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Neuropsychological studies of primary developmental dyslexia

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NEUROPSYCHOLOGICAL STUDIES
OF
PRIMARY DEVELOPMENTAL DYSLEXIA

by

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that we might learn more about and perhaps better explain central nervous system information-processing in primary developmental dyslexia and its subgroups.

ABSTRACT

An experiment was designed to assess possible electrophysiological correlates in primary developmental dyslexia and its subgroups. By using the Camp and Dolcourt modification of the Boder Diagnostic Screening Test, 33 adult subjects with primary developmental dyslexia were discriminated from a population of adults with reading incompetencies; further subgrouping rendered 12 dysphonetics, 11 dyseidetics, 10 mixed. Twelve controls were used. The dyslexic subjects satisfied criteria relative to vision, hearing, I.Q., neurological status, emotional status and adequacy of a conventional educational opportunity.

Using the montage, P_3-C_z and P_4-C_z, 12 event-related potential (ERP) types were recorded from each subject for each of the combinations of state (visual attending, auditory attending, passive), mode (visual, auditory) and condition (target, standard). The task was to discriminate and silently count targets (30 dim flashes or 30 soft clicks depending on the attending state, visual or auditory) from the bimodally presented 150 flashes and 150 clicks. There were three runs (visual attending, auditory attending, passive).

Inspection of the grand-averaged visual and auditory ERPs determined designated latency bands for the dependent variables, which were measures of amplitude-Power (by computer program) for the total (0-450 msec), 50-150 msec, 125-250 msec, and 250-450 msec latency bands.

To assess possible ERP correlates in this design of signal recognition between and within modalities, the data were analyzed by a mixed-model 5 factor Repeated Measures Analysis of Variance (ANOVA).

Among the significant interactions (P equals or exceeds the .05 level of significance) were Mode by Lead for Total Power, 50-150 msec Power and for 125-250 msec Power; Group by Lead for 250-450 msec Power; State by Condition by Lead for Total Power and for 250-450 msec Power; Mode by Condition by Lead for Total Power, for 50-150 msec Power and for 125-250 msec Power; Group (dysphonetic versus dyseidetic) by State by Lead for 250-450 msec Power; Group (dysphonetic versus dyseidetic) by Mode by Condition for 250-450 msec Power; Group (dysphonetic versus dyseidetic) by State by Mode by Condition for 50-150 msec Power; Group (dysphonetic versus dyseidetic) by State by Condition by Lead for 250-450 msec Power. To further investigate this last interaction, t tests were carried out comparing the dysphonetic and dyseidetic groups on each combination of state, condition and lead, collapsed over mode; no significant differences were found.

The P_4-P_3 difference for each combination of state, mode and condition was analyzed in a one-way ANOVA across groups for 250-450 msec Power. A planned comparison between the dysphonetic and dyseidetic groups for all 12 combinations did not achieve significance at the .05 level. However, this planned comparison did show marginal significance for P_4-P_3 differences on several combinations.

The dysphonetics and dyseidetics were compared on P_4 Power (visual attending state-visual target)-P_3 Power (auditory attending state-auditory target). Using a separate variances t test the dyseidetics had a significantly higher P_4-P_3 difference than the dysphonetics. However, subsequent analysis indicated that this significant t test might be due more to intragroup variance than to group differences.

Inspection of a scatter plot showed that high values of P_4 were associated with low values of P_3 for four of eleven dyseidetic subjects, and that high values of P_3 and low values of P_4 were associated with four of twelve dysphonetic subjects. Analysis by the chi-square statistic indicated that the distributions of the dyseidetics and dysphonetics were significantly different.

Possible explanations as to why ERP measures did not more fully discriminate between dyslexics and normals and among subgroups of dyslexics include subject selection methods, independent (task) and dependent variable selection methods, electrode placement and measurement techniques.

HISTORICAL PERSPECTIVES AND BACKGROUND INFORMATION

The learning disabilities are the clinically noted, functionally expressed problems that professionals in psychology, education, medicine, and other associated disciplines encounter in children and adults who have difficulty with cognition, behavior, or both. They comprise four symptom-complexes, which are not mutually exclusive (Johnson and Myklebust, 1967; Tarnopol, 1971):

1. The dyslexia-dysgraphia syndromes
2. The motor-perceptual dysfunction syndromes
3. The language delays
4. The syndromes of distractibility, hyperactivity, and decreased attention span.

The learning disabilities are usually the expression of those primary neurophysiologic and neuropsychologic states that are termed the minimal cerebral dysfunctions: deviations of the central nervous system manifested by various combinations of impairments in perception, conceptualization, language, reading, memory, and control of attention, impulse, or motor function, in children or adults who (1) can see, (2) can hear, (3) whose general IQ is within normal limits (although IQ scores often show wide discrepancies between verbal and performance abilities), (4) manifest no obvious neurologic damage, (5) have no primary emotional disturbance, and (6) have been given an adequate educational opportunity (Clements, 1966).

The minimal cerebral dysfunctions relate pathophysiologically to some definitive and some as yet unknown genetic problems, and to deleterious pre-, peri-, and postnatal factors. The effects of the pathophysiologic deviations are markedly influenced by the interactions of the child with his environment, and by training and education.

The position of the dyslexias within the broad area of <u>reading incompetence</u> has only recently begun to assume clear outlines. It was estimated a decade ago (Rabinovitch, 1968) that at least 10% of all children in the United States are handicapped by reading incompetence before they reach the seventh grade. An accepted definition of reading incompetence is a significant discrepancy between actual and expected reading levels for performance mental age; considered "significant" is one year's reading delay in children up to 10 years of age; 2 years' delay in those older than 10 years.

Heretofore, the diagnosis of the syndromes of the dyslexias involved a process of exclusion of the individual from a universe of children and adults with <u>reading incompetence</u> due to other causes. Saunders (1962) calculated that 20-30% of contemporary school children showed reading incompetence. The estimate referred to "normal" children, specifically excluding those who, in more or less definable categories, were in specific treatment and educational programs, such as the trainable mentally retarded, the physically handicapped, the autistic or primarily emotionally disturbed, and the visually and hearing impaired. Some children with reading incompetence are found in classes for the educationally or neurologically handicapped or the learning disabled.

In about two-thirds to three-fourths of the children with reading incompetence, this handicap is traceable to lack of motivation and/or educational opportunity of a socio-cultural nature. About one-fourth to one-third have primary developmental dyslexia, hypothesized as a neurophysiologically-based state. In rare instances in children, dyslexia is attributable to psychopathology or to a definitive acquired cerebral lesion. Blanchard (1946), approaching the learning disabilities from a psychoanalytic point of view, has stressed the motivational aspects of learning and the primary neurotic causes of difficulties in these areas, especially those pertaining to reading and writing. Differences of opinion persist between those who propose organic causes for the learning disabilities, and those who suggest psychogenic causes. As many workers attest, however, secondary psychopathology soon assumes great importance in primary developmental dyslexia, because of the pressures to read, and the early appearance of social, academic, and practical handicaps experienced by the person who is unable to read without discernible cause (Orton, 1937; Rawson, 1968; Cronin, 1968; Rosenthal, 1973).

Primary reading incompetence has been termed primary developmental dyslexia (Saunders, 1962; Eisenberg, 1966; Rabinovitch, 1968; Gofman, 1969; Critchley, 1970b). Persons with primary developmental dyslexia are deficient in the ability to deal with letters and words as symbols, hence, to integrate the meaningfulness of written material. Children and adults with this disorder have no visual or hearing difficulties. Their general intellectual functioning is normal or above, although they may show marked divergences in responses to subtests. They have no obvious neurological deficit. They have had adequate, conventional educational opportunities. They have no primary emotional disturbance, were originally well motivated, and came from culturally adequate homes. Yet they cannot learn to read, spell and write with normal proficiency. About 5-10% of the general population is said to have primary developmental dyslexia (Critchley, 1970b).

Although hotly contested, the hypothesis has been proposed that primary developmental dyslexia reflects a basically disturbed pattern of neurologic organization. Most observers have held that it is endogenous, biologic, and perhaps genetic in etiology (Rosenthal, 1977).

The diagnosis is still made largely by exclusion, and is hampered by the problems inherent in that process. Enhancing these problems, primary developmental dyslexia often does not exist alone, but may occur together with one or more of the three other major clinical entities within the framework of the learning disabilities: the motor-perceptual dysfunction syndromes, the language delays and the syndromes of distractibility, hyperactivity and decreased attention span.

Since primary developmental dyslexia has been recognized, the burden it implies for the affected individual and for society has become increasingly evident. There has been growing theoretical and therapeutic interest in this entity.

Three subtypes have been defined (Boder, 1971), and a number of workers have sought to develop type-specific therapeutic approaches to the education of the dyslexic child and adult.

Both diagnosis and therapy, however, demand further refinement. The diagnosis of primary developmental dyslexia is still made by exclusion of at least six forms of reading incompetence due to other causes. This inefficient and at times confusing procedure can be significantly reduced if neurophysiologic and anatomic bases of dyslexia and its subtypes can be specified. Such delineation can also be reasonably expected to have positive implications for improvements in therapy.

Primary developmental dyslexia is a specific, often genetically determined difficulty in learning to read, spell and write, in persons (1) whose general intelligence is average or above, (2) who have no obvious brain pathology and no significant impairment of (3) hearing or (4) vision, and (5) who initially showed no resistance to conventional instruction methods and (6) manifest no primary emotional disturbance.

BODER'S PROPOSED CONSTRUCT: READING-SPELLING-WRITING DYSFUNCTION

Boder (1971) attempted to develop, clarify, and establish primary developmental dyslexia as a useful psychological construct of reading-spelling-writing dysfunction. She also proposed that there are at least dysphonetic, dyseidetic and mixed subtypes; and suggested that these subtypes are related to different neurophysiological dysfunctions which may have genetic causes.

During the first eight months of 1968, 350 children with reading incompetence were referred by schools to Boder for testing. Children below the third grade, and those whose reading competence was less than two years below grade level as shown by the Jastek Wide Range Achievement Test (WRAT) were excluded from the study. Remaining were 107 children who were designated dyslexic, by a process of diagnosis by exclusion and in whom further testing was done. The group of 107 dyslexics included 39 siblings from 16 families.

Stressing that the reading-spelling-writing patterns have diagnostic, prognostic, and therapeutic implications, Boder defined three subtypes of dyslexia as follows:

I. Dysphonetic dyslexia (63%). Children with dysphonetic dyslexia reflect problems with sound-symbol integration and in developing "phonics skills". They tend to read globally and have difficulty with words not in their sight vocabulary. They tend to guess at words from minimal clues, often selecting one that is close in meaning but phonetically different from the word they are attempting to read (semantic substitution errors), such as "funny" for "laugh", "quack" for "duck", and "whole" for "full". Being unable to auditorize, the subject of this group reads by sight and spells correctly to dictation only those words in his sight vocabulary that he can revisualize (can form an eidetic image of the word "somewhere" and copy it). Remedial reading techniques stressing sight-see approaches may help.

II. Dyseidetic dyslexia (9%). Children in this group have little visual memory, and read "by ear" by a groping process of phonetic analysis, sounding out familiar as well as unfamiliar combinations of letters, rather than by visual-whole-word Gestalts. The child of this group spells poorly but not bizarrely ("sed" for "said"; "rit" for "right"; and "sos" for "sauce"). Words in their limited sight vocabulary that are not spelled phonetically are often written incorrectly; those that are spelled phonetically, even when unfamiliar, may be written correctly. Remedial techniques stress phonic strengths rather than visual memory weaknesses.

III. Mixed dysphonetic-dyseidetic (28%). These children, and often adults, cannot read, spell, or write "by ear" or "by eye". Even with multisensorial approaches -- visual-auditory, and especially tactile-kinesthetic -- the response to remedial teaching is painfully slow.

To raise the diagnosis of primary developmental dyslexia from being one of exclusion only, Boder has proposed a specific diagnostic screening test which purports not only to discriminate dyslexics from normals, but also to distinguish among dysphonetic, dyseidetic and mixed subtypes of dyslexia by assessing the subject's differential ability to read and then spell "known" and "unknown" words.

Convergent and supportive clinical data suggesting not only the existence of dyslexia but also that these subgroups might exist have come from other sources.

<u>JOHNSON AND MYKLEBUST'S CATEGORIES: VISUAL AND AUDITORY DYSLEXICS</u>.

Johnson and Myklebust (1967), using a wide variety of psychoeducational testing procedures, especially standardized tests of <u>reading readiness</u> and <u>reading diagnosis</u>, identified subtypes of primary developmental dyslexia which they call <u>visual dyslexia</u> and <u>auditory dyslexia</u>. The visual dyslexic usually cannot learn the word as a whole; has problems with visual discrimination, memory, analysis, synthesis, and sequencing, and tends to make reversals in reading, writing, and spelling. The auditory dyslexic may be able to associate the word <u>milk</u> with the liquid in a carton, but cannot relate the visual components of the word to their auditory equivalents. These subjects manifest problems with auditory discrimination, analysis and synthesis, and sequencing.

<u>KINSBOURNE AND WARRINGTON'S CATEGORIES: A LANGUAGE RETARDATION GROUP AND A GERSTMANN GROUP</u>

Kinsbourne and Warrington (1966) studied a group of thirteen slow readers and were able to divide them into subgroups on the basis of at least a twenty point disparity between their verbal and performance IQ scores on the WISC. Group I was a language-retardation group with a lower verbal than performance IQ, who showed other language problems such as disorders in verbalization and receptive language difficulties. The children of this group were often males, had a positive family history for learning difficulty, few or no soft signs on neurological examination, and were rather slow to acquire language. Group II, the Gerstmann group with lower performance than verbal IQ, showed specific problems on tests of finger differentiation and order as well as impaired performance on constructional tasks and mechanical arithmetic, but had neither expressive nor receptive speech or language disorders. This group was composed of children, as often male as female, in whom soft signs did appear on neurological examination, as well as left-right discrimination problems and sequence confusions in letters, causing misreading and misspelling and also poor visual memory. These children misread and misspelled by using letters that sounded right, implying that they were "attacking" the word phonetically.

BATEMAN'S CATEGORIES: VISUAL LEARNERS, AUDITORY LEARNERS, CHILDREN WITH DEFICITS IN BOTH VISUAL AND AUDITORY SKILLS; THERAPEUTIC IMPLICATIONS

Bateman (1968), on the basis of characteristic test profiles on the ITPA, identified three subgroups among children with reading disabilities: 1) those who have poor auditory memory but good visual memory, 2) those with poor visual memory but good auditory memory, and 3) those with deficits in both visual and auditory memory whose reading disability is severe and persistent. Bateman suggested that remedially, a sight-word method of reading instruction might be used for Group 1, a phonics approach would be best for Group 2, and a tactile-kinesthetic approach for Group 3.

SMITH'S CATEGORIES: THREE DIFFERENT PATTERNS BASED ON THE WISC AND THE WAIS

Smith (1970) using the WISC and the WAIS as diagnostic and research tools came to similar conclusions. Smith investigated patterns of cognitive-perceptual abilities in 300 educationally-handicapped Anglo boys between grades 1 and 6 using a control group of 74 Anglo boys attending regular classes. Three patterns of functioning were delineated in the learning disabled group; none of these was present in the control group. Pattern I (67.33 per cent) had strength in Spatial Ability and Spatial Organization, earned lower scores in Symbol Manipulation than in Spatial Organization, and were deficient in Sequencing Ability. Pattern II (14.66 per cent) had deficits in Spatial Organization and/or Spatial Ability and/or Perceptual Organization and frequently had deficits in Visual-Motor Coordination. Pattern III (18 per cent) had characteristics of both Pattern I and Pattern II.

