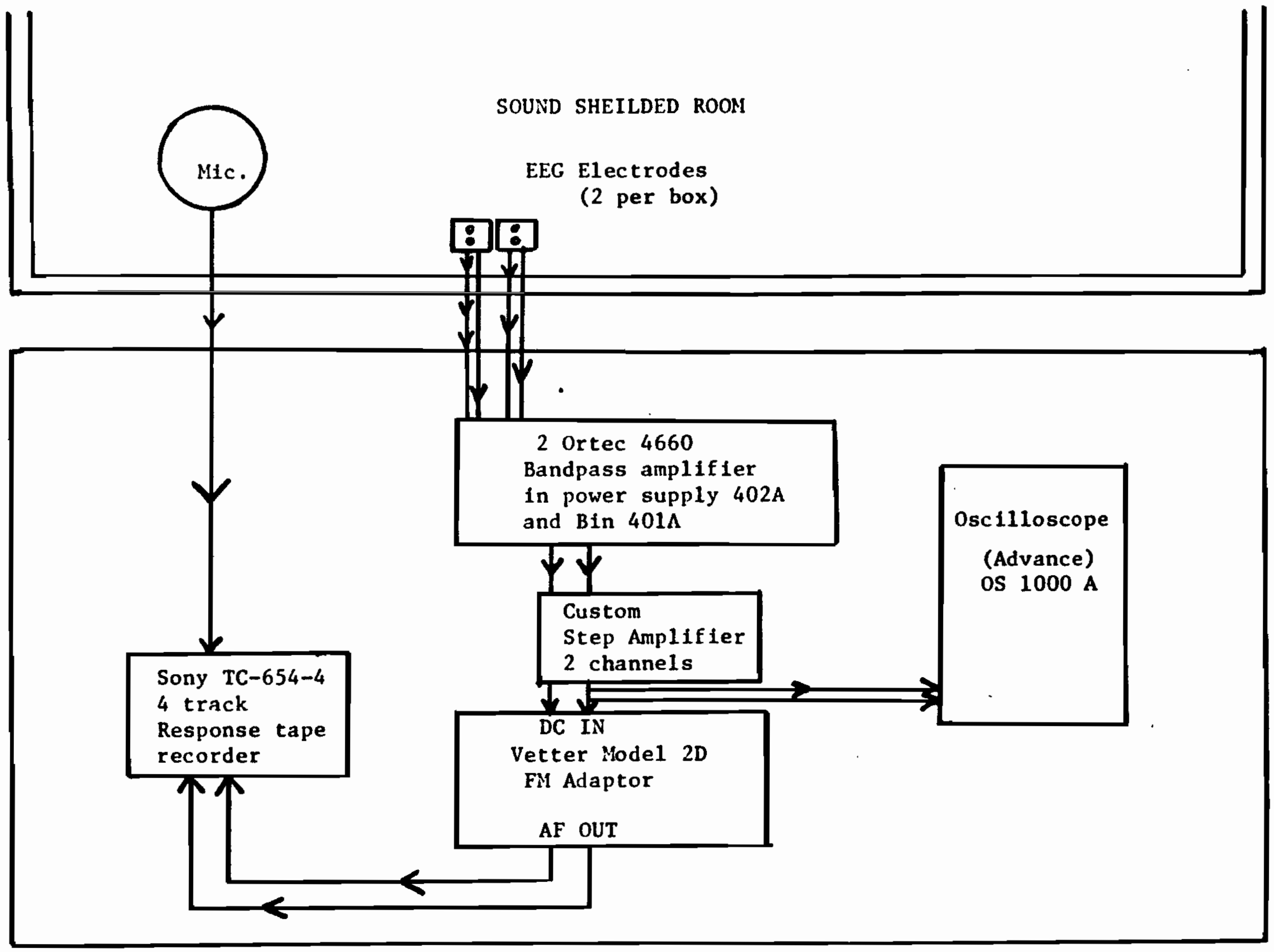
There will be no pain, electric shock, or punishing experience involved. The entire experiment should take no longer than three hours. If, however, you feel that you no longer wish to participate in this study, you may stop at any time. If you wish to participate in this study please sign below. Your name will never be used in regard to any data collected from this experiment, as all subjects will remain anonymous. Your signature only indicates that you have read this page and are willing to participate in this study.