MATTIS, FRENCH AND RAPIN'S DYSLEXIA CATEGORIES: I. A LANGUAGE DISORDER GROUP, II. AN ARTICULATORY AND GRAPHO-MOTOR DYSCOORDINATION GROUP AND III. A VISUO-SPATIAL PERCEPTUAL DISORDER GROUP

In an attempt to delineate causal factors in dyslexia, Mattis, French and Rapin (1975) assessed 113 children, referred for evaluation of learning and behavior disorders. The age range was 8-18 years.

Of the 113 tested, all had a verbal or performance IQ greater than 80, had normal visual and auditory acuity, had adequate academic exposure and showed no evidence of psychosis or thought disorder.

The 113 subjects were divided into three groups:

1. Those with brain damage who could read (n=31).
2. Those with brain damage who were dyslexic (n=53).
3. Those without brain damage who were dyslexic (n = 29).

A diagnosis of brain damage was based on:

1. A history of an encephalopathic event and subsequent abnormal development.
2. Abnormal findings on the clinical neurological examination.
3. Significant abnormalities on the elctroencephalogram or skull X-rays.

and 4. Abnormality on special neuroradiographic study (pneumoencephalogram or arteriogram).

Dyslexia was operationally defined as a reading retardation on the Jastek Wide Range Achievement Test of two or more grades below the level appropriate for age. Eighty-two childrent were classified as dyslexic. The authors felt that a most significant finding was the <u>similarity</u> between the primary developmental dyslexic and the brain-damaged dyslexic groups. On the basis of subsequent neuropsychological examinations it was often difficult to infer reliably whether or not a given dyslexic child had experienced an early encephalopathic event. The authors felt that in both primary developmental dyslexia and in the dyslexia associated with recognizable brain damage, <u>one presumes brain dysfunction</u>.

Interestingly, 79% (23/29) of the children of the non-brain-damaged dyslexic group had a family history of reading disability.

Based on a battery of subsequent neuropsychological examinations, the dyslexic children -- both the primary developmental dyslexic group and the brain-damaged dyslexic group -- were divided into three syndromes. Although primary developmental dyslexics and brain-damaged dyslexics differed in the number presenting in each of the three syndromes, there were no differences between the two dyslexic groups within the same syndrome.

Syndrome I: (31 Subjects) Language Disorder.

The children with this syndrome presented with anomia, disorder of comprehension, disorder of imitative speech, and disorder of speech-sound discrimination. They had intact visual and constructional skills and adequate graphomotor coordination.

Syndrome II: (30 Subjects) Articulatory and Graphomotor Dyscoordination.

These children may present with an assortment of gross or fine motor coordination disorders but especially with buccal-lingual dyspraxia with resultant poor speech and graphomotor dyscoordination. These children presented with intact visuo-spatial perception, language and constructional skills.

Syndrome III: (13 Subjects) Visuo-spatial Perceptual Disorder.

These children possess a verbal IQ which is at least

10 points higher than the performance IQ. Their constructional ability is poor and their visuo-spatial perception is markedly poorer. Storage and/or retrieval of visual stimuli are processed very inefficiently. These children maintain intact language, graphomotor coordination and speech-blending skills.

The authors stress that their results support a model of dyslexia as being caused by multiple independent defects in higher cortical functioning.

Convergent and supportive neurologic data suggesting not only the existence of dyslexia but also that these subgroups might exist have come from other sources.

CRITCHLEY'S DIVISION OF DYSLEXIA INTO TWO SUBTYPES: AGNOSIC (SPATIAL) AND SYMBOLIC (LANGUAGE)

Critchley (1970a), working with adult neurologically-impaired patients, suggested that there may be two types of dyslexia -- the agnosic type, and the symbolic type. Agnosic dyslexia was said to represent an underlying disorder of spatioconstructional manipulations, whereby geometric and other figures cannot be either assembled or interpreted as letters. Standing in contrast are the more usual cases, in which it is the symbolic nature of the print or writing that cannot be understood -- the grapheme-phoneme relationship. Critchley also stated that it is possible to distinguish left parietal dysgraphia from right parietal dysgraphia, the latter being characterized by gross defects in spatial arrangements, often with an inordinately broad left margin.

HECAEN'S DISTINCTION BETWEEN LEFT AND RIGHT PARIETAL ALEXIAS AND AGRAPHIAS

Subdivisions of the dyslexias (alexias) had been noted by Hecaen (1967) in his discussion of brain mechanisms. In studies of the parietal lobes he had noted that the alexias and agraphias of right parietal lesions differ from those caused by left-sided lesions; the latter bear on the comprehension or transcription of the graphic code. The alexias and agraphias due to right parietal lesions are disturbances in writing and reading which come from perceptual difficulties with the spatial arrangements of letters and sentences. Spatial dyslexia is characterized not only by neglect of the left side of the text, and sometimes by neglect of one or more words (or more likely, of a part of a word), but also by difficulty in passing from one line to another. Occipital as well as parietal lesions may be involved. Those features of spatial dysgraphias that separate them from the dysgraphias due to lesions of the left hemisphere include writing on the right side of the page, inability to write in a straight line (diagonal or wavy writing), and alterations involving mainly the vertical strokes (m, n, i, v) and more rarely letters or words. These alterations usually do not destroy the actual structure of the word, which remains legible, and the grammatical structure of sentences is never altered.

LURIA'S CONTRIBUTION RELATING TO DIFFERENCES IN SEQUELAE OF LEFT AND RIGHT BRAIN LESIONS

Luria (1973) discussed the differences in pathology between lesions of the left and right hemispheres. Massive lesions of the right parieto-occipital region interfere with processes of spatial gnosis and praxis, a most significant feature of which is unawareness of the left half of the visual field manifested not only when complex drawings are examined during reading, but also in the patient's spontaneous writing and drawing. On the other hand, lesions of the parieto-occipital zones of the left hemisphere at times specifically relate to components of reading from the points of view of higher symbolic processes, complex logical grammatical structures, and also specifically phonetic analysis. Disturbances of phonemic hearing arise only in lesions of the left temporal lobe. At times, the principal feature of the clinical picture is that the patient cannot retain even a short series of sounds, syllables, or words in his memory (i.e., auditory sequencing difficulty). The patient either confuses their order or simply states that some of the elements of the sequence have been forgotten.

Supportive and convergent scientific data from different sources exist that strengthen the concept of differential and specialized cerebral (hemispheric) functioning in adults. In recent years testing for and information relating to cerebral dominance (differential functioning and lateralized specialization) have come from:

1. Cortico-Anatomical Techniques (hemispherectomy, Lenneberg, 1967; cortical mapping, Penfield and Roberts, 1966; and split-brain surgery, Sperry and Gazzaniga, 1967).
2. Intracarotid Sodium Amytal Techniques (Wada and Rasmussen, 1960).
3. Dichotic Listening Techniques (Bakker, 1969).
4. Dichoptic Techniques (Kimura, 1969).
5. Regional Cerebral Blood Flow Techniques (Ingvar and Schwartz, 1974).

It has been suggested that the two hemispheres are not functionally equivalent and that the left hemisphere processes analytic, language, verbal, and linear-reasoning tasks; the right hemisphere is involved with processing information of a Gestalt, holistic, synthetic spatial-geometric-relational nature.

Supportive and convergent electrophysiologic data exist that strengthen the concepts of cortical specialization and differential hemispheric utilization in adults. The excellent and comprehensive reviews by Callaway (1975) and Donchin et al. (1977) sum and integrate the earlier work of Bogen, Ornstein, Buchsbaum and Fedio, Brown et al., Morrell and Salamy, Galin and Ornstein, Doyle et al., Dumas and Morgan. Asymmetry of cortical functioning can be reflected in asymmetric electroencephalograms (EEG) and averaged evoked cortical potentials, depending upon the evoking stimulus and the type and location of the cognitive process that stimulus sets into motion.

Tasks presumed to utilize the left hemisphere differentially have included composing letters, word search tasks, mental arithmetic, and "verbal" listening. Right hemisphere tasks have included modified Kohs Blocks, Seashore Tonal Memory, drawing tasks, spatial imagery tasks, and music listening tests.

An overview of most of these studies indicates that the independent variable is defined in terms of tasks assigned to the subject. The dependent variable is some parameter of the scalp-recorded EEG activity. Studies are of two categories according to the dependent variable utilized (Donchin et al. 1977):

1. Those studies which focus on the ongoing EEG activity and in which frequency domain parameters are measured.

2. Those studies which analyze the EEG in the time domain which are concerned with waveforms of event-related potentials (ERPs) taken from the EEG by signal averaging.

1. Until recently, neurophysiological studies attempting to establish correlations between specific reading disabilities and EEG tracings have not been particularly helpful (Klasen, 1973), even though the incidence of abnormal EEGs is higher in children with minimal brain dysfunction than in normal controls (Boder, 1971). Critchley (1970b), reviewing EEG studies in dyslexia, noted that mild dysrhythmias suggestive of cortical immaturity are often found, which may be most evident in the parieto-occipital areas bilaterally. Among the problems in the interpretation of EEG data which

Critchley mentioned are the coexisting positive "soft" neurological findings which are more conspicuous in younger dyslexics, and the confused diagnostic standards for dyslexia in older groups, wherein psychiatric overlays are quite prominent.

Recognizing that there are differences between the EEGs of dyslexics and normals, but that refinements of technique were required, Sklar (1971) examined twelve dyslexics (ten boys, two girls, aged nine to eighteen years) in whom all of Boder's three subgroups were represented, but most were of Subgroup I (dysphonetic). The EEGs were evaluated not by direct visual inspection, but by a computer search for disparities, following which a computer classification of normal and dyslexic children was rendered, using spectral analysis of their EEGs. Sklar found that the two groups could be differentiated especially during the rest, eyes-closed phase. The most prominent spectral differences appeared in the parieto-occipital region; the dyslexic children on the average had more energy in the 3-7 Hz and 16-32 Hz bands -- the normals, in the 9-14 Hz band (Hz refers to a unit of frequency in the EEG equal to one cycle per second). However, during the actual reading task the autospectral disparity between the two sample populations was reversed at 16-32 Hz, in that here, normals had greater energy. The mean coherences for all activity within the same hemisphere were higher for dyslexics, whereas the coherences tended to be higher for normals between symmetrical regions across the midline. However, if the EEG, or more specifically, the coherences between hemispheres, is taken as an index of the transfer of information in the central nervous system, then the greatest differences between normals and dyslexics might have been expected to occur during the reading task, rather than during the state of rest, eyes-closed.

Hanley (1975), working with adult dyslexics (not subgrouped according to the Boder classification) noted that in general, the findings with respect to shared activity as calculated from the coherence function were similar to those in children, in that those without dyslexia showed greater shared activity between symmetrical placements across the hemispheres. Hanley took this to be valuable evidence of the robustness of the coherence findings in the face of known maturational processes in the EEG in the progression from childhood to adulthood. In addition, Hanley believed he could visually assess the standard EEG without computer aid and diagnose dyslexia. He believed that dyslexics generate more theta activity (4-7 Hz) from the parieto-occipital areas bilaterally than do non-dyslexics, and that the dyslexics show at the same time broad-band alpha, which is poorly defined and spread out over the 8-14 Hz band.

Callaway and Harris (1974) have described a new way to assess how the central nervous system processes data by intrahemispheric measures of coupling between cortical areas. When two areas of the brain are in active functional communication, then some relationship should exist between the EEGs from these two areas. The two EEGs can at any instant be classified on the basis of polarity and direction of change of potential (that is, slope), and the results of such a classification can be used to measure coupling. Functional communications between the visual area and each of the left and right hemispheres were manipulated by assigning verbal (left hemisphere) and spatial (right hemisphere) tasks to nine right-handed subjects. Their results indicated that appositional (right hemisphere) processing of visual data (examining a picture) tends to increase coupling between the occiput and the right hemisphere; and propositional (read silently-left hemisphere) processing tends to increase coupling to the left. Changes in EEG coupling that accompany changes in cognitive processing support the idea that the EEG is actually related to electrical events involved in information processing of the central nervous system.

Bali et al. (1975) cited the work of Davis and Wada (1974), who measured coherences between averaged evoked potentials recorded from temporal and parietal leads and found that clicks induced more coherence in the speech dominant hemisphere than on the other side, and that flashes produced more coherence in the other, non-speech dominant hemisphere. Bali et al. replicated the Davis and Wada data by using the same stimulus paradigm but a method of EEG analysis by cortical coupling. In right-handed subjects, the left-right ratio for clicks was found to be greater than the left-right ratio for flashes for frontal-parietal lead pairs.

In a preliminary study, Bali et al. (1975), working with eleven older dyslexics (not divided into clinical subgroups) found a reversal of their results obtained with normals. Nine of the eleven dyslexics showed left-right ratios of coupling higher for flash than for clicks.

2. There are comprehensive and excellent reviews of the development of measures for averaged evoked cortical potentials (Callaway, 1975; Donchin et al., 1977; Yingling, 1978; Halliday, 1979; Regan, 1979). The EEG is a continuous record of ongoing variations in electrical potential (voltage) between pairs of electrodes. The correlation between a particular sensory signal and the ensuing electrical response of the brain was firmly established in the mid and late 1930s, but much refined only since the early 1960s. These potential fluctuations may be referred to as event-related potentials (ERPs). The ERP technique has greatly assisted the neurophysiologist in the tracing of sensory impulses along specific afferent systems to their terminals in the cortex. However, because the sensory ERP, as recorded from the scalp is relatively small (4-15 microvolts) with respect to the background EEG (20-100 microvolts), the accurate mapping of the minute current fields set up by the deliberate stimulation of a sense organ had to await the development of special purpose computers (averagers). With these devices repetitive samples of EEG are automatically summated. Electrical activity which is unrelated to the onset of a stimulus tends to cancel with successive sweeps while the ERP, initiated by the stimulus reinforces itself, so that it can be quantified. Since the EEG background activity

(noise) is not correlated with the stimulus (signal), but varies randomly in relation to it, the summed background noise builds up much less rapidly than the summed evoked potentials (ERPs). Thus, is the signal-to-noise ratio enhanced. When an adequate number of individual ERPs (30-100) have been summed and stored, the automatic averaging computer calculates the average amplitude of each point on the trace and displays the average curve.

An EEG-ERP system requires high quality, high gain amplifiers (to amplify the signal with a minimum of distortion), an analog to digital converter (to digitize the signal), a device to average the digitized signal, a means of storing the data for later analysis, and peripheral equipment to generate signals.

The ERP presents itself as a complex sequence of polarity reversals consisting of a series of voltage changes (peaks, amplitudes) that occur at reliable time points following a stimulus. ERPs may endure for 500 msec or more. Each deflection varies somewhat depending on the modality stimulated and on the locus from which it was recorded. Although there is some specificity of response following auditory, somatosensory and visual stimulation, a certain degree of similarity across modalities is also apparent. There are several specific measurement techniques, designed to reduce the large data volume of ERPs (one ERP may consist of 25,000 data points):

1. Measures of latency and amplitude for each component of the ERP waveform are obtained. Special purpose computer programs have been developed to sequentially sample these measures.

2. These measurements focus on the broad features of the ERP. Computer programs exist which can measure power-amplitude of the entire ERP waveform or any latency band components therein.

3. Multivariate statistical procedures are applied to the ERP waveform. Specific applications of one or more of these measurement techniques depend on theoretical, technical and instrumental considerations.

Numerous classification systems have been devised to describe the various undulations of the ERP response. The most universal scheme divides the ERP waveform into early (exogenous) and later (endogenous) components. The post-stimulus exogenous components (up to 60-100 msec) represent stages in the afferent stream and these deflections can only be recorded in association with some sensory stimulus. Their scalp distribution depends on the modality of the stimulus (e.g. auditory, visual) and their morphology on the physical parameters of the stimulus.