Name ___________________________

APPENDIX E

Schematic of Equipment Used for Recording EEG Activity and Stimulus Responses

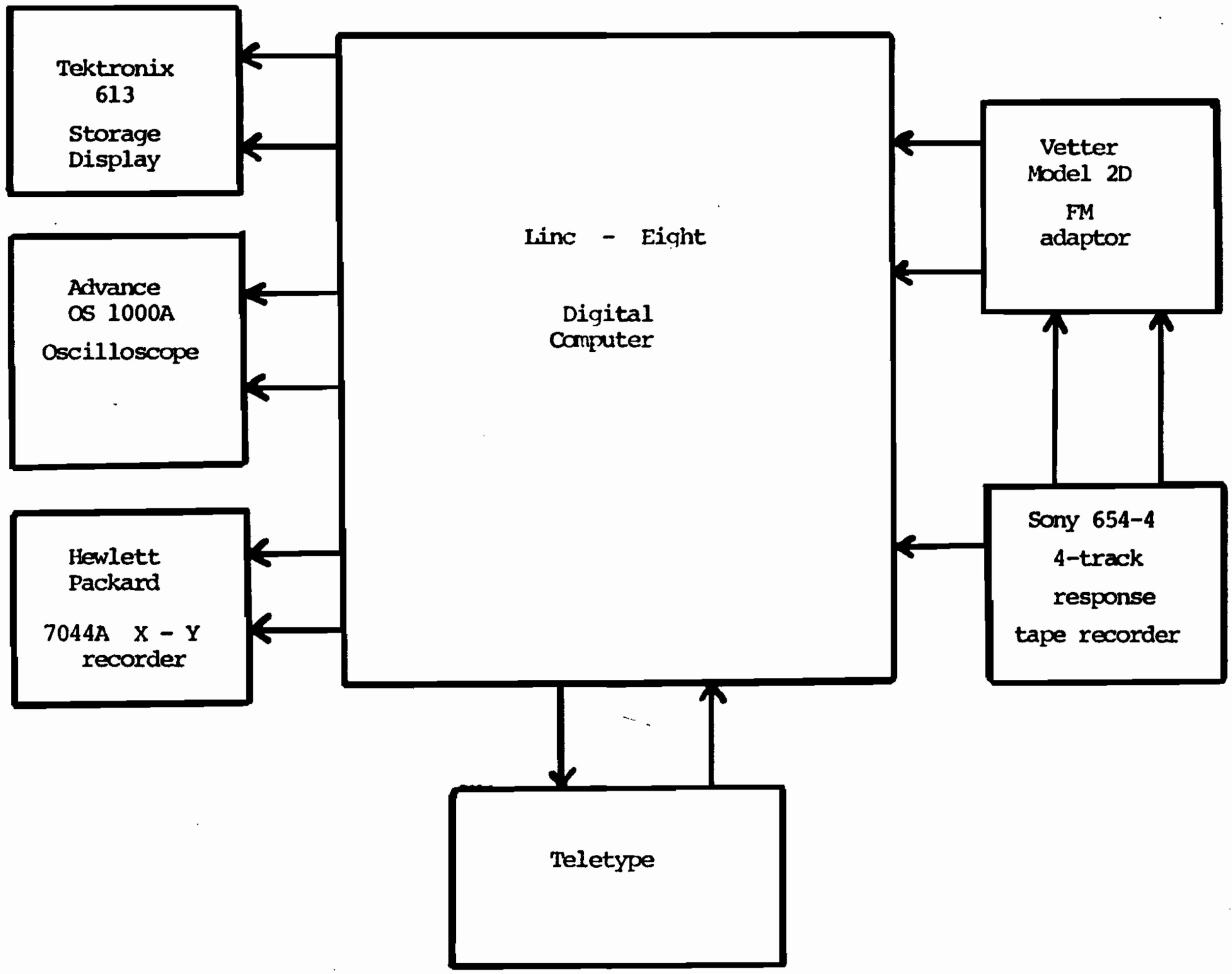
Schematic of Equipment Used for Recording EEG Activity and Stimulus Responses