There are measurable very early components of the ERP (up to 10 msec) which are called the far-field or brainstem response. For example, in response to an auditory stimulus the far-field response would include the first five waves (components) which are thought to reflect the activity of various relay nuclei in the auditory pathway. Since the brainstem response does not require voluntary cooperation, it can be elicited in newborns and others with limited behavioral repertoires. The exogenous components are sensitive to changes in the intensity of a stimulus but do not reflect higher cognitive activity. By contrast, the later ERP components are affected by psychological factors, are sensitive to task parameters and are believed to be manifestations of cortical information processing activities invoked by task demands. A distinct class of pre-event endogenous components relate to preparatory or anticipatory cortical activity and can occur when subjects just expect a stimulus (contingent negative variation or expectancy wave at about 500 msec).

Naming of late components is a problem and even a danger if the assignment of a name lulls us into thinking that naming something is the same as knowing what it is (Callaway, 1975). All waves from 30 msec on are not equivalent, regardless of whether or not components can be named. Positive potentials do not have the same significance as negative potentials. There are good arguments for using monopolar recordings (one active scalp electrode and a relatively inactive reference electrode such as linked ears). Some laboratories favor bipolar recordings resulting in a mixed contribution from both active electrodes. Modality differences in ERPs occur, e.g., somatosensory, auditory, visual. Still there are some general thoughts about the endogenous components. Waves from about 100-200 msec may reflect simple attention or perhaps early selective attention. Components from about 200-400 msec may reflect more complex recognition, discrimination and perhaps stimulus categorization.

Recent efforts have established the diagnostic utility of the ERP technique, particularly in the assessment of sensory integrity, the tracking of central nervous system maturation and in the anatomical localization of lesions. Cortical auditory, visual and somatosensory ERPs have respectively provided valuable information on hearing loss, visual disorders and peripheral, spinal cord and cerebral lesions. Computer based averaging procedures have been used to study central nervous system development. Changes in amplitude, latency and waveform of the cortical evoked responses have been shown to correlate highly with cerebral maturation. For example, with increasing age, ERP late components become more stable, and ERP variability and latencies decrease. Attempts to correlate abnormalities in specific brain-stem ERP components with localized brainstem lesions have demonstrated the usefulness of this method in determining the site of neurological damage. Starr and Achor (1975) used the brain-stem ERP to distinguish structural from metabolic conditions affecting brainstem pathways. Drug-induced coma did not alter the brainstem response. However, the anatomical localization of brainstem and midbrain tumors was greatly facilitated by brainstem ERP recordings. In a study of over 100 patients, Stockard and Rossiter (1977) correlated parameters of the auditory brainstem ERP with postmortem or radiologic identification of brainstem lesions. They found that neurologic embarrassment (tumors, vascular lesions, infarcts, hemorrhage, etc.) at the level of the pontomedullary junction, caudal pons, rostral pons or midbrain, thalamus and thalamic radiations, coincided with modifications of waves II - VII respectively.

Taken together, these studies demonstrate the potential diagnostic and prognostic value of the ERP technique. The success thus far achieved with regard to specific neurophysiological and anatomical dysfunction has encouraged the application of ERP technology to the understanding of brain organization in general, especially in more subtle areas of cerebral dysfunctioning and learning disabilities. Particular emphasis has been placed on lateralized specialization of function.

Callaway (1973) has shown that there are positive correlations between ERPs and more conventional measures of intelligence. More importantly, these positive correlations show that one can obtain a reflection of the _relation between ongoing neurophysiological and cognitive states_. Callaway found that brighter subjects show shorter latencies, lower ERP variability, and plasticity of the evoked response. The plasticity will correlate with intelligence only when intelligent subjects _would be expected_ to be more plastic, in that they would be expected to show more change than the less bright, from task to task, in their cognitive responses.
In broader terms, the issue is not whether ERPs can predict

intelligence, but whether or not the ERP measures individual differences in brain function (Halliday, 1979). The relation between ERPs and intelligence probably reflects the differences in subjects' ongoing cognitive processing rather than hard-wired differences in neurophysiological organization. Therefore, it would appear more appropriate to examine how specific psychological processes like attention and memory and different task requirements affect the ERP.

Beck and his associates (Dustman, Schenkenberg, and Beck, 1976) were among the first to examine the hemispheric distribution of evoked cortical activity. They found that responses to simple visual stimuli (flashes) were consistently larger over the right parietal area of children and adults. Left-right amplitude differences were not seen in mongoloid or mentally retarded children.

Buchsbaum and Fedio (1970) reported hemispheric differences in ERPs to verbal and nonverbal stimuli presented to the left and right visual fields. Activation of the left hemi-retina-hemisphere (dominant) yielded greater differences in ERP waveforms for the two classes of stimuli.

Yet inconsistencies appear in studies of the laterality of visual ERPs (Donchin et al., 1977). Studies of hemispheric differences in visual ERPs have been particularly hampered by the need to assure that the ERP elicited by stimulation of a retinal half field is generated entirely within a single hemisphere. Whereas it has been well-established that stimulation of different visual half fields elicits different scalp distributions, the comparison of the hemispheric distributions of visual ERPs are not as straightforward. Several investigators have reported that visual ERPs recorded over homologous regions in normal subjects are symmetric. Other researchers, however, have maintained that visual ERPs recorded from the right hemisphere are larger than those recorded from the left hemisphere.

Galin and Ellis (1975) felt that asymmetries in evoked potential amplitude might be in part dependent on asymmetries in the alpha amplitude of the background EEG, which the authors believed to be a function of the particular and preferred cognitive mode the subject is using. Galin and Ellis recorded flash evoked potentials and background EEG in six right-handed adults from left and right temporal and parietal areas not while the subjects were "at rest", but rather while they performed specific verbal (writing from memory) and spatial (modified Kohs Block Design) tasks. Previous studies had shown that in spatial tasks (right hemisphere) the alpha ratio (right/left) was lower than in verbal tasks (left hemisphere); the hemisphere engaged by the task develops proportionately less alpha power. In this study the authors found that the overall power and peak amplitude characteristics of the evoked potential asymmetry reflected lateralization of cognitive processes but not as consistently as the concomitant asymmetry in EEG alpha power. Such results are provocative and suggest that baseline asymmetry in ERPs may depend upon variability in on-going EEG activity which may, in turn, depend upon subject state variables.

Considerable controversy exists regarding the lateral distribution of the various components of auditory ERPs (Donchin et al., 1977). The maximal contralateral projection to the auditory cortex as well as the oft-observed dominance of one ear over the other in dichotic listening tasks suggest that, at least under certain conditions, different auditory ERPs should be recorded over the two hemispheres. Most investigators concur that right and left ear stimulation generate different scalp distributions, but there is no agreement on the specifics of these distributions. The majority of reports maintain that there is a general predominance of the contralateral response; some find the difference as a shorter latency response, others as a larger amplitude response, and a few in both of these measures of the contralateral response. Some investigators reported a small but consistent tendency for larger responses to appear contralateral to the stimulated ear, but the effect was greater over the left hemisphere in response to right ear stimulation. Other researchers report that the right hemisphere response is consistently larger only for left ear stimulation.

Morrell and Salamy (1971) studied hemispheric difference to natural speech stimuli (phonemic sounds-nonsense words) versus pure tones. They were able to show that verbal ERPs were larger on the left side of the head. The greatest asymmetry occurred over the tempro-parietal region. This effect became reversed when tone stimuli were presented. They also observed a posterior-anterior gradient with the size of the

ERP becoming progressively smaller as the recording electrode was moved forward. This relationship was most orderly over the left hemisphere in response to speech sounds.

However, different results were found by Davis and Wada (1974) who computed the coherence functions between occipital and temporal scalp regions following simple click and flash stimuli. The ERP to clicks generated greater occipital-temporal coherence on the speech dominant side whereas the non-dominant side showed a greater degree of similarity (in the 6 - 15 Hz band) to flashes of light. These results, according to the authors, indicate that hemispheric asymmetries exist for unstructured, nonverbal stimuli and suggest that coherent processes of the brain, as seen in surface recordings, are related to the perception of visual and auditory forms; and that ERP asymmetry may not necessarily be dependent on cognitive-complex stimuli only. Davis and Wada assume that high coherence on a side indicates increased data processing on that side. There is, however, an alternative view (Callaway, 1975). Perhaps, as they suggest, clicks are processed on the dominant side more than are flashes -- but that does not seem necessarily to follow, since evoked potentials may show more differentiation (with lower coherences) on the side where the principal processing is being carried out. Even if the explanation given by Davis and Wada is not entirely satisfactory, their observation is apparently replicable (Bali et al., 1975).

Callaway (1975) feels that asymmetry of cortical function can be reflected in asymmetrical ERPs and EEGs. As a working hypothesis, he suggests that the ERP is more differentiated when recorded from the hemisphere presumed to be most involved with cognitive processing of the evoking stimulus. With simpler processes, the ERP over the engaged hemisphere may be larger; but with more complex processes the ERP may be more complex and smaller -- perhaps due to a less homogeneous set of ERPs being included in the average.

Recent experimental data is available based upon more involved and sophisticated designs relating to ERP asymmetries associated with cognitive functioning and linguistic processing. Earlier experiments had involved tasks and discriminations pertaining to more basic perceptual units, i.e., clicks, tones and flashes. Recent studies of ERPs are designed more to assess higher cognitive processing such as verbal versus non-verbal variables, relevant versus irrelevant stimuli, different language types and noun-verb differences. Usually, either an auditory or a visual modality is involved; at times, both.

Matsumiya et al. (1972) compared the auditory ERPs from two bipolar recordings, W_1-P_3 and W_2-P_4 in four conditions:

1. Undiscriminated words
2. Undiscriminated sounds
3. Discriminated sounds (task was to tally the different types of sounds)
4. Meaningful speech.

The conditions were designed to contrast low and high significance levels of noises (conditions 2 and 3) and low and high significance levels of words (conditions 1 and 4). The wave (W wave) with peak asymmetry occurred 100 msec after stimulus onset. When the subject had to use the meaning of each word maximally (condition 4) the asymmetry was largest, seen as increased peak to peak amplitude of the W wave in the left hemisphere relative to the right (P= .01).* The same was true but to a lesser extent for the sounds (condition 3) (P = .05). No group statistical significance was found between words in condition 1 and sounds in condition 2. The authors ascribe this hemispheric asymmetry, for both words and sounds, to the <u>significance</u> (or meaningfulness) of the auditory stimuli for the subject rather than to the linguistic features of the stimulus (verbal versus non-verbal materials).

Goto et al. (1979) studied ERPs during processing of linguistic information to determine whether or not ERPs could be useful for testing the recognition of Japanese sentences and words. In the Japanese orthography, two types of non-alphabetic symbols, Kana (phonetic symbols for syllables) and Kanji (logographic symbols representing lexical morphemes) are used in combination. For <u>sentence recognition</u>, subjects were required to respond with different key presses when sequentially presented sentences, <u>visual or aural</u>, were recognized as meaningful or meaningless by key information in the presentation. In healthy subjects, P300 amplitudes (from C_3 and C_4 referenced to ipsilateral mastoid processes) to the

* (P =) means less than or equal to.

beginning of information and to the key information were larger than those to the other parts of the presented information. A delayed semantic matching paradigm using synonym, antonym and semantically neutral word pairs was used in the word recognition test; and subjects were required to press a different switch according to semantic match or mismatch between either two successive Kanji or two successive Kana words, but they were presented only visually. In healthy right-handed subjects P300 and P650 amplitudes (temporal and parietal leads referenced to linked ears) to the second Kanji showed a right greater than left asymmetry. P300 amplitudes to the second Kana words showed the same, but P650 amplitudes to the second Kana words showed a left greater than right asymmetry.

These findings, the authors felt, were compatible with the hypothesis that Kana and Kanji are processed differentially in the hemispheres.

Recent research by Brown and Lehmann (1977) has focused upon ERPs evoked by noun and verb meanings of homophones ("a pretty rose", "the boatman rows"). Comparing the ERP scalp field topographies, the maps were searched for the location of maximal positive (peaks) and negative (troughs) values. There was a general tendency for the peaks of the noun fields to be located to the right of the verb fields and vice-versa for the troughs. A second group of three Swiss-Germans who listened to comparable Swiss-German sentences demonstrated similar tendencies but lower reliability. The authors feel that these results show that neural fields are differentially activated by nouns and verbs, which suggests that topographically different neural populations process nouns and verbs.

Since higher cortical functions are beginning to be studied in normals, recent research has been aimed at disclosing subtle differences in the brain organization of cognitively impaired subjects. These studies employ the cortical ERP as a means of distinguishing normal and learning disabled children. Particular emphasis has been directed toward the problem of primary developmental dyslexia.

The experiments of Fenelon (1968), Fenelon (1978), Conners (1971), Shields (1973), Preston et al. (1974), Preston et al. (1977), Weber and Omenn (1977), Sobotka and May (1977), Lux (1977), Symann-Louett et al. (1977), Njiokiktjien et al. (1977), Shelburne (1978), Musso and Harter (1978) and Fried et al. (In press) are summarized in Tables I - XVII.

TABLE I

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Fenelon-1968 Expectancy Waves and Other Complex Cerebral Events in Dyslexic and Normal Subjects	Two (2) dyslexic children Dyslexia diagnosed on the basis of unconflicting case history and scholastic psychometric, and speech therapy evidence.	Two (2) normal children and four (4) normal young adults	Standard silver, silver-chloride scalp electrodes secured by a rubber headcap. Vertex potentials from C_z obtained - referenced to right mastoid. Pure tones delivered binaurally via stereo headphones. Single flashes were provided by a photostimulator. Semantic stimuli were back projected to a milk glass screen. To evoke the classical Contingent Negative Var. (CNV), a single flash (S_1) was followed by a 1000 CPS tone (S_2) of mildly unpleasant intensity. For the consonant-vowel-consonant (CVC) series, trigrams (S_2) were presented serially. Adult subjects were to find word associates as quickly as possible. Children Continued.	For the CVC series, the 6 year old dyslexic developed no expectancy (E) wave in the S_1-S_2 interval. The temporal association of the two stimuli and the contingency involved produced no expectancy in the child, as if verbal stimuli held no meaning or significance. In the post S_2 period, a positive component is totally lacking which may be interpreted as an indication of continuing general expectancy already indicated in the large post S_2 negative wave. The records of the 6 year old normal and the 8 year old Continued.

TABLE I (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
			were asked to think of similar but real words as quickly as possible.	dyslexic are similar, but they differed markedly from those of the 8 year old normal and adults, and also from that of the 6 year old dyslexic. Upon inquiry, it was noted that the two normal children matched words to the trigrams in some instances. The dyslexics appeared not to have such verbal associations.

TABLE II

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Fenelon - 1978 Hemispheric Effects of Stimulus Sequence and Side of Stimulation on Slow Potentials in Children with Reading Problems.	Seven (7) problem readers, (mean age 114 (±11.6) months), mean IQ 113.4 (±12.8) but retarded 12 months or more in reading achievement on at least 2 of 3 group reading tests. All subjects were uniformly right-handed.	Seven (7) normal readers were of comparable chronological age (114 (±5.4) months) and intelligence (mean IQ 117 ± 13.4). All subjects were uniformly right-handed.	Ag/AgCl electrodes were applied to the scalp at sites F_4, F_3, P_4, P_3 and referred to common mastoids. Audio signals were 700 Hz or 1000 Hz pure tones of 100 msec. duration-delivered through earphones at 70dB. Visual signals were low-intensity flashes, subtending a retinal angle of 1 degree and displaced about 9 degrees from a central unilluminated fixation spot. The paradigm was a simple S_1-S_2 motor response sequence, the subject responding to S_2 with a button held in the right hand. Following training trails, the experiment was conducted in two stages: Continued.	Data from unimodal and bimodal conditions were submitted to 2 (groups) X 2 (stimulus conditions) X 2 (hemispheres) X 2 (anterior-posterior locations) analyses of variance. Correlation coefficients were computed from group-average data for each wave form pair by shifting in one point increments ±64 points from the origin. The data for unimodal visual stimulation and for bimodal stimulation do not support the hypothesis that CNV develops comparatively weakly in the left parietal region of problem Continued.

TABLE II (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
			1. On-line averaging of 8 eye-movement-free responses (where: A_1=700 Hz tone, A_2=1000 Hz tone, V=visual stimulus, L=left ear or left visual field and R=right side) in each of the following conditions: LV_1-LV_2, RV_1-RV_2, LA_1-LA_2, RA_1-RA_2 2. Each subject received 16 trials each for: A_1-RV_2 and RV_1-A_2 (binaural 1000 Hz stimulation) in predetermined random sequences. Various slow potential measures were taken using off-line cursor and integration programs. The analyses	readers. Some support for this is derived however, from the auditory stimulation data. In the right hemisphere during right-sided stimulation, frontal parietal correlations are lower in problem readers than in normals. Conversely in the left hemisphere, during left-sided stimulation, frontal-parietal correlations are lower in normals than in problem readers.

Continued.

TABLE II (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
			reported are based on maximum peak-to-peak CNV amplitudes measured during the interval from 400 msec past S_1 to the onset of S_2. Maximum positive peak was determined for the unimodal sequences, in the interval 400-480 msec post S_1. In the bimodal sequences post S_1 positivity was prolonged and the corresponding point was taken in the 650-730 msec interval. Maximum negative peak in both sequences was measured in the 80 msec interval prior to S_2.	

TABLE III

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Conners (1971[1]) Cortical Visual Evoked Response in Children with Learning Disorders	6 family members, index case-male age 11.6, sister age 15.0, sister age 9.9, brother age 13.8, father age 37.3 = poor readers and mother age 36.9= good reader	None except mother	Active leads to scalp at O_1, O_2, P_3 and P_4 with a ground at F_{pz} and referencing to C_z. (International 10-20 system). All stimuli presented with eyes closed. Dim and bright flashes presented. S's instructed to press telegraph key to dim (1/5 of total) flashes. Stimuli delivered at 1.6 second intervals. 64 trials were averaged for each subject.	Left parietal visual evoked response (P_3) noticeably attenuated at 200 msec. (N200-negative component) for index case and in poor readers. Whereas O_1 and O_2 and P_4 are highly similar in waveform and amplitude. Mother (good reader) shows very little difference in waveforms with O_1 and P_3 leads having similar morphologies.

TABLE IV

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Conners (1971[2]) Cortical Visual Evoked Response in Children with Learning Disorders	27 subjects, 3rd and 4th graders, mean age 9.9 years, attending summer remedial reading institute for children with learning disabilities.	None	Same as in Conners 1971[1]	Correlation coefficients between visual evoked responses and scores on the Wide Range Achievement Test were computed. In each case good reading achievement directly related to amount of negativity (voltage) at 200 msec at the P_3 electrode.

TABLE V

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Conners (1971[3]) Cortical Visual Evoked Response in Children with Learning Disorders	20 male students aged 9-15, mean 11.9 years. 10 of the worst readers matched with 10 of the better readers on age, I.Q., and social class, at a private school for children with learning disorders.		Same as in Conners 1971[1] - Reading achievement scores used to calculate a learning quotient. Mean learning quotient for poor readers = 75.2, for good readers = 98.1.	Same as in Conners 1971[2]

TABLE VI

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Conners (1971[4]) Cortical Visual Evoked Response in Children with Learning Disorders	25 children from Learning Disabilities Clinic, half with low verbal-high performance I.Q. (WISC) and half vice-versa. Children matched on full scale I.Q., age and sex.		Same as in Conners 1971[1].	Latencies of N200 significantly increased at O_1 and O_2 in high verbal-low performance group. Low verbal-high performance subjects had higher amplitudes of P140 at P_3, P_4 and O_2.

TABLE VII

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Shields (1973) Brain Responses to Stimuli in Disorders of Information Processing	10 children between the ages of 10-13 who exhibited learning disabilities in processing visual information. All had verbal I.Q.s of 90 or above on WISC. The subjects were defined as having difficulty in visual processing if they scored below to 30th percentile on comparison to a normative population on 4 or more of 10 tests of visual processing.	10 normal children matched to experimental group on basis of age, sex, handedness, verbal I.Q., and socioeconomic status, but received scores above the 30th percentile on all tests in the battery of measures of visual processing skills.	Average evoked responses were recorded from corresponding scalp locations in the ROLANDIC area of each cerebral hemisphere (C_3, C_4). Light flashes, pictures, designs, words and nonsense words used. 100 stimulus items used--20 of each type--each exposed for 500 msec with random intervals of 4 to 8 seconds between stimuli. Order of presentation of stimuli randomized for each subject.	Average amplitudes and latencies for AER (visual) peaks compared by t-tests between normal and learning disabled group. In learning disabled children, the latencies of the AERs significantly longer than in normals. (True for all component peaks-P_1, N_1, P_2, N_2, and P_3 - but peaks not specified in msec from stimulus). Peaks P_1 and P_3 were larger in amplitude in learning disabled group.

TABLE VIII

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Preston, Guthrie, and Childs (1974) Visual Evoked Responses (VERs) in Normal and Disabled Readers	9 disabled readers, mean age 9 yrs. 9 mos., mean I.Q. of 103 (PPVT)*, reading level of 2.3 (Gates-MacGinitie Test) *Peabody Picture Vocabulary Test	2 groups (1) matched on age and I.Q. (2) matched on reading level and I.Q.	4 types of visual stimuli 1) 50 msec light flash 2) 300 msec light flash 3) 50 msec exposure to word "cat" 4) 300 msec exposure to word "cat". Interstimulus interval was 1 sec with 50 stimuli presented for each run. For all S's, 8 runs were made with 2 presentations each of the 4 types of stimuli. The order was randomized. Electrodes attached to O_1, O_2, P_3, P_4, C_z. Reference electrode to the left mastoid and a ground to the forehead.	Purpose to replicate Conners (1971) findings. Disabled readers showed substantially lower amplitudes than control groups (1) and (2) at 180 msec at P_3 for light flashes and words. It is assumed that the electrode at P_3 reflects activity in the area of the left angular gyrus. Also the stimulus "cat" produced larger negative amplitudes than the light flash in all 3 groups including the disabled readers.

TABLE IX

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Preston, Guthrie, Kirsch, Gertman, and Childs (1977) VERs in Normal and Disabled Adult Readers	9 disabled readers with at least one reading disabled child. Adults Average age = 40.12 years. Scores on Gray Oral Reading Test = 68.11. Scores on WRAT spelling = 7.17. Scores on Slosson IQ = 112.67.	9 normal readers who had no children with reading disabilities. Adults - Average age = 36.24 yrs. Scores on Gray Oral Reading Test = 91.78. Scores on WRAT spelling = 12.89. Scores on Slosson IQ = 124.78.	Each subject tested twice under two conditions. (1) 100 msec non-patterned flashes of white light presented. (2) A series of 3-letter words used as stimuli-(tin, din, bin, pin, sin, bid, bit, bum, ban, bun) Each run = 50-stimuli with an inter-stimulus interval of 2 sec. For word runs, each of the ten words occurred from 3-7 times in pseudo-random order with no word succeeding itself. For the word runs, S's counted silently the number of times bin occurred on the first run and tin on the second. Electrodes were attached to P_3, P_4, O_1, O_2--all referenced to linked Continued.	Variables were (1) stimuli (flash vs. words) (2) hemisphere -- (right vs. left) (3) placement (parietal vs. occipital) (4) groups (normal vs. disabled). Results were: (1) Increased amplitude for P200 and the LPC on the left side for word stimuli only. (2) Increased LPC amplitude on the parietal leads compared to occipital for flash and word stimuli with greater increase for words. (3) A larger difference exists between words and flash on the left parietal electrode for normals compared to disabled readers on the Continued.

TABLE IX (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
			mastoids. 4 measures of amplitude taken. (1) Peak to peak measures for P100-N140. (2) Peak to peak for N140-P200. (3) P200 from baseline. (4) A late positive component (LPC) = average of positive amplitudes from baseline at latencies 250, 350, 450 and 550 msec.	P200 and LPC measures.

TABLE X

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Weber, and Omenn (1977) Auditory and Visual Evoked Responses in Children with Familial Reading Disabilities	Study 1: 3 large families with many members with specific dyslexia were located via the school district. 3 members from Family "W", 3 members from Family "C", 5 members from Family "G". The diagnosis of dyslexia made via one or more of following tests: A. School academic records B. Slingerland Screening Test C. Boder word lists D. Parent interviews. All available I.Q. scores	Study 1: 10 (9?) non-affected family members from the 3 families. Study 2: None.	Recording electrodes positioned over each parietal area referenced to linked mastoids. The visual stimulus was a light flash from a photostimulator which was 100 cm from the subject's nose. The auditory stimulus was a 200 msec burst of white noise via binaural earphones at a level of 70dB. Each subject received randomized presentation of 64 light flashes and 64 noise bursts. The mean duration of the variable interstimulus interval was 3.7 sec. Each subject was randomly assigned to push a button for either flash or noise (for arousal level). 4 AERs (2 stimuli x 2 hemispheres) obtained	Study 1: 3 of 11 affected family members showed reduced VERs from the left hemisphere. But 2 of 9 normal family members showed the same. ALSO, the number of subjects showing smaller left hemisphere responses is offset by about an equal number of subjects showing small right hemisphere responses (in the dyslexics). A comparison of hemispheric asymmetry in microvolts showed no differences between the two groups for VERs and AERs. But the dyslexics showed large AER
	Continued.		Continued.	Continued.

TABLE X (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
	were 100 or above. "Dyslexics" showed test results at least two years lower than expected for chronological age and nonverbal I.Q. Study 2: 18 additional dyslexic children.		from each subject. Amplitude measurements for the VERs obtained by measuring difference between N150 and P190 msec. Amplitude of the AERs based on difference between N100 and P200 msec. Study 2: Same paradigm as Study 1	and VER latencies--agrees with Shields (1973). Study 2: Analysis based on 18 children with dyslexia and eldest affected child of 3 families of Study 1. There were children who demonstrated smaller AERs and VERs over the left hemisphere than the right (6 for AER and 5 for VER) but as in Study 1 this was offset by children who showed the opposite effect (3 and 4 children respectively). A comparison of the group left-right amplitude differences showed no difference for AER or VER. Subgroup- Continued.

TABLE X (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
				ing the children via types of spelling errors, handedness, or most affected sensory modality (auditory or visual) produced no evidence of hemispheric asymmetry.

TABLE XI

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Sobotka and May (1977) Visual Evoked Potentials and Reaction Time in Normal and Dyslexic Children	Twenty-four (24) right-handed males (6 in each of 4 age groups: 7, 9, 11 and 13). Subjects had no gross sensory or motor defects, no general emotional disorder and no abnormal EEG. Reading retardation defined as having a Wide-Range Achievement Test (WRAT)-standard score more than ten (10) points below the child's Peabody Picture Vocabulary Test (PPVT) I.Q. Also all those defined as dyslexic read more than six (6) months below grade level.	Twenty-four (24) right-handed males (6 in each of 4 age groups: 7, 9, 11 and 13). Controls matched for age, sex, race and school. In addition to the WRAT and the PPVT I.Q., other neuropsychological tests were done: the WISC, Verbal Fluency, Dichotic Listening, Auditory-Visual Integration and the Bender-Gestalt tests.	Grass gold electrodes used with active leads to O_1, O_2, P_3, P_4, with referencing to C_z. Visual evoked responses (VERs) were recorded from the four scalp locations to 64 bright flashes while the subjects responded to the dim flashes by depressing a response key. Eyes were closed at all times. One-fourth ($\frac{1}{4}$) of the flashes were dim randomly interspersed with the bright flashes.	Three (3) major deflections noted--P_1, N_1 and P_2. Two amplitude measures were used (as peak to trough). P_1-N_1 and N_1-P_2 and three latency measures: P_1, N_1 and P_2 were obtained for each VER. A mean reaction time (RT) was derived for each child. An overall hemispheric asymmetry in VER amplitude (right more than left) was seen in both experimental and control subjects. Dyslexics exhibited an increased amplitude to unattended stimuli and a slower RT to attended stimuli.

Continued.

TABLE XI (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
				Normals exhibited significant correlations between RT and VER latency but dyslexics did not. The authors suggest that differences in selective attentional ability might be expected to result in greater VER amplitudes to non-signal stimuli for subjects with selective attentional difficulties.

TABLE XII

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Lux (1977) Detection of Learning Disabilities Using the Visually Evoked Cortical Potential (VECP)	Subjects were nine (9) high school students ranging in ages from 14-17 years (6 males and 3 females). All subjects were in regular classes. One of the subjects was identified as learning disabled and remediated subsequently.	None	Two (2) types of tests were given to the 9 subjects: 1. A conventional achievement test-Wide Range Achievement Test (WRAT) 2. Measurements of the subjects' VECP's. The results of 1 and 2 were then correlated. A learning disability score was computed that ranged from -50 to +50 on a scale from dyscalculia to normal to dyslexia. The VECP was measured from the two (2) hemispheres and the latency differences between the various peaks were measured. The latency of the right side minus the latency of the left Continued.	The peak showing the widest amount of variance was at approximately 160 msec after the stimulus recorded from the parietal lobes. There is a strong correlation between latency and learning disability. The computed correlation coefficient is approximately .79 which corresponds to a significance of .01. The author proposes that the VECP could be used to detect learning disabilities. It was found that a comparison of the Continued.

TABLE XII (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
			side was used. These latency differences were then plotted against the learning disability scores and the correlation computed. In order to provide a numerical score for comparison with the latency differences the following learning disability score (LDS) was computed for each subject: $LDS = arithmetic\ score - \frac{reading\ score + spelling\ score}{2}$ All the LDS scores were normalized to a mean of 100 and standard deviation of 15 before computation. For the VECP's, four Continued.	responses from the two parietal lobes to a checkerboard pattern could provide such a detector. The latency differences had a correlation of .79 with scores on a test of learning disabilities for high school aged children.

TABLE XII (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
			active electrodes from O_1, O_2, P_3, P_4 were referenced to the vertex. The 2 ears were used as grounds. Input voltages were sampled every 2 msec for the 512 msec epoch following the presentation of the stimulus. The stimulus consisted of a checkerboard pattern back illuminated by a photostimulator viewed at a distance of one meter. The stimuli were presented at 1 Hertz rate. The check size varied from 4 to 32 millimeters. The stimuli were presented in a counterbalanced sequence. The average of the responses to 32 stimulus presentations was computed.	

TABLE XIII

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Symann-Louett Gascon, Matsumiya and Lombroso (1977) Wave Form Difference in Visual Evoked Responses between Normal and Reading Disabled Children	10 Disabled readers-median age: 12.6 - I.Q. (by WISC or Stanford Binet) above 90. All were right-handed and right-footed and most had right eye dominance. All were at least 2 grade levels behind in reading.	12 normal readers-median age 12.0 - I.Q. (by WISC or Stanford Binet) above 90. All were right-handed and right-footed and most had right eye dominance.	Stimuli to elicit visual evoked responses consisted of 16 most frequently used words (Thorndyke-Lorge list of 1944). The words were either names of animals or parts of the body and were 3 or 4 letters long and were displayed on an oscilloscope slaved to a PDP-12 computer. The computer controlled the stimulus presentation and also averaged the evoked responses. The display lasted for 10 msec at a maximum intensity and had a 2 msec raising time as well as a 12 msec decay time. The words appeared on the screen at 4 second intervals. No discrimination task was required but the subjects were told that Continued.	Grand average curves were obtained by averaging all the individual curves from disabled and normal readers. At C_z, O_1 and O_2 the waveforms for disabled and normal groups show more similarity than at P_3, P_4, W_1 and W_2. At the P and W locations, the grand average curves in the control group are more complex in the first 200 msec analysis time. The reading disabled subjects appear to show 2 peaks between 200 and 350 msec instead of the single one exhibited by the controls. Continued.