APPENDIX F

Schematic of Evoked Response Computation System

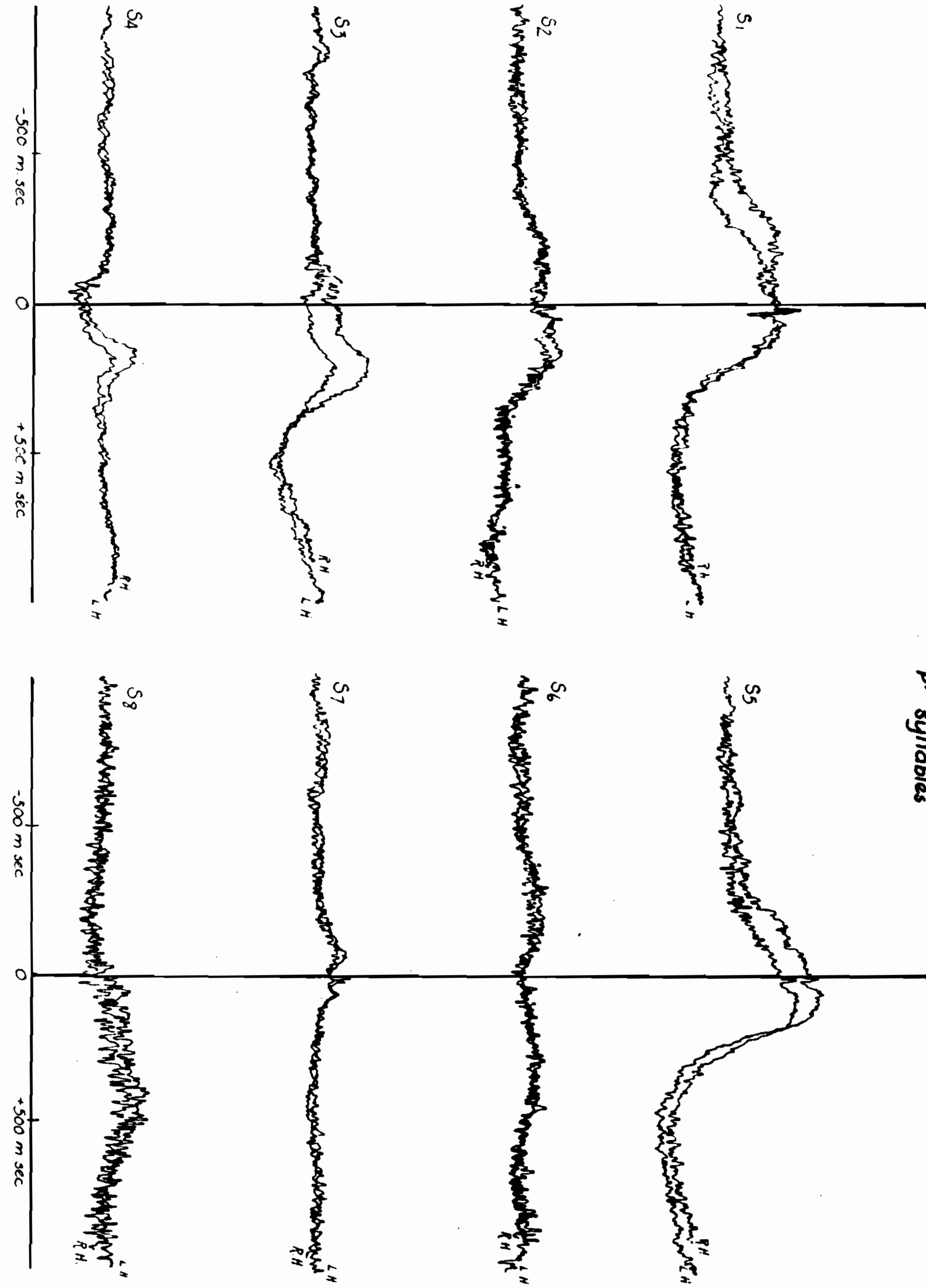
SCHEMATIC OF EVOKED RESPONSE COMPUTATION SYSTEM