TABLE XIII (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
			they would be questioned later as to what words they had seen. The 16 stimulus words were presented in random fashion; each word was presented 6 or 7 times so that the total number of stimulus presentations was 110. Gold cup electrodes from C_z, P_3, P_4, O_1 and O_2 as well as from W_1 (left inferior parietal location-WERNICKE's AREA) and W_2. All electrodes were referred to linked earlobes. 110 responses were recorded and later 100 responses were averaged off-line, discarding undesirable responses contaminated by large artifactual potentials such as eye movements, body movements and blinking.	Individual curves were then examined by counting the number of waves appearing before (early components) and after (late components) 200 msec. Only those waves whose amplitude (measured from the preceding peak) exceeded 2.5 microvolts were counted. The control group exhibited more early components than the disabled group at all electrode locations. But only at P_3 and W_1 did the differences reach a significance level. The disabled reader group on the other hand showed more waves in the late components Continued.

TABLE XIII (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
				at all recording locations, except for O_1, than the control group, but none were statistically significant. The total number of waves (early and late) also did not show significant differences between the two groups.

TABLE XIV

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Njiokiktjien, Visser and de Rijke (1977) EEG and Visual Evoked Responses (VERs) in Children with Learning Disabilities	58 children (53 boys and 5 girls) ranging in age from 6-12 years (mean age 8.5, SD=1.7). 49 were outpatients and 9 were receiving residential treatment for additional behavior disorders. None showed classical neurological conditions such as cerebral palsy and none had a primary psychiatric syndrome. None had a total score on the WISC of less than 90 I.Q. Ophthalmologic exams were within normal limits. The neuropsychological data were grouped as Continued.	None in this study but because of similarity of design the control group was normal group described by Blom (1974). The control group of 6 normal test subjects were young adults (19-25 years).	Evoked potentials were recorded by means of surface electrodes from leads: O_1-P_0 (APR = Average Potential Reference) O_2-P_0 O_1-APR O_2-APR Signals were amplified and recorded by means of a Mingograph EEG and signals stored by means of an FM analogue tape recorder for off-line processing. The light stimulus was delivered by a photostimulator at intervals randomized by hand, avoiding epochs with artifacts. Minimum flash interval was 2 seconds, while flash duration was 10 msec. For each of the 4 arriving signals, 60 VERs were averaged. The sampling interval Continued.	The VER in children with learning disorders showed significantly longer latencies in the secondary complex (waves III, IV, V, VI ranging from 139 $\pm$ 19 msec to 306 $\pm$ 34 msec). The amplitudes of Wave II (from 79 $\pm$ 11 msec to 95 $\pm$ 19 msec) and wave III (from 139 $\pm$ 19 msec to 148 $\pm$ 20 msec) were significantly higher. In the subgroup with low test score (clinically least severe) the VER did not differ significantly from that in the group with a high test score (clinically most severe). A normal EEG did not exclude Continued.

TABLE XIV (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
	follows: 1. dyslexia 2. dysphasia 3. writing disorders 4. spatial motor disorders 5. spatial sensory disorders 6. dyscalculia 7. visual perception 8. concentration and attention Two subgroups were established, by a scoring system for these 8 conditions. 1. clinically least severe 2. clinically most severe.		was 1.5 msec and the total analysis epoch was 600 msec including 100 msec of pre-stimulus time. In each VER 6 main waves were identified. Absolute and mean latency and amplitude values were calculated for the 58 subjects. In addition, ensemble averaging of the individually averaged evoked responses of all the subjects gave a "pooled VER". Peak identification of the "pooled VER" was also performed.	an abnormal VER. Yet, in the subgroup with a disturbed EEG, more peaks were absent and the primary complex of waves I and II was more retarded than in the subgroup with a normal EEG (wave I, from 55 $\pm$ 10 msec to 78 $\pm$ 26 msec) (wave II from 79 $\pm$ 11 msec to 95 $\pm$ 19 msec).

TABLE XV

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Shelburne (1978) Visual Evoked Potentials to Language Stimuli in Children with Reading Disabilities	Nine (9) male children, ages 9 to 14 (mean age: 11 years); children with relatively pure reading disabilities (no evidence of neurological, sensory or psychiatric handicap).	(Previous studies done with normal subjects).	Active leads C_z, P_3, and P_4 referred to linked ears. Visual stimuli, consisting of white letters on a black background, presented sequentially to form consonant-vowel-consonant (CVC) trigrams. Each trial was the presentation of a blank-CVC-blank presentation at fixed one (1) second intervals. The CVC's formed either words or paired nonsense syllables with the same first two letters as the word. Trials consisted of randomized presentations of fifty (50) words and fifty (50) paired nonsense syllables. A toggle switch was used to indicate "word" or "nonsense syllable".	Visual evoked potentials (VEP's) for each position in the CVC trigram were averaged separately. Point by point comparisons between waveforms were performed to determine the latencies at which statistically significant differences occurred. Normal children who performed well on this problem solving task showed greater positive amplitude of VEP's (at 390-850 msec latency windows) from third position stimuli than VEP's from first or second position stimuli. Continued.

TABLE XV (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
				The absence of VEP differences in both dyslexic and normal children was associated with poor task performance. Dyslexic children were characterized by no VEP differences between third position responses and first and second position responses.

TABLE XVI

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Musso and Harter (1978) Contingent Negative Variation, Evoked Potential and Psychophysical Measures of Selective Attention in Children with Learning Disabilities	Two (2) groups (each with 9 children) based on the Slingerland Screening Test -- 1. Visual perceptual problems (VRD) and, 2. Auditory perceptual problems (ARD). All were free of gross neurological damage and were taking no medication. Eye exams were within normal limits. Reading disabilities based on VRD (#1) and ARD (#2).	A control group of 9 children matched for age (7-12), I.Q. (above 90) and and sex. No reading disabilities.	Visual discrimination attentional task -- that consisted of flashing a warning stimulus (S_1 - a clown's face) followed after 1100 msec by one of two randomly presented flashes-- a relevant (S_2 rel) or an irrelevant (S_2 irrel) stimulus. The entire S_1-S_2 sequence was repeated once every five seconds. Reward tokens were used. Four pairs of S_2's were used--each representing a different level of complexity in terms of discriminability; red and green diffuse light, vertical and horizontal lines, the letters B & D and the words WAS and SAW. Each stimulus of the pair was both relevant and irrelevant <u>Continued</u>.	All children gave larger VEP's to relevant as opposed to irrelevant stimuli. The VRD group showed greater rel-irrel differentiation in their O_z VEP's than the normal group which suggests that the VRD group was selectively attending more in the visual discrimination task, perhaps as a compensatory-mechanism for their deficiency. The latency of P300 measured from O_z and C_z indicated that the VRD children had longer latencies than the ARD group, who in turn had longer <u>Continued</u>.

TABLE XVI (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
			for one condition, giving a total of 8 different problems, 2 for each pair. Each condition consisted of at least 32 presentations of each stimulus of a pair in random order. Cortical potentials were recorded, amplified and averaged, starting at the onset of S_1. Active electrodes were at O_z and C_z and referenced to the right earlobe. VEP latency was quantified by measuring the time between the onset of S_2 and the peak of the prominent positive component occurring between 270 and 435 msec (P300) after onset of S_2. The effect of selective attention to relevant and irrelevant stimuli on VEP amplitude	latencies than the normal group. This suggests that the reading disabled child processes sensory information at a slower rate than the normal child.

Continued.

TABLE XVI (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
			was quantified by measuring the peak to trough amplitude of the surface negative and positive components at about 200 and 300 msec, respectively, after S_2 and finding the difference in this measure when a given S_2 was relevant or irrelevant.	

TABLE XVII

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
Fried, Tanguay, Boder, Doubleday and Greensite (In Press) Developmental Dyslexia: Electrophysiologic Corroboration of Clinical Subgroups	5 dysphonetic readers, 6 dyseidetic readers, 2 "mixed type" (Diagnosis into above 3 subgroups of dyslexia via Boder Diagnostic Screening Test.) All were of normal intelligence. All were reading at least two grade levels below the norm.	9 normal readers at or above grade level in reading.	All subjects had normal hearing. Each subject given standard Dichotic Listening Test in which stimuli were consonant-vowel pairs. Electrodes attached at F_7, F_8, W_1, W_2 - each referenced to paired ears. Subject's EEG was recorded (GRASS P-511-filters at .3 and 100 Hz). Randomly ordered words (do or go) 350 msec in length or strummed musical chords A_7 or D_7, each with a duration of 350 msec presented at 70dB via headset. Total of 120 words and 120 chords presented in groups of 40 word-chord stimuli at a time with rest periods between. Evoked responses for Continued.	Dichotic Listening Studies: No significant differences in scores found between normals and dyslexics or between groups of dyslexics. Comparison of word and music chord evoked responses: A. Amplitude differences between word and musical chord stimuli using integrated amplitude values obtained for each AER. The word/word and musical chord amplitude ratios were calculated for F_7, F_8, W_1, and W_2. No significant interhemispheric differences in the ratios were found for either normals or Continued.

TABLE XVII (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHOD AND MEASURES	RESULTS
			words and chords averaged off-line (PDP-11 computer). A. Integrated amplitude of each evoked response waveform calculated: 1) Responses normalized. 2) Mean baseline calculated for that part of waveform between 50-300 msec after stimulus. 3. Waveform rectified and integrated around that baseline. 4) Results expressed as integrated amplitude for the 50-300 msec segment of response. B. AERs to words and chords compared at each site (Cross correlational analysis). 125 separate product- Continued.	dyslexics: nor did the ratio differentiate between the 2 groups. B. Cross-correlational comparison of word and musical chord evoked responses. Data from W_1 and W_2 - for 7 of 9 normals. Latency of the responses to words was less than to musical chords. When normals compared in terms of lag at which the MAXr was found there were significant differences between normal and dysphonetic subjects in terms of AERs over the left hemisphere and between normal and dyseidetic Continued.

TABLE XVII (Continued)

AUTHOR	EXPERIMENTAL GROUP	CONTROLS	METHODS AND MEASURES	RESULTS
			moment correlations between AER waveform segments. Point of maximum correlation = MAXr.	subjects in terms of AERs over the right hemisphere. "Mixed" subjects showed an abnormal degree of waveform similarity over both hemispheres. Data from F_7 and F_8 showed a similar trend but the results were not significant.

RATIONALE FOR THIS STUDY

Although some ERP asymmetries and differences were found in part in all of the reported studies either by principal components analyses or some other parameter (see Tables I-XVII) between the normal and "dyslexic" groups, there are significant difficulties in the interpretation of the results because of:

I. Clinical and Subject Considerations:

A. There is a lack of consistent definition and resultant confusion with relation to the make-up of and qualifications for entry into the experimental groups. An experimental group composed of those subjects with primary developmental dyslexia - children or adults, should be reading at least two years below expected grade level by standardized reading examinations <u>and</u>:

1. Have no significant problems with vision (by standardized examination)
2. Have no significant problems with hearing (by standardized examination)
3. Have a general IQ within normal limits
4. Manifest no obvious neurologic damage
5. Manifest no primary emotional disturbance
6. Have had an adequate conventional educational opportunity.

B. In addition were <u>subgroups of dyslexics</u> to be considered as subjects in experimental groups, those subgroups should be arrived at by standardized assessments which fulfill the psychological requirements of test reliability and validity.

II. Electrophysiological Considerations:

A. There is a lack of standardization in the methodology, experimental designs, and measurements of the assessments of neurophysiological functioning in the perceptual-cognitive processes in primary developmental dyslexia (Evans, 1977):

1. The nature of the stimulus to be presented: tones, flashes, chords, tachistoscopically-presented words, patterns, dictated words (e.g. sense modality, intensity, duration, interstimulus interval, number, order of presentations).
2. Cortical areas and corresponding scalp electrode sites from which ERPs are to be recorded.
3. Aspects of ERPs to be measured - e.g. overall amplitude, amplitudes at specific times after onset of stimulus, variability of the ERP, latencies to specified points of the ERP.

4. EEG frequencies that will be involved in the ERP measure.
5. Rate of sampling of the EEG by the computer.
6. Methods of statistical analyses.

Yet given the convergent and supportive data enumerated above:

A. From Clinical Sources

B. From Neurologic Sources

C. From Diverse Scientific Sources

D. From Electrophysiological Sources

It is postulated:

A. that differential and specialized cerebral (lateralized hemispheric) functions exist.

B. that a specific syndrome - primary developmental dyslexia exists - and that dysphonetic, dyseidetic and mixed subgroups exist.

Anecdotal evidence from educators has suggested that some children are auditory learners, some are visual learners and some are both. Is there a preferred cognitive style which is particular to an individual? In many ordinary activities "normal people" simply alternate or integrate between cognitive modes - as the need arises - if they are neurophysiologically able to alternate and/or integrate. An "interference hypothesis" might describe a situation in which an inefficient and inappropriate but required cognitive style is being used to process a certain task while at the same time preventing the more efficient mode from working (Galin and Ornstein, 1973) - for example, when a teacher specifically requires a phonics approach to the learning of reading-spelling-writing of a student whose preferred cognitive mode is that of a visual-spatial-Gestalt (Sight-Say) approach. The implication is that an individual's preferred (innate) cognitive style (which may now be assessed by EEG and ERP measures) may facilitate his learning of one type of subject matter, such as spatial-relational, while hindering the learning of another type, such as verbal-analytic.

Are Boder's dysphonetic and dyseidetic subgroups extreme versions, neurophysiologically (and genetically) based of those markedly dysfunctioned in auditory (verbal-left hemisphere) and visual (spatial-right hemisphere) cognitive styles? Is Boder's mixed group a combination of both auditory and visual dysfunctioning?

HYPOTHESIS

ERP measures will not discriminate:

a. Between dyslexics and normals

b. Among subgroups of dyslexics - dysphonetics, dyseidetics, mixed.

PURPOSE OF THIS STUDY:

1. To increase scientific knowledge about central nervous system functioning in the processing of information. Can we infer hemispheric utilization from electrophysiologic parameters?
2. To increase our understanding of central nervous system processing in those subjects with primary developmental dyslexia and the dysphonetic, dyseidetic and mixed subtypes, by defining clusters on the basis of psychometric testing and then attempting to find electrophysiologic measures which will discriminate among these clusters; to investigate suggested etiologies for primary developmental dyslexia.
3. To evaluate the utility of ERP methods for diagnosis and subclassification in dyslexia.
   a. To distinguish those with primary developmental dyslexia from those with other causes of reading incompetence.
   b. To distinguish among those with dysphonetic, dyseidetic and mixed subtypes of primary developmental dyslexia.
   c. To allow for an <u>early</u>, <u>non-invasive</u>, and <u>predictive</u> diagnosis of dyslexia and its subtypes so as to permit: a) Early detection and by so doing, b) establish the possible institution of <u>early differential</u> remedial educational techniques; c) and by

early detection, diagnosis, explanation and remediation, to prevent the psychopathologies which are frequent sequelae in those subjects with primary developmental dyslexia.

METHODS OF PROCEDURE

SUBJECTS - SCREENING AND SELECTION

Adult subjects were selected to eliminate, as much as possible, factors relating to maturation of the central nervous system. The subjects were adult patients with reading incompetence at the Learning Disabilities Clinic of the Department of Pediatrics at the Kaiser-Permanente Medical Center in Oakland, California. The control subjects were recruited from hospital personnel and from one of the local high schools. Data for the subjects relating to dyslexic subgroup, ages and sex are listed in Appendix 2.

Each dyslexic subject had a complete physical and neurological examination which indicated no gross neurological problems. Routine standardized vision (16 of the 33 dyslexic subjects wore glasses) and audiometric examinations were within normal limits, as were routine urinalyses, complete blood counts and amino acid screens. Careful review of their records and individual interviews indicated that there were no primary emotional disturbances and that each dyslexic subject had been given the opportunity for a conventional and adequate educational experience. Yet, all the dyslexic subjects had significant problems all through their school years in reading, spelling and writing.

Individual IQ testing, either by the WAIS or the WISC, was done for each of the dyslexic subjects by a psychometrist licensed in the State of California. The results are listed in Appendix 2.