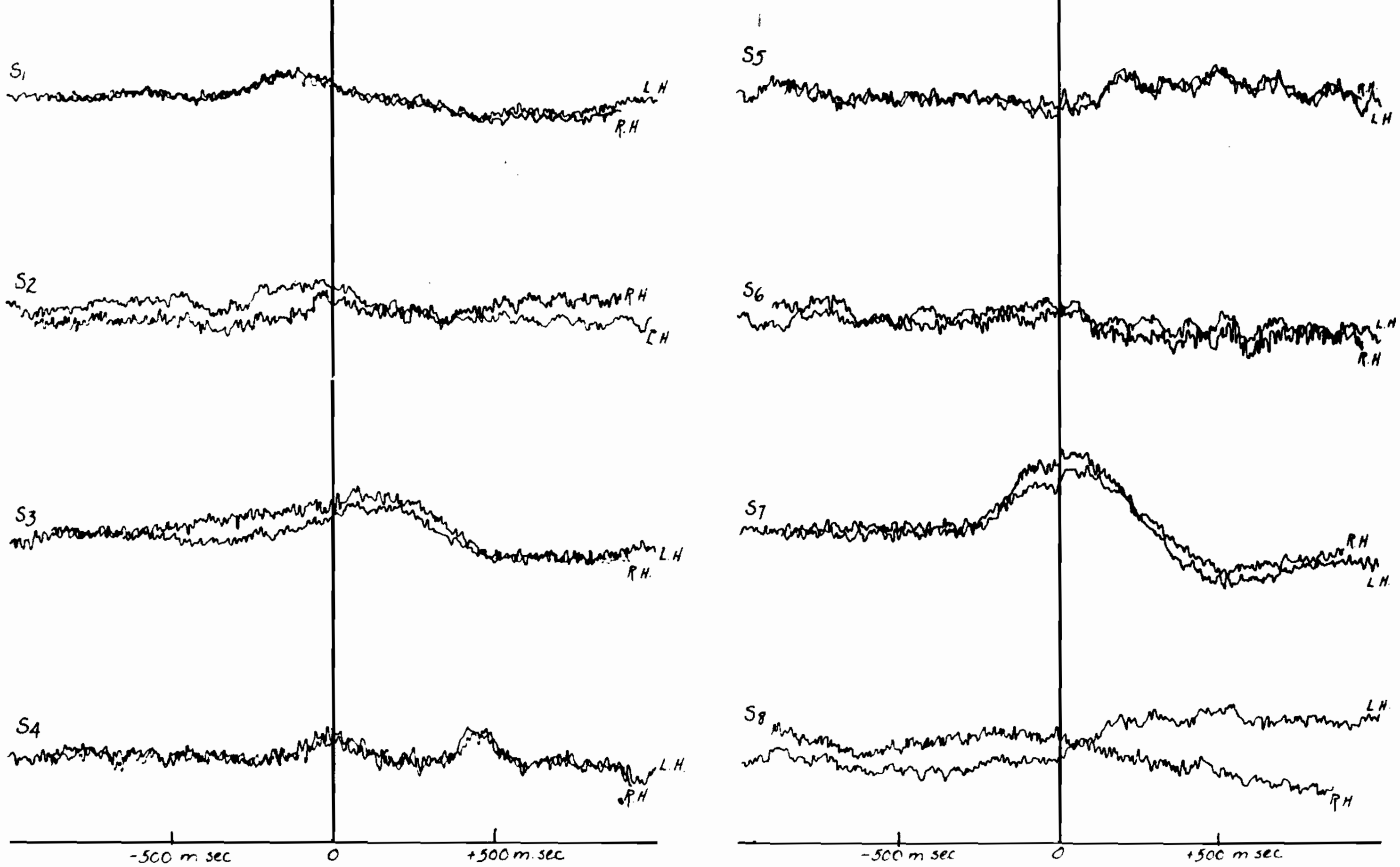
APPENDIX G

Averaged Evoked Responses for /p/ Syllables: Individual Data for Normal Speakers, Mild Stutterers and Severe Stutterers

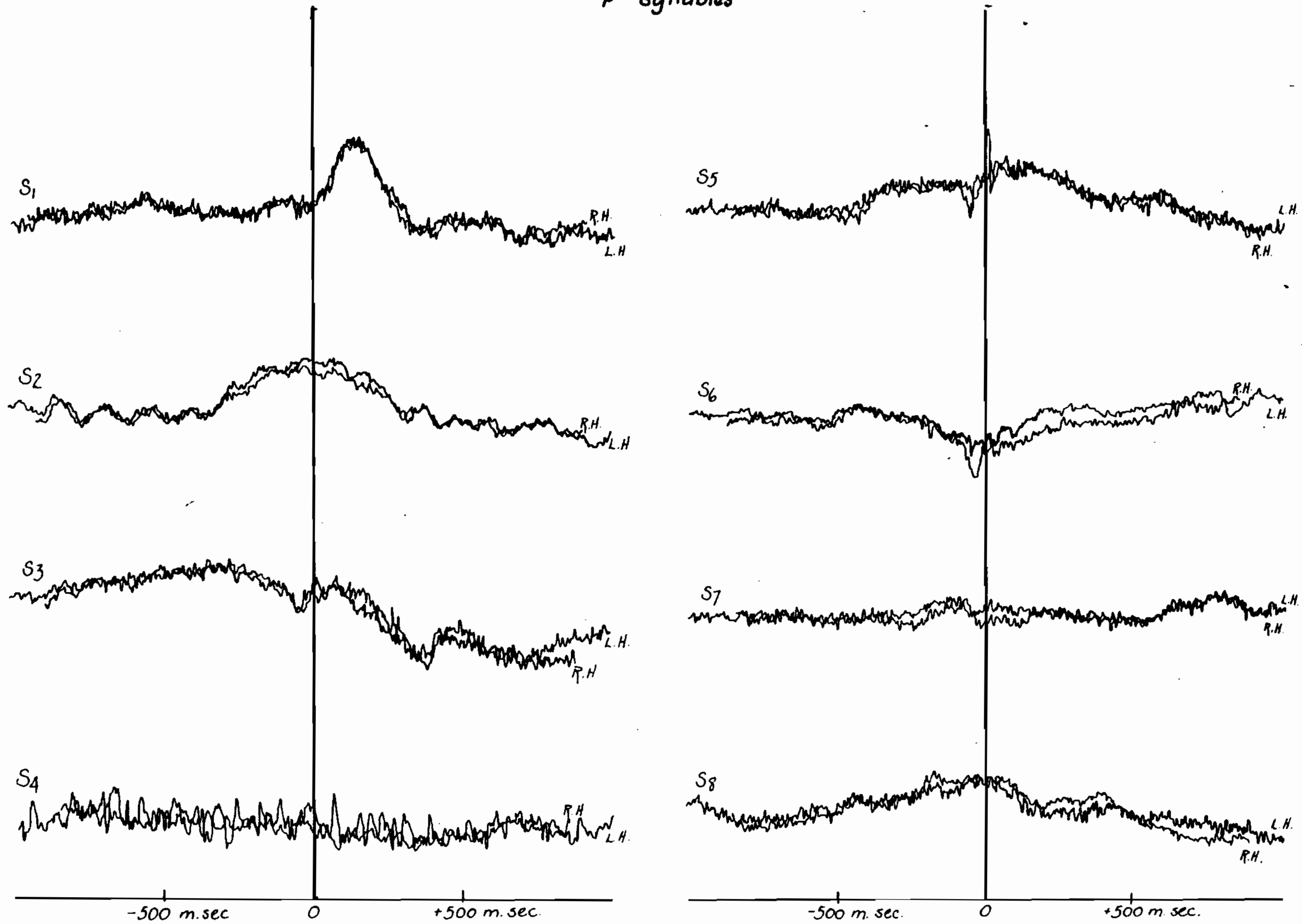
Normal Speakers
'p' syllables



Mild Stutterers
'p' syllables



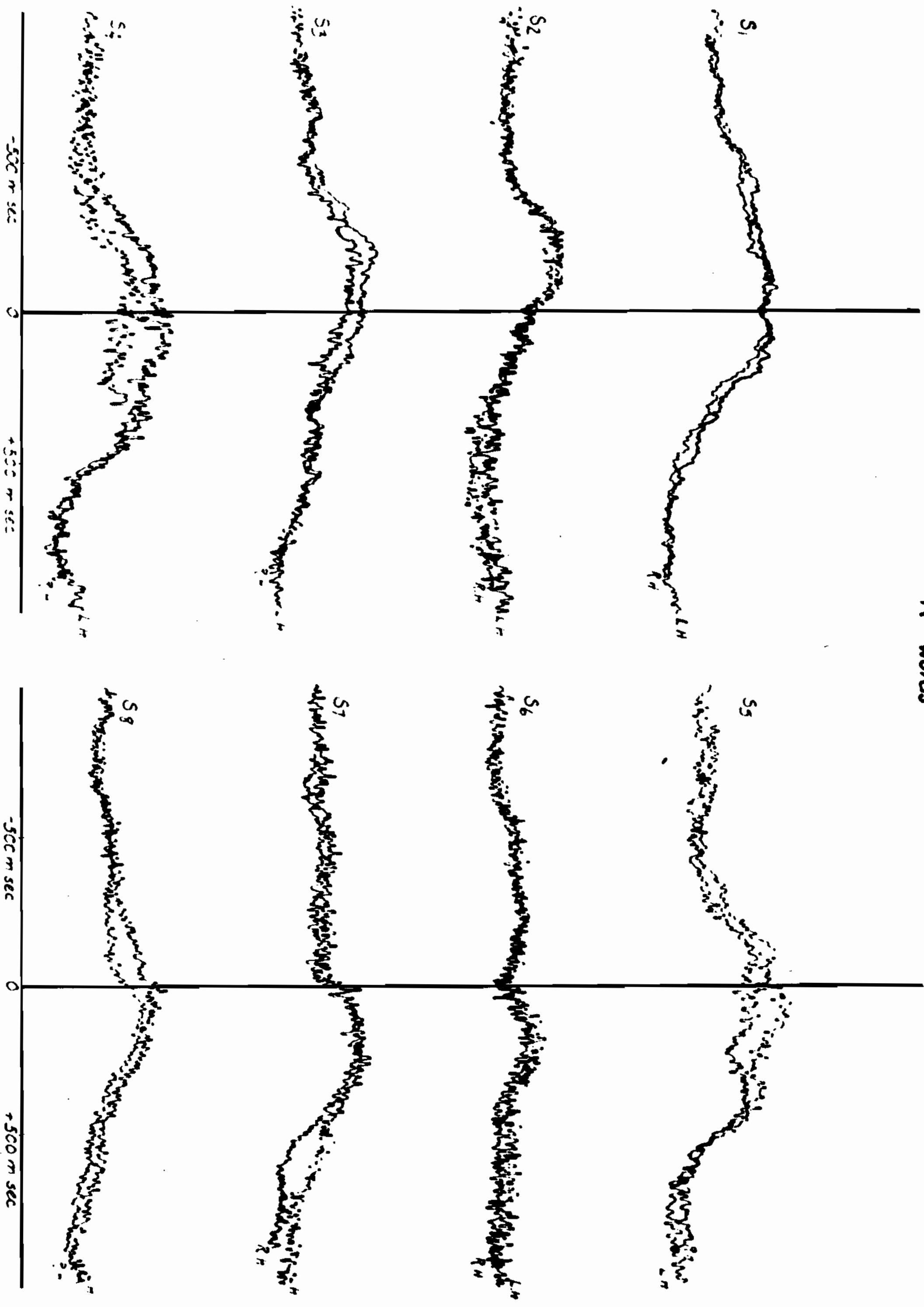
Severe Stutterers
(p) syllables