All of the control subjects were volunteers who were functioning adequately as workers in a hospital or students in a local high school. They had no problems with physical or mental health, could hear and see adequately and had experienced no difficulties with their conventional educations. They reported no dysfunctions with reading, spelling, or writing.

BODER TEST DESCRIPTION

The diagnosis of dyslexia and the division into the subtypes of dysphonetic, dyseidetic and mixed dyslexia was made by the Camp and Dolcourt Modification of The Boder Diagnostic Screening Test (Camp and Dolcourt, 1977).

Two forms of the Boder procedures were constructed so that half of the 20 words at each grade level were spelled phonetically and half nonphonetically. For the spelling test, the examiner then selected the list of words at the grade level where the subject read only 50% correctly. In most instances, the spelling test would automatically present both known and unknown, phonetic and nonphonetic words. If a subject read only phonetic or nonphonetic words correctly, the examiner could drop back one grade level to obtain the needed sample of phonetic or nonphonetic words.

The specific forms constructed for this study were prepared using Taylor and Frankenpohl's (1960) list of vocabulary common to 10 basal readers. Twenty phonetic and 20 nonphonetic words were selected from each grade level except primer. (At the primer level there were less than 20 nonphonetic words; so the primer lists were the same on both forms.) Phonetic and nonphonetic classification of the words was made independently by two judges. Half of the phonetic and half of the nonphonetic words were assigned randomly to Form A and Form B. Within each form, phonetic and nonphonetic, words were randomly ordered within a grade level (Appendix 1).

The reading test was administered by asking the subject to begin reading aloud at the primer level and to continue until he was able to read only 7-13 of the words within a grade level at sight. A word was judged to be in the sight vocabulary if it was pronounced correctly in less than 2 seconds. For the spelling test, the subject was presented the list of words from the grade level at which he read 7-13 words at sight. The spelling test was administered by the examiner's pronouncing the word, using the word in a sentence, and then repeating the word.

Scoring: Reading level was scored as grade equivalent. Year was specified as corresponding to that of the list on which 7-13 flash words were identified correctly; in addition, each word in the list could be given an additional .05 of a year credit. For example, a subject whose best performance was nine words at third-grade level could be given a grade equivalent of 3.45.

Type of reading errors was recorded on the reading test. Flash vocabulary spelled correctly, unknown phonetic words spelled correctly, and known nonphonetic words misspelled were all calculated as percentages. Classification of spelling errors into "phonetic equivalents", "bizarre", and "other" was based on the following criteria;

Bizarre errors involved errors of major proportions in the word. A bizarre error bears little, if any, relation to the correct spelling. There must be at least two misplaced sounds in the spelling. These misplaced sounds must not be the result of simply reversing two sounds, or dropping a sound. Two missing sounds, however, are classified as bizarre, because there is little resemblance between the spelling of that word and the correct spelling by the time there are two misplaced sounds (exclusive of reverals). Examples of this include basakaeks for breakfast, beare for brave, alloe for only, and lathen for light. Semantic substitutions such as cow for calves do not fall in this category, but instead are grouped as "other" errors.

Phonetic equivalents are errors in spelling such that the word, though spelled incorrectly, is still readable. If one asks the question, "If I did not know how to spell the word, would this be a logical way to try to spell it?" The answer must be "yes" if this error is to be scored as a phonetic equivalent. All phonetic sounds must be present in the subject's spelling, and there can be no extra sounds. If there is a sound missing, or if there is a reversal in addition to the word being a phonetic equivalent, the error may not be scored as a phonetic equivalent, because it does not satisfy the requirement that it be a logical way of spelling the word. Examples are colume for column, schoefer for chauffeur, det for debt.

"Other" errors include all errors not categorized as bizarre phonetic equivalents. Common errors are reversals (beard for bread), a single omitted sound (dark for drank), or semantic substitutions (cow for calves).

After the reading test as indicated above, the spelling test is given.

THE WORDS WHICH HAD BEEN READ CORRECTLY IN 2 SECONDS WERE NOTED.

IT WAS THEN NOTED WHICH DICTATED WORDS WERE SPELLED CORRECTLY.

THEN - % KNOWN VOCABULARY SPELLED CORRECTLY = TOTAL WORDS SPELLED CORRECTLY/TOTAL WORDS READ CORRECTLY.

FOR EACH WORD SPELLED INCORRECTLY, A DETERMINATION WAS MADE AS TO THE TYPE OF ERROR:

PHONETIC EQUIVALENT - error
or BIZARRE - error
or OTHER - error

THUS:

$$\text{PERCENTAGE PHONETIC EQUIVALENT} = \frac{\text{TOTAL PHONETIC EQUIVALENT}}{\text{TOTAL MISSPELLED}}$$

AND - TO DETERMINE CLASSIFICATION:

FOR DIAGNOSIS OF DYSPHONETIC -

1. % Phonetic equivalents $<$ 50% and
   % known vocabulary spelled correctly $<$ 50%

or

2. % Phonetic equivalents $<$ 50%
   and % known vocabulary spelled correctly $\geq$ 50%

and Bizarre errors 4 or more

FOR DIAGNOSIS OF DYSEIDETIC -

% Phonetic equivalents $\geq$ 50%

and % known vocabulary spelled correctly $<$ 50%

FOR DIAGNOSIS OF MIXED -

1. % Phonetic equivalents $\geq$ 50%

and % known vocabulary spelled correctly $\geq$ 50%

or

2. % Phonetic equivalents $<$ 50%

and % known vocabulary spelled correctly $\geq$ 50%

and Bizarre errors $<$ 4.

The Camp and Dolcourt Modification of The Boder Diagnostic Screening Test (Camp and Dolcourt, 1977) was then given to the 33 adult subjects with reading incompetence.

The results indicated:

Dysphonetic Group	= N = 12
Dyseidetic Group	= N = 11
*Mixed Group	= N = 10
Total	N = 33

*Originally, the Screening Test was given to 34 adult subjects. However, during data transfer, the ERP record of one mixed subject was lost and that subject was eliminated from the study.

EVENT-RELATED POTENTIALS - APPARATUS

A modification of Schwent-Hillyard selective attention paradigm was used which involved both visual and auditory vigilance tasks as well as a passive state (Hillyard et al., 1973; Schwent et al., 1976).

The presentation and the timing of the visual and auditory stimuli as well as the acquisition, on-line averaging and storage of the electrophysiological data were monitored by a prototypic DATA GENERAL NOVA 1220 computer. A schematic overview of the system is shown in Figure 1.

The 33 dyslexic and 12 control subjects were tested in an electrically-shielded, light-controlled and sound-attenuated room in the EEG department of the Kaiser-Permanente Medical Center in Oakland, California. The subjects were seated upright in a comfortable chair. A Consent to Participate Form was presented, explained and signed by the adult subjects or by a parent of a minor subject. Since reading was an acknowledged problem with the experimental subjects, the Consent to Participate Form was read and explained to the subjects and their parents. Before the start of each session, the subject was given adequate information and sufficient practice to ensure that the study's design and procedure were fully comprehended. The standardized subject instructions were given:

A. General Information About Study:

1. Purpose
2. Subjects and controls
3. The EEG, the NOVA computer, stimuli, order, runs.

B. Consent to Participate Form.

C. Training Program:

1. Order, runs, time, task.
2. Discriminate (and count) dim from bright flashes.
3. Discriminate (and count) soft from loud clicks.
4. Passive (no count) state.

D. 1. Move as little as possible.

2. Remain awake. With eyes open.
3. Toggle switch for necessary interruptions.

Grass gold disc electrodes were attached by 1) abrasive salt paste, 2) Med-cream (EEG electrode cream) and 3) Grass electrode cream with active leads to the scalp at: F_3, F_4, P_3, P_4, O_1 and O_2, referenced to C_z and grounded to linked ears (A_1 and A_2) according to the International 10-20 System (Jasper, 1958). A diagram of this system is shown in Figure 2. An electrooculogram (EOG) channel was monitored from the left lateral canthus and the left supraorbital ridge by two gold electrodes (X_1 and X_2) to measure and eliminate those ERP individual trials which were contaminated by excessive eye movements or muscle artifacts. Those ERPs which were so contaminated, as determined by preset computer-programmed eye-limits, were automatically rejected from the on-line averaging but the program was so written that further stimulus presentations occurred until the required number of target and non-target (standard) visual and auditory stimuli were averaged. The EEG channel-electrode relationships were:

Channel 1 = Electrodes F_3 - C_z

Channel 2 = Electrodes P_3 - C_z

Channel 3 = Electrodes O_1 - C_z

Channel 4 = Electrodes C_z - $(A_1 + A_2)$

Channel 5 = Electrodes F_4 - C_z

Channel 6 = Electrodes P_4 - C_z

Channel 7 = Electrodes O_2 - C_z

Channel 8 = Electrodes EOG

The EEG amplification was recorded on a Mingograph EEG 8 standard polygraph which was interfaced with the prototypic 1220 NOVA computer. The low and high filters for the EEG were set at 0 and 30 Hz (band pass 0-30), respectively. The results of the 7 EEG ERP recording channelswere fed into the 1220 NOVA where they were digitized (analog to digital conversion) and the signals averaged, using an analysis time of 500 msec with sampling occurring at 5 msec intervals, rendering 100 data points per each ERP waveform. Each stimulus occurred at the 50 msec latency point of the 500 msec ERP analysis time. The averaged ERPs were stored on floppy discs for later analysis.

Electrode skin impedances were measured for each subject before the first and after the last of the three designated runs. Electrode impedances were kept below 5K ohms usually and there was no material change between the pre- and post-run measures.

EVENT-RELATED POTENTIALS - EXPERIMENTAL DESIGN

ERPs to both randomly mixed flashes and clicks were measured under states of:

1. Attention to flashes with eyes open.

2. Attention to clicks with eyes open.

3. Non-attention (passive) with eyes open.

rendering three runs per subject. Each run consisted of 150 flashes, 30 of which were dim (target condition) and 120 of which were bright (non-target or standard condition) and 150 clicks, 30 of which were soft (target condition) and 120 of which were loud (non-target or standard condition). These four stimuli were presented singly in a randomized sequence. The interstimulus interval was randomized from 800-1200 msec to avoid predictability and synchronization with the heart rate. Each run took approximately 15-20 minutes. The randomly mixed flashes <u>and</u> clicks (both target <u>and</u> standard) were presented three times (three runs) to each of the dyslexic and control subjects, each time with different instructions:

1. Count the dim flashes - targets. With eyes open.
2. Count the soft clicks - targets. With eyes open.
3. Passively observe the display. With eyes open.

The subjects were asked what the counts were at the end of the visual and auditory attending runs.

The order of the runs was counterbalanced into six orders which were randomly assigned to each subject as they came to the testing situation. Each of the three runs then yielded four averaged ERPs - two visual (target and standard) and two auditory (target and standard) to the randomly mixed flashes and clicks.

The subjects observed a circular fixation point, a disc, 2 cm in diameter, which was centrally mounted upon a rectangular piece of milkglass (94 cm by 61 cm) which was 97 cm from the subject's nasion.

A custom-built photostimulator (placed immediately behind the milkglass visual field) was used to produce the dim (target) and bright (standard) flashes. The duration of both the dim (target) and bright (standard) flashes was 10 msec. The stimulus intensity of the bright flash was 1.84 foot-candles; the dim flash measured at 0.92 foot candles (Minolta-Autometer-Professional).

The clicks were delivered by binaural stereo headphones (Tracor RA 125). The stimulus duration of both the soft (target) and loud (standard) clicks was 10 msec. The relative amplitude of the loud click was 8 decibels greater than that of the soft click (Rudnose Electro-Acoustic Ear - RA 106 A).

Visual displays (per graphics video display screen of the 1220 NOVA computer) of the averaged ERPs were monitored for each subject, for each state (run), for each condition (visual target, visual standard, auditory target, auditory standard), for each lead in order to detect any gross problems, i.e., loose electrodes, so that the run could be repeated if it were necessary. Polaroid photographs were taken of all the averaged ERPs for each subject via the 1220 NOVA display screen. A toggle switch was available to the experimenter and the subject for necessary interruptions of the procedure. Standard EEG ink records were recorded simultaneously to monitor the procedures.

ANALYSIS OF THE DATA - RESULTS

The 12 ERP types which were summed and averaged for leads P_3 and P_4 for each subject were as follows:

Mode	Condition	State: Visual Attending	Auditory Attending	Passive
Visual	Target			
	Standard			
Auditory	Target			
	Standard			

The groups were:

Dysphonetics		N = 12
Dyseidetics		N = 11
Mixed		N = 10
Controls		N = 12
Subjects	Total	N = 45

The leads were:

P_3 and P_4

A review of the literature (Tables I - XVII) indicates that ERP data can be and has been analyzed in several quite different ways.

The data from this study was first analyzed by a grand averaging process of the averaged ERPs. Grand averages were obtained for the 12 averaged ERPs indicated above for leads P_3 and P_4 for each of the four experimental groups. Examples of grand averaging are seen in Figures 3 and 4.

Visual inspection of the grand averaged ERPs indicated at which latencies maximal positive and negative amplitudes occurred, for both the visual and auditory modes (Figures 5 and 6). Since these maximal voltages occurred in similar latency bands for both the visual and auditory modes, it was decided to measure and assess, as the dependent variables of this study:

1. Amplitude of the total latency band from 0 - 450 msec.
2. Amplitude of the latency band from 50 - 150 msec.
3. Amplitude of the latency band from 125 - 250 msec.
4. Amplitude of the latency band from 250 - 450 msec.

for both the visual and auditory modes wherein 0 time = time of stimulus onset. These amplitude measures (in microvolts) for the designated latency bands were obtained by computing the standard deviation of the averaged ERP across time.

The standard deviation of the averaged ERP (computed across time) is the square root of the average of squared deviations of the individual voltages measured from mean voltage. With impedance constant, power is proportionate to voltage squared. Thus the standard deviation across time is an estimate of the square root of the average power. This approach to amplitude measurement uses square root (standard deviation rather than variance) so as to generate a number expressed in volts (or microvolts). This computer-programmed method is relatively straightforward, de-emphasizes the smaller and possibly random undulations of the waveform and avoids inherent problems of bias when the experimenter has to define waves and components. On the other hand, the program's simplicity is offset by its inability to capture and quantify other features of the averaged ERP.

The ERP data which had been stored on floppy discs was then analyzed by a Schwent-Hillyard Peak Output Program in the 1220 NOVA computer. The average of 30 target ERP and 120 standard ERP samples, both visual and auditory, were computed to produce averaged ERPs, each composed of 100 individual averaged voltages (per 500 msec total latency band). For each averaged ERP, the standard deviation (SD) across the 100 average voltages was computed. This provided a measure roughly equivalent to the square root of mean power in the averaged ERP but which had amplitude in microvolts as its dimension. Heretofore in the context of this study, averaged ERP amplitude measures will refer to the averaged ERP/SD measures. A detailed discussion of this measure and its relationship to other measures is found in Callaway and Halliday (1973) and Callaway (1975).

The data were analyzed by a mixed-model 5 factor Repeated Measures Analysis of Variance (ANOVA) (Winer, 1971) using a program written by Bostrom (1978), in parallel fashion for each of the dependent variables:

1. Averaged ERP Amplitude (averaged ERP/SD) - 0 - 450 msec, total.
2. Averaged ERP Amplitude (averaged ERP/SD) - 50 - 150 msec.

3. Averaged ERP Amplitude (averaged ERP/SD) - 125 - 250 msec.
4. Averaged ERP Amplitude (averaged ERP/SD) - 250 - 450 msec.

In addition, multivariate repeated measures analyses were carried out where appropriate (Bock, 1975).

All averaged ERP/SD measures were rendered in microvolts. Each of the four latency bands was the dependent variable in one analysis involving five factors.