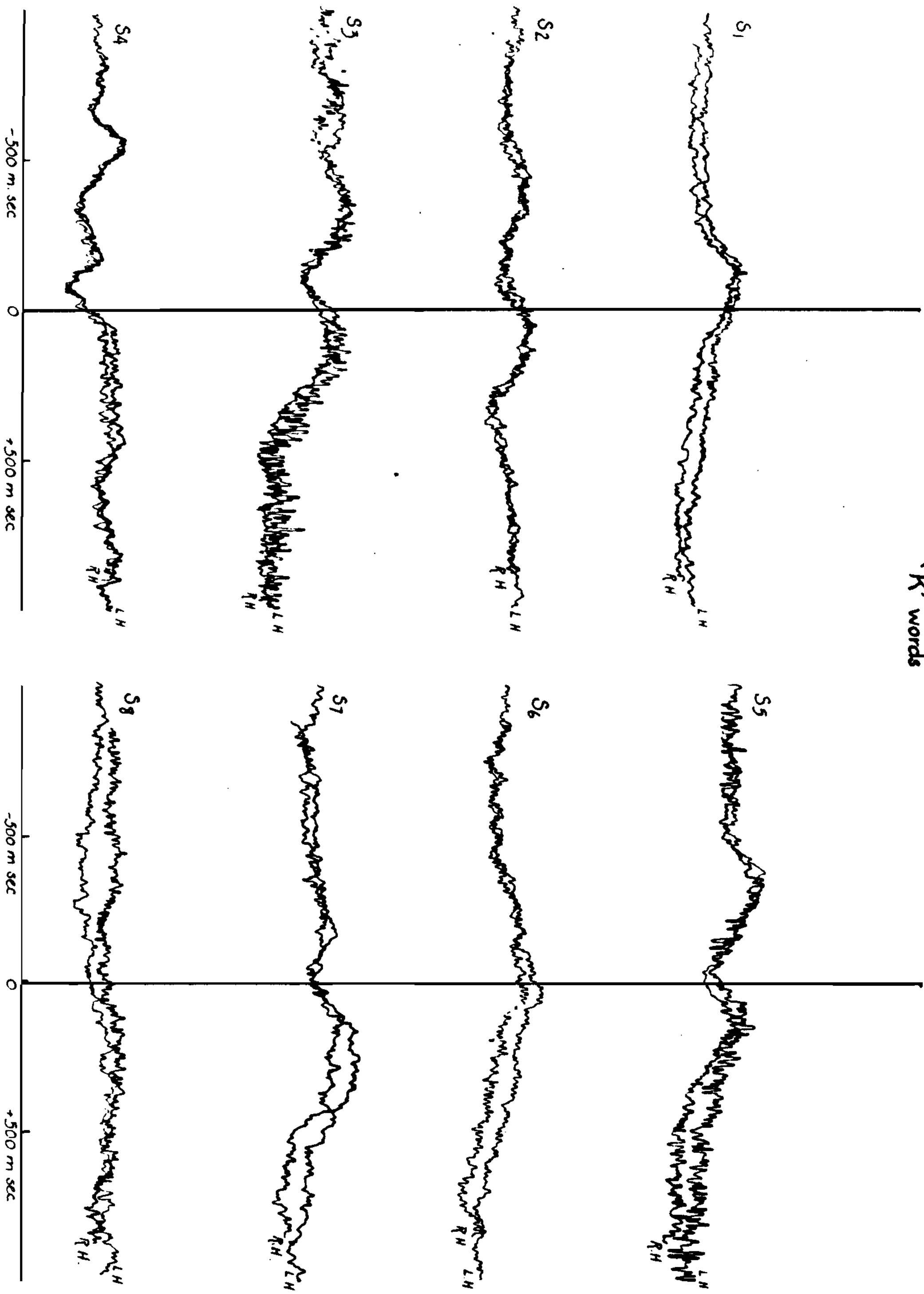


APPENDIX H

Averaged Evoked Responses for /k/ Words: Individual Data for Normal Speakers, Mild Stutterers and Severe Stutterers