A. Group (four levels):
   1. Control
   2. Dyseidetic
   3. Mixed
   4. Dysphonetic
B. State (three levels):
   1. Visual attending
   2. Auditory attending
   3. Passive
C. Modality (two levels):
   1. Visual
   2. Auditory
D. Condition (two levels):
   1. Target
   2. Standard
E. Lead (two levels):
   1. P_3
   2. P_4

As part of the data analysis, planned comparisons for the group and state factors were included:

$Group_1$ - Compare the Control Group to the Mixed Group

$Group_2$ - Compare the Control and Mixed Groups together to the Dyseidetic and Dysphonetic Groups together.

$Group_3$ - Compare the Dyseidetic Group to the Dysphonetic Group.

$State_1$ - Compare the Visual Attending and the Auditory Attending States together to the Passive State.

$State_2$ - Compare the Visual Attending State to the Auditory Attending State.

RESULTS

The results of this study will be organized and reported beginning with main effects and then continuing through the higher order interactions. The results of the statistical procedures were considered significant if they equaled or exceeded the .05 level of significance. The factors considered included GROUP-STATE-MODE-CONDITION-LEAD. Power will refer to the mean averaged ERP/SD in microvolts.

STATE - The main effect of state was significant for Total Power (F(2,82) = 4.51, P=.014)* and for 250-450 msec Power (F(2,82) = 5.35, P=.007) but not for the two other dependent variables, i.e., 50-150 msec Power and 125-250 msec Power. This significance was due to the difference between the visual and auditory attending states taken together and averaged versus the passive state. There was consistently stronger power in the visual and auditory states versus the passive state (S_1) with no significant power difference between the visual and auditory states themselves (S_2), as shown in the planned comparisons. S_1 was significant for Total Power (F(1,41) = 10.29, P = .003) and for 250-450 msec Power (F(1,41) = 10.20, P = .003).

MODE - The main effect of mode was significant for Total Power (F(1,41) = 19.81, P = .001), for 50-150 msec Power (F(1,41) = 18.29, P = .001) and for 125-250 msec Power (F(1,41) = 5.10, P = .030) but not for the other dependent variable, i.e.

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* (P ≐) means less than or equal to.

250-450 msec Power. This significance was due to the difference between visual mode and auditory mode power with consistently stronger power in the auditory mode.

CONDITION - The main effect of condition was significant for 50-150 msec Power ($F(1,41) = 11.03$, $P = .002$) and for 250-450 msec Power ($F(1,41) = 83.35$, $P = .001$) but not for the other dependent variables, i.e. Total Power and 125-250 msec Power. This significance was due to the difference between target condition and standard (non-target) condition power. The stronger power was noted in standard over target in the 50-150 msec latency band but was reversed in the 250-450 msec latency band in that, here, target power exceeded that of standard.

LEAD - The main effect of lead was significant for Total Power ($F(1,41) = 4.67$, $P = .037$), for 50-150 msec Power ($F(1,41) = 5.83$, $P = .021$) and for 250-450 msec Power ($F(1,41) = 38.69$, $P = .001$), but not for the other dependent variable, i.e., 125-250 msec Power. The significance was due to the difference between the P_3 and P_4 lead power with consistently stronger power at the P_4 lead.

STATE BY MODE - The interaction between state and mode was significant for Total Power ($F(2,82) = 11.7$, $P = .001$) but not for the other dependent variables, i.e., 50-150 msec Power, 125-250 msec Power, and 250-450 msec Power. Inspection of the graph (Figure 7) indicates that auditory mode power was stronger consistently over visual mode power for all three states, i.e., visual attending, auditory attending and passive, but markedly so for the auditory attending and passive states.

MODE BY CONDITION - The interaction between mode and condition was significant for Total Power ($F(1,41) = 8.03$, $P = .007$) and for 125-250 msec Power ($F(1,41) = 4.33$, $P = .044$) but not for the other dependent variables, i.e., 50-150 msec Power and 250-450 msec Power. Inspection of the graph (Figure 8) for the Total (0-450 msec) latency band indicates that auditory mode power was consistently stronger than visual mode power for both condition 1 (target) and condition 2 (standard). However, visual mode power was only slightly stronger in condition 1 versus condition 2; and auditory mode power was only slightly stronger in condition 2 versus condition 1. Inspection of the graph (Figure 8) for the 125-250 msec latency band indicates that auditory mode power was consistently stronger than visual mode power for both condition 1 and condition 2. However, visual mode power was only slightly stronger in condition 1 versus condition 2; and auditory mode power was only slightly stronger in condition 2 versus condition 1.

MODE BY LEAD - The interaction between mode and lead was significant for Total Power ($F(1,41) = 4.13$, $P = .048$), for 50-150 msec Power ($F(1,41) = 11.15$, $P = .002$) and for 125-250 msec Power ($F(1,41) = 4.67$, $P = .037$) but not for the other dependent variable, i.e., 250-450 msec Power. Inspection of the graph (Figure 9) indicates that auditory mode power was consistently stronger than visual mode power in these three latency bands for both leads P_3 and P_4. In all three latency bands, visual mode power was stronger at P_4 versus P_3. However, auditory mode power was slightly stronger at P_4 than at

P_3 for the total latency band, equal in power at P_4 and P_3 for the 50-150 msec latency band but slightly stronger at P_3 than at P_4 for the 125-250 msec latency band.

GROUP BY LEAD - The interaction between group and lead was significant for 250-450 msec Power ($F(3,41) = 3.16$, $P = .035$) but not for the other dependent variables, i.e., Total Power, 50-150 msec Power and 125-250 msec Power. Inspection of the graph (Figure 10) indicates that P_4 power was consistently stronger than P_3 for all the groups, but more so for the dyseidetics and controls.

Comparisons of P_4 to P_3 power when collapsed over state, mode and condition showed significantly stronger power in P_4 in the dyseidetic group ($t(10) = 3.93$, $P = .003$) and in the control group ($t(11) = 4.73$, $P = .001$). For the dysphonetic group, the P_4 power was marginally stronger ($t(11) = 2.14$, $P = .056$).

STATE BY CONDITION BY LEAD - The interaction of state by condition by lead was significant for Total Power ($F_0(2,40) = 3.95$, $P = .028$ - Multivariate Generalized F Ratio) and for 250-450 msec Power ($F(2,82) = 9.76$, $P = .001$) but not for the other dependent variables, i.e., 50-150 msec Power and 125-250 msec Power. Inspection of the graph (Figure 11) indicates that for the total (0-450 msec) latency band, P_4 power consistently was stronger than P_3 power for the visual attending, auditory attending and passive states for both target and standard conditions. Generally, power was weaker for the P_3 and P_4

leads for target and standard conditions within the passive state versus both the visual attending and auditory attending states.

For the total latency band, P_4 power is significantly stronger than P_3 power for the visual attending state-target condition ($t(44) = 2.55$, $P = .015$) and for the auditory attending state-target condition ($t(44) = 2.23$, $P = .031$). In these calculations power is collapsed over mode. There were no other significant differences.

Inspection of the graph (Figure 12) indicates that for the 250-450 msec latency band, P_4 power was consistently stronger than P_3 power for the visual attending, auditory attending and passive states for both target and standard conditions, this being more marked for the target condition of the visual attending state. For the 250-450 msec latency band, P_4 power is significantly stronger than P_3 power in all combinations of state and condition (collapsed over mode) except in the passive state-target condition. Visual attending state-target condition - ($t(44) = 4.52$, $P = .001$). Visual attending state-standard condition - ($t(44) = 3.32$, $P = .002$). Auditory attending state-target condition - ($t(44) = 3.45$, $P = .002$). Auditory attending state - standard condition - ($t(44) = 4.43$, $P = .001$). Passive state - standard condition - ($t(44) = 5.36$, $P = .001$).

MODE BY CONDITION BY LEAD - The interaction of mode by condition by lead was significant for Total Power ($F(1,41) = 5.33$, $P = .026$) for 50-150 msec Power ($F(1,41) = 9.56$, $P = .004$) and for 125-250 msec Power ($F(1,41) = 4.21$, $P = .047$) but not for the other dependent variable, i.e., 250-450 msec Power. Inspection of the graphs (Figures 13, 14, 15) indicates that auditory power was consistently stronger than visual power in all three latency bands for both the target and standard conditions and for both the P_3 and P_4 leads. This difference is present but somehwat less marked in the P_4 lead of the target condition of the 125-250 msec latency band.

For Total Power, auditory power was significantly stronger than visual power in all four combinations of condition and lead (collapsed over state).

P_3 - target condition - ($t(44) = 3.66$, $P = .001$)
P_4 - target condition - ($t(44) = 3.20$, $P = .003$)
P_3 standard condition - ($t(44) = 5.19$, $P = .001$)
P_4 standard condition - ($t(44) = 3.39$, $P = .002$)

For 50-150 msec power, auditory power was significantly stronger than visual power in all four combinations of condition and lead (collapsed over state) except for the P_4 - standard condition wherein the difference was only marginally significant.

P_3 - target condition - ($t(44) = 4.47$, $P = .001$)
P_4 - target condition - ($t(44) = 2.48$, $P = .007$)
P_3 standard condition - ($t(44) = 5.41$, $P = .001$)
P_4 standard condition - ($t(44) = 1.96$, $P = .056$)

Similar analysis of 125-250 msec Power showed that auditory power was significantly stronger than visual power only for the P_3-standard condition combination ($t(44) = 3.51$, $P = .002$). The other three combinations did not show any significance.

<u>GROUP (DYSPHONETIC VERSUS DYSEIDETIC) BY STATE BY LEAD</u> - The interaction of group (dysphonetic versus dyseidetic) by state by lead was significant for 250-450 msec Power ($F(2,82) = 3.30$, $P = .042$) but not for the other dependent variables, i.e., Total (0-450 msec) Power, 50-150 msec Power and 125-250 msec Power. Inspection of the graphs (Figures 16, 17 and 18) (including results for the mixed and control groups as well, for contrast) indicates that P_4 power was consistently stronger than P_3 power for the visual attending, auditory attending and passive states for all the groups; but most markedly so for the dyseidetics in the visual attending state (and for the controls in the auditory attending state).

Within each state, the four groups were compared on the P_4-P_3 difference collapsed over mode and condition using a one-way ANOVA. In the visual attending state and in the passive state there were no significant differences over all the groups or on the three group planned comparisons. In the auditory attending state, the overall test of group differences was significant ($F(3,39) = 4.11$, $P = .013$). The planned comparisons indicate that this significance was due mainly to the control group - mixed group difference ($F(1,39) = 9.16$, $P = .005$).

GROUP (DYSPHONETIC VERSUS DYSEIDETIC) BY MODE BY CONDITION - The interaction of group (dysphonetic versus dyseidetic) by mode by condition was significant for 250-450 msec Power ($F(1,41) = 4.63$, $P = .037$) but not for the other dependent variables, i.e., Total (0-450 msec) Power, 50-150 msec Power, and 125-250 msec Power. Inspection of the graphs (Figures 19 and 20) (including results for the mixed and control groups as well, for contrast) indicates that:

a. Power is consistently stronger in the target condition versus the standard condition for all groups for both the visual and auditory modes.

b. In the target condition, auditory mode power is only minimally stronger than visual mode power for the dysphonetic group; in the standard condition visual mode power is somewhat stronger than auditory mode power for the dysphonetic group.

c. In the target condition, visual mode power is stronger than auditory mode power for the dyseidetic group; this is reversed in the standard condition.

d. In the target condition, visual mode power for the dyseidetic group is clearly stronger than visual mode power for the dysphonetic group; this is reversed in the standard condition.

e. In the target condition, auditory mode power of the dyseidetic group is only minimally stronger than auditory mode power of the dysphonetic group; in the standard condition, this effect is more obvious.

f. Visual mode power is generally stronger than auditory mode power for both the target and standard conditions for the mixed and control groups; but this effect is especially marked for the control group in the standard condition.

However, the G_3 (dysphonetic versus dyseidetic) mode interactions within either the target or standard conditions were not significant.

GROUP BY STATE BY MODE BY CONDITION - The interaction of group by state by mode by condition was significant for 50-150 msec Power ($F(6,82) = 3.20$, $P = .008$). Further analysis of the interactions of the group planned comparisons by state, mode and condition was significant for the comparison of primary interest, that of the dysphonetic versus the dyseidetic group - by state, by mode and by condition for 50-150 msec Power ($F(2,82) = 7.48$, $P = .001$) but not for the other dependent variables, i.e., Total (0-450 msec) Power, 125-250 msec Power and 250-450 msec Power. Inspection of the graphs (Figures 21, 22, 23, 24, 25 and 26) (including results for the mixed and control groups as well, for contrast) indicates that:

a. Auditory mode power is consistently stronger than visual mode power for both the dysphonetic and dyseidetic groups, for the target and standard conditions for the visual and auditory attending and passive states.

b. Auditory mode power is markedly stronger than visual mode power for the dyseidetic group in the visual attending state-target condition. This difference still exists but is much less marked for the auditory attending state-target condition. This difference is least marked in the passive state-target condition.

c. For the dysphonetic group, auditory mode power is consistently stronger than visual mode power. The greatest difference is noted in the auditory attending state-standard condition; the smallest difference is noted in the visual attending state-target condition.

d. The differences between auditory mode power and visual mode power are less marked in the mixed and control groups, with auditory mode power generally stronger than visual mode power. The only interactions which show visual mode power as stronger than auditory mode power occur in the:

1. Control group - visual attending state-target condition (minimally).

2. Mixed group - visual attending state-standard condition (minimally).

3. Mixed group - passive state - target condition.

To further investigate this interaction, t tests were carried out comparing the dysphonetic and dyseidetic groups on each combination of state, mode and condition, collapsed over lead. No significant differences were found.

GROUP BY STATE BY CONDITION BY LEAD - The interactions of the group planned comparisons by state, condition and lead showed significance for the comparison of primary interest, that of the dysphonetic versus the dyseidetic group - by state, by condition and by lead for 250-450 msec Power ($F(2,82) = 3.46$, $P = .036$), but not for the other dependent variables, i.e., Total (0-450 msec) Power, 50-150 msec Power and 125-250 msec Power. Inspection of the graphs (Figures 27, 28, 29, 30, 31, and 32) (including results for the mixed and control groups as well, for contrast) indicates that:

a. P_4 Power was consistently stronger than P_3 Power for both the dysphonetic and dyseidetic groups for the visual attending state (both target and standard conditions). This difference was most marked for the dyseidetics in the target condition.

b. P_3 Power was slightly stronger than P_4 Power for the dysphonetic group for the auditory attending state (target condition only). P_4 Power was stronger than P_3 Power for the dyseidetic group for the auditory attending state (target condition) and for the dysphonetic and dyseidetic groups for the auditory attending state (standard condition).

c. P_4 Power was stronger than P_3 Power for both the dysphonetic and dyseidetic groups for the passive state (both target and standard conditions); but these were minimal differences in the target condition for both groups.

d. P_4 Power was generally stronger than P_3 Power for the mixed and control groups for the visual and auditory attending and passive states (both target and standard conditions). These differences were, however, not marked for the mixed group for the auditory attending state (both target and standard conditions) and for the passive state (both target and standard conditions).

To further investigate this interaction, t tests were carried out comparing the dysphonetic and dyseidetic groups on each combination of state, condition and lead collapsed over mode. No significant differences were found.

DISCUSSION

By using the technique of computer averaging of scalp-recorded event related potentials (ERPs), it has become possible to begin to investigate the electrophysiological mechanisms thought to underlie the more subtle aspects of cognition and information processing in humans. By utilizing the time-locked nature of the ERP, and averaging the EEG activity over several and enough occurrences of the stimulus, the signal to noise ratio can be improved. This averaged ERP manifests itself as a series of voltage shifts or components which occur and can be identified at reliable time points from the onset of the specific stimulus event.