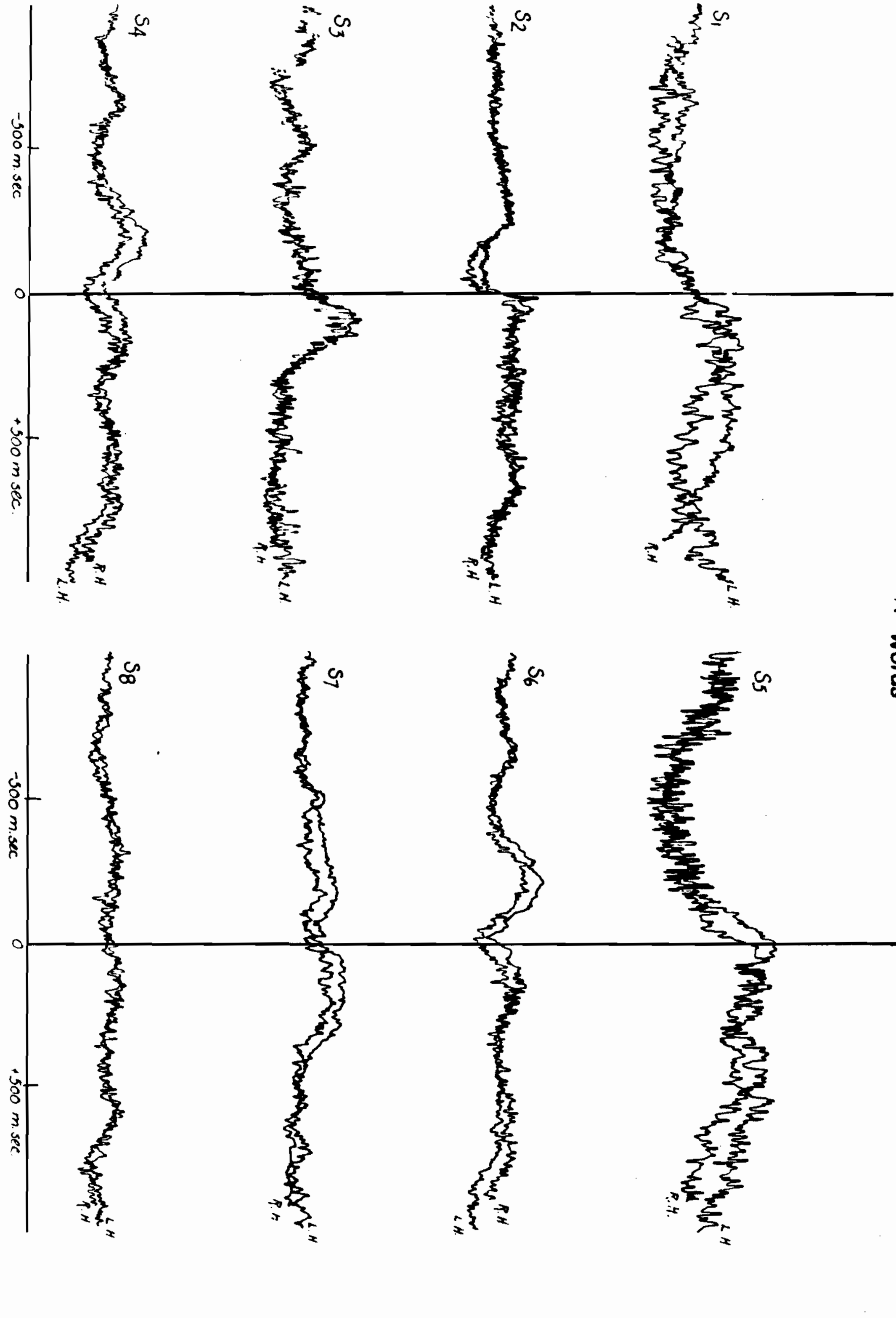
Normal Speakers
'K' words





Mild Stutterers
'K' words

Severe Stutterers
'K' words



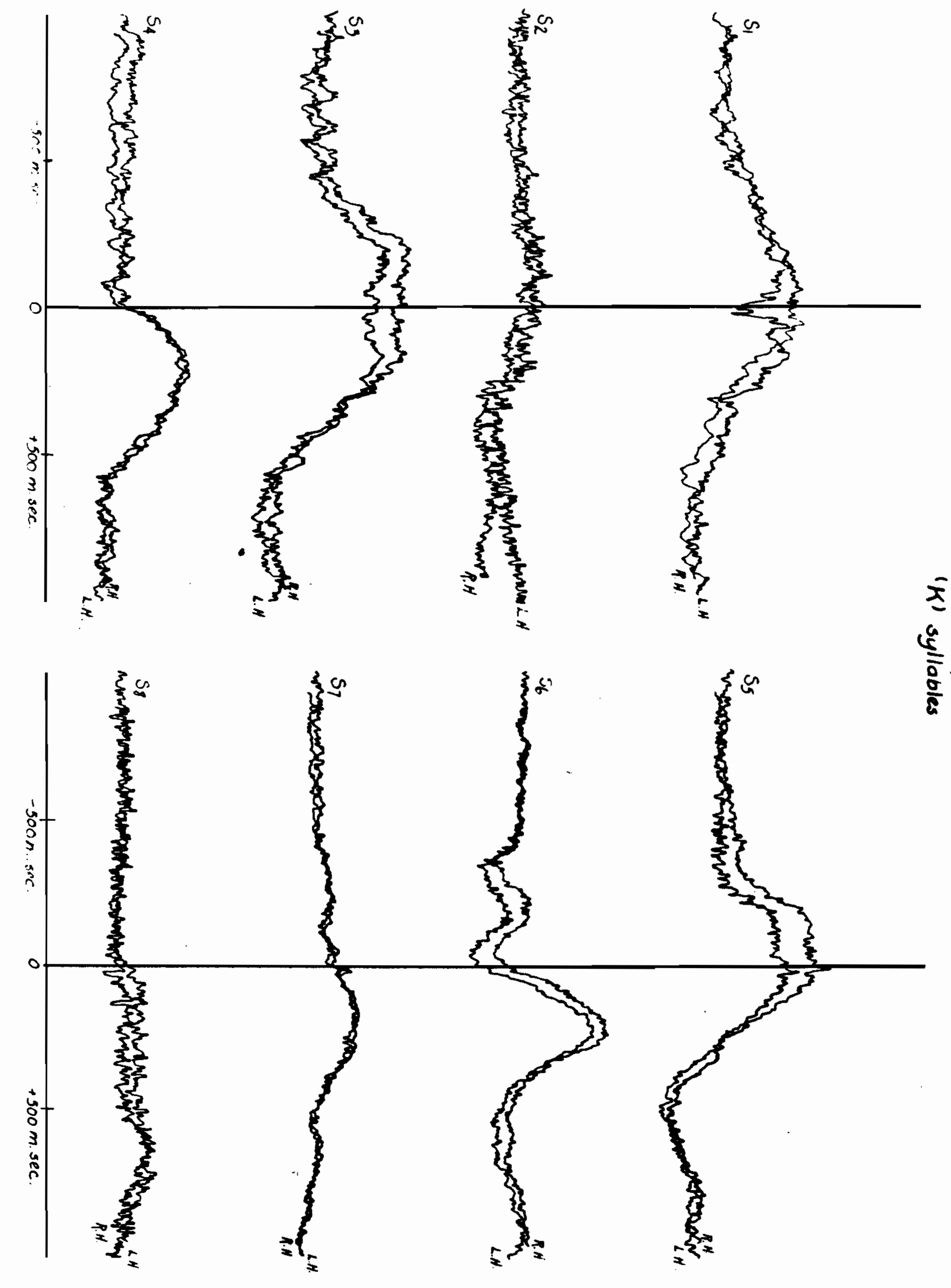
APPENDIX I

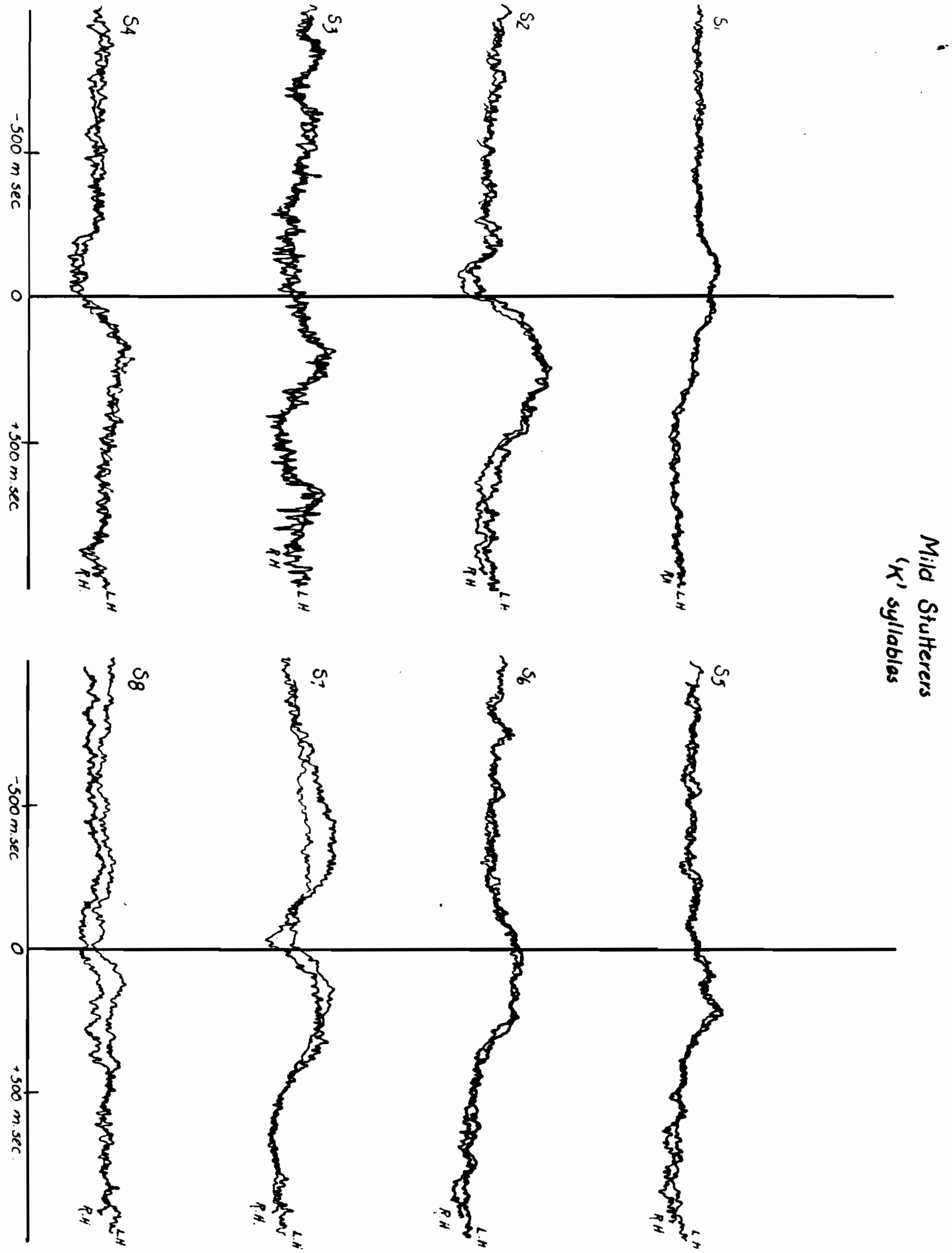
Averaged Evoked Responses for /k/ Syllables

Individual Data for Normal Speakers,

Mild Stutterers and Severe Stutterers

Normal Speakers
'K' syllables




Mild Stutterers
'K' syllables
S1
S2
S3
S4
S5
S6
S7
S8
L.H
R.H
-500 m.sec
0
+500 m.sec

Severe Stutterers
'K' syllables