This study was both intricate and complicated. It had to do with reading-spelling-writing dysfunctions noted in humans, but of a subtle, even amorphous nature. In recent years, supportive and convergent data from clinical studies, from neurological studies, from diverse scientific studies, and from electrophysiological studies have suggested that an identifiable and measurable diagnostic category - primary developmental dyslexia - exists within the reading incompetencies. These studies also suggest that dysphonetic, dyseidetic and mixed subgroups exist, and that:

a. Dysphonetics manifest information-processing problems in the left cerebral hemisphere.

b. Dyseidetics manifest information processing problems in the right cerebral hemisphere.

c. Mixed dyslexics manifest information-processing problems in both hemispheres.

Much of the evidence for the existence of primary developmental dyslexia and its three subgroups comes from clinical studies using the ITPA, the WISC and the WAIS, standardized reading tests, and the Camp-Dolcourt Modification of the Boder Diagnostic Screening Test. Even though these tests satisfy the criteria for reliability, validity and replicability, there is a language-based commonality among them which limits their support for the construct validity of primary developmental dyslexia and its subgroups. Were electrophysiological measures to correlate highly with language-based measures of primary developmental dyslexia and its subgroups, its construct validity would be strengthened.

The hypothesis proposed states that electrophysiological measures as outlined in the Methods Section cannot discriminate:

a. Between dyslexics and normal readers.

b. Among subgroups of dyslexics-dysphonetics-dyseidetics-mixed.

The development of the experimental design required that choices, with relation to definition and measurement, be made pertaining to five factors which match the five factors measured by the ANOVA.

a. Group - From a population of subjects with reading incompetence, a subset of dyslexic adults was identified by the Camp-Dolcourt Modification of the Boder Diagnostic

Screening Test (1977). Further identification resulted in this subgroup classification:

1. Dysphonetic Dyslexic Subgroup, N = 12
2. Dyseidetic Dyslexic Subgroup, N = 11
3. Mixed Dyslexic Subgroup, N = 10
4. Control Group, N = 12

Individual assessment of the dyslexics insured that:

a. Their general intelligence was average or above.
b. They had no obvious brain pathology.
c. There was no significant impairment of hearing.
d. There was no significant impairment of vision.
e. They had an adequate conventional educational opportunity.
f. They manifested no primary emotional disturbance.

Adults, rather than children, were chosen for the experimental group, to minimize as much as possible the effects of maturation of the central nervous system.

STATE-MODE-CONDITION - Since the hypothesis focused a primary interest on the dysphonetic and dyseidetic subgroups, the experimental design called for two attending states, that of auditory attending and visual attending with a passive state as a control. In the real world, visual and auditory events (modes), both relevant (target condition) and irrelevant (non-target, standard condition) often occur together, intermittently, even simultaneously. Granted that, a dual stimulus approach was felt to be reasonable which involved the assessment of ERP correlates of signal recognition, both across and within visual and auditory modalities concurrently.

In some previous ERP-dyslexia studies, tasks were required (Fenelon, 1968; Fenelon, 1978; Preston et al., 1977; Weber and Omenn, 1977; Sobotka and May, 1977; Shelburne, 1978; Musso and Harter, 1978). Of these, a motor response was required (toggle switch, key press) in some (Fenelon, 1978; Weber and Omenn, 1977; Sobotka and May, 1977; Shelburne, 1978). In the other studies, the discrimination tasks consisted of silent counting. In the study by Symann-Louett et al. (1977), no discrimination task was required but the subjects were told that they would be questioned later as to what they had seen. In the Conners (1971) studies, all stimuli were presented with eyes closed.

Of the experimental groups of primary interest, the dysphonetics and the dyseidetics are purported to manifest selective difficulties in processing aspects of reading-spelling-writing. Therefore, it was decided to use a discrimination task which would purposively and selectively "cognitively burden" these two groups, especially with relation to its effect on the <u>endogenous</u> (after 150 msec) <u>components</u> of the ERP. These endogenous components are believed to be manifestations of cortical information-processing activities and therefore also greatly sensitive to task demands (Donchin et al., 1977). Ideally, to differentially engage the left and right hemispheres with tasks (independent variables) that would maximize the differences which the hypothesis suggests exist in the dyslexic groups, tachistoscopically flashed words (both known and unknown) and dictated words (both known and unknown - when spelled) should have been used. However, it was felt important to establish ERP responses in the experimental groups to more basic perceptual units first, i.e., to flashes and to clicks, for which asymmetrical ERP responses had already been established in normal subjects (Davis and Wada, 1977) and for dyslexic subjects (not divided into clinical subgroups) (Bali et al., 1975). The time requirements of the design with relation to state, mode and condition factors and the number of stimuli required for adequate ERP averaging allowed only for the flashes and clicks. To have added the flashed words and dictated words (pilot studies) would have been too tiring for the subjects. Therefore, the task was to discriminate and count "silently, in your head" the targets (30 dim flashes or 30 soft clicks depending on the attending state, visual or auditory, from the multimodally presented 150 flashes and 150 clicks for each of the three runs). To enhance the validation of the task variable, the target counts were asked for at the end of each run and written down in the log. No motoric response was required from the subjects so as to limit extraneous muscular movement which might confound EEG activity. In addition, if such a motoric response were to inadvertently cause a considerable degree of muscular movement, lateral asymmetries could appear (Donchin et al., 1977).

<u>LEAD</u> - The leads of primary interest were P_3 and P_4. The choice of lead was made in part to replicate those electrode placements of previous ERP-dyslexia studies (Tables II-VI and VIII-XV). Gevins and Schaffer (In press) caution that positioning the electrodes based on the International 10-20 System (anatomy of the skull) does not guarantee an exact placement with respect to the anatomy of the brain. Still, either by conviction, but more often by inference (Neville, 1979), the scalp electrode placement at P_3 is to measure electrical activity at the left angular gyrus, cortical area 39 of the inferior parietal lobule. The angular gyrus is considered by Geschwind (1965) to be the association area for association areas and is anatomically located at the junction where occipital, parietal and temporal lobes meet. Since these are the processing areas for visual, haptic and auditory stimuli, respectively, and since successful integration among these senses is purported to be basic to language acquisition skills, dysfunction of the left angular gyrus has been suggested as a cause for reading dysfunction (Preston et al., 1974). Geschwind reports that lesions of the left angular gyrus relate to decreases in naming ability but do not affect grammatic skills. This association area for association areas permits the intermodal associations necessary for object naming, a fundamental requirement of language function, the written manifestations of which are reading-spelling-writing. A child learns new words more easily by being able to successfully relate and integrate the auditory stimulus "broom" with the visual stimulus "broom" with the tactile stimulus, "broom". Were an inherent neurophysiologically

based inability to relate and integrate these diverse modes of the same stimulus, "broom", to exist (primary developmental dyslexia), then it might be suggested that the problem was at the left angular gyrus and that changed electrical activity at P_3 might be a correlate of this problem.

Yet it has not been clear as to what is encumbered the most in the decrease in naming ability secondary to lesions of the left angular gyrus; are the auditory, visual and tactile modes equally or differentially affected? Based on previous clinical studies, neurological studies, diverse scientific studies and electrophysiological studies, one would expect that the auditory mode would be the most affected by interference of function at the left angular gyrus, the scalp electrode placement for which is assumed to be at P_3. It is appropriate to place an homologous electrode at P_4, given the support for the existence of dyseidetic dyslexia (Boder, 1971) and the spatio-constructional types of dyslexia which are secondary to trauma of the right hemisphere (Critchley, 1970a; Hecaen, 1967; Luria, 1973).

MONTAGE - There is a necessity for a common reference (either "active" or "inactive") equidistant from the two electrodes being compared for proper recording from the scalp. Donchin et al. (1977) feels that linked ears (or mastoids and chin) or an active midline placement is adequate for this purpose. However, Shucard et al. (1977) favor bipolar recordings with an active common lead at C_z rather than using a "created neutral" midline reference by combining the presumably relatively inert lateral linked ear leads. (Temporal lobe electrical activity is, at times, picked up by the ear leads.) Shucard et al. indicate that their pilot experiments using different electrode sites, including a linked ear reference, indicated that the lateral electrode-C_z placement produced the clearest lateralized responses to the different task requirements and also allowed for the averaging of fewer responses to obtain scorable ERPs. Shucard et al. further argue that since C_z is common to both lateral placements, differences in electrical activity at the lateral recording sites would still be discernible from the bipolar response. Since the hypothesis of this study has to do with different task requirements engaging different cerebral hemispheres, a P_3-C_z and P_4-C_z montage was selected to maximize the obtaining of lateralized responses.

Shucard et al. stress that in this montage the obtained ERPs reflect voltage differences between P_3 and C_z and P_4 and C_z electrodes and that the C_z site actually produces the higher amplitude response. Therefore, a higher ERP amplitude recorded from one hemisphere indicates a greater potential difference between the parietal electrode of that hemisphere and the C_z reference. Thus a higher amplitude left hemisphere ERP response is the result of a lower amplitude response at its lateral site, i.e., P_3, compared with the P_4 site. Conversely, a higher amplitude right hemisphere ERP response indicates a lower amplitude response at its lateral site, i.e., P_4, compared with the P_3 site.

INTERPRETATIONS AND IMPLICATIONS

The most interesting result of the ANOVA was that the interactions of the group planned comparisons by state, condition and lead (but collapsed over mode) showed significance for the comparison of primary interest, that of the dysphonetic versus the dyseidetic group but only for the 250-450 msec Power dependent variable (Figures 27, 28, 29, 30, 31 and 32). It is interesting that the differences occurred within the 250-450 msec latency band which encompasses the P300. Although the precise nature of the psychological variables which determine the amplitude of the P300 are not well understood, it has been interpreted as a sign of the later stages of information-processing including response set selection, decision making, stimulus categorization and reduction of uncertainty (Sutton et al., 1967; Broadbent, 1970). The findings of this study are in accord, since the task of this experiment required silent counting of one type of one stimulus from a bimodal presentation.

To further investigate this interaction, t tests were carried out comparing the dysphonetic and dyseidetic groups on each combination of state, condition and lead collapsed over mode. No significant differences were found. Then each combination of the four factors (for each dependent variable) was analyzed in a one-way ANOVA across the four groups and in a t test between the dysphonetic and dyseidetic groups. No significance was found at the .05 level. A Principal Components

Factor Analysis was carried out on the 12 P_4-P_3 differences generated by all the combinations of state, mode and condition for 250-450 msec Power. This analysis yielded four factors, with Eigen values greater than 1, which accounted for 67% of the variance. However, none of these factors showed any significant differences between the dysphonetic and dyseidetic groups.

Then, the P_4-P_3 difference for each combination of state, mode and condition was analyzed in a one-way ANOVA across groups for 250-450 msec Power. A planned comparison between the dysphonetic and dyseidetic groups for all 12 combinations of state, mode and condition did not achieve significance at the .05 level. However, this planned comparison did show marginal significance for P_4-P_3 differences on several combinations (Table XVIII).

The planned comparison between the dysphonetic and dyseidetic groups for the combination of visual attending state-visual mode-target condition showed a marginal significance ($F(1,41) = 3.26$, $P = .077$). Examination of the means of the P_4-P_3 difference showed that this difference was larger in the dyseidetic group. Recalling the montage of this study, P_3-C_z and P_4-C_z and Shucard's (1977) explanation, it appears that the increased P_4-P_3 difference in the dyseidetics actually reflected a stronger voltage difference between P_4 and C_z as compared to P_3 and C_z (Figure 33) and therefore, the result of a weaker power response at the P_4 site itself.

The planned comparison between the dysphonetic and dyseidetic groups for a P_4-P_3 difference for the combination of auditory attending state-visual mode-target condition showed a marginal significance ($F(1,41) = 3.57$, $P = .065$). Examination of the means of the P_4-P_3 difference showed that this difference was larger in the dyseidetic group.

The planned comparison between the dysphonetic and dyseidetic groups for a P_4-P_3 difference for the combination of passive state-visual mode-standard condition, showed a marginal significance ($F(1,41) = 3.23$, $P = .079$). Examination of the means of the P_4-P_3 difference showed that this difference was larger in the dyseidetic group.

It is interesting that the marginally significant P_4-P_3 dysphonetic versus dyseidetic difference occurred mostly for the target (relevant) and not for the standard (irrelevant) condition. This finding is in accord with work done by Hillyard et al. (1973) who, in their studies of selective attention, found an auditory ERP positive component peaking at 250 to 400 msec (P300), which was elicited only after the signal (relevant) and not after the standard (irrelevant) stimuli. Ford et al. (1973) confirmed and expanded the findings of Hillyard et al. (1973) by measuring ERP correlates of signal recognition between and within auditory and visual modalities. Their principal findings were:

A. For the relevant stimuli: a large N200 (for the auditory ERPs, the most negative peak between 190-270 msec; for the visual ERPs, the most negative peak between 170-280 msec) and a large P300.

B. For the irrelevant stimuli in the same modality: a large N200 and a median amplitude P300.

C. For the irrelevant stimuli in the different modality: a smaller or non-existant N200 and a small or non-existant P300.

The authors feel that the N200 data may imply gating of the stimuli or that a preliminary decision based on modality parameters is going on which precedes the ultimate decision as reflected in the P300, i.e., a definitive match between a sensory event and a neural template.

Significant ANOVA interactions involving group (especially the planned comparison of primary interest - dysphonetics versus dyseidetics) were found:

Group by Lead - for 250-450 msec Power - Figure 10.

Group (dysphonetic versus dyseidetic) by State by Lead - for 250-450 msec Power - Figures16, 17 and 18.

Group (dysphonetic versus dyseidetic) by Mode by Condition - for 250-450 msec Power - Figures19, 20 and 21.

Group (dysphonetic versus dyseidetic) by State by Mode by Condition - for 50-150 msec Power - Figures22, 23, 24, 25, and 26.

Group (dysphonetic versus dyseidetic) by State by Condition by Lead - for 250-450 msec Power - Figures 27, 28, 29, 30, 31 and 32.

Therefore, since some factor interactions of the ANOVA were significant, the null hypothesis can be rejected.

The rationale of this study suggested that the dysphonetics manifest information-processing problems in the left cerebral hemisphere and the dyseidetics manifest such problems in the right cerebral hemisphere and that:

1. The dysphonetics would be burdened most by a task involving the auditory attending state-auditory mode-auditory target - at P_3.

2. The dyseidetics would be burdened most by a task involving the visual attending state-visual mode-visual target at P_4.

A t test was carried out between the dysphonetics and dyseidetics for the 250-450 msec latency band, wherein previous significant ANOVA interactions were found. These two groups were compared on P_4 Power (visual attending state-visual target)-P_3 Power (auditory attending state-auditory target). Using a separate variances t test the dyseidetics had a significantly higher P_4-P_3 difference than the dysphonetics - ($t(16.58) = 2.11$, $P = .0497$). However, a Mann-Whitney U test yielded a P value between .05 and .10 (one-tailed) suggesting that this significant t test might be due more to intragroup variance than to group differences. A scatter plot was constructed of the P_4 versus P_3 values (for each subject of each group - Figure 34). Inspection of the scatter plot showed that high values of P_4 were associated with low values of P_3 for four of the eleven dyseidetic subjects, and that high values of P_3 and low values of P_4 were associated with four of the twelve dysphonetics. Dysphonetics and dyseidetics were classified into three groups:

1. Those with P_4 values greater than 4.0
and P_3 values less than 3.0

2. Those with P_3 values greater than 1.75 and P_4 values less than 2.25

3. All others.

	High P_4 Low P_3	All Others	High P_3 Low P_4	
Dyseidetics	4	7	0	= 11
Dysphonetics	0	8	4	= 12

The distributions of the dyseidetics and dysphonetics in these three groups were significantly different ($\chi^2(2) = 8.04$, $P = .025$).

Because of the variation noted within the dysphonetic and dyseidetic groups, inferences must be made with care. However, recalling the montage of this study, P_3-C_z and P_4-C_z and Shucard's (1977) explanation, the stronger power at P_4 relative to P_3 actually reflects a stronger voltage difference between P_4 and C_z as compared to P_3 and C_z, and therefore is the result of weaker power at the P_4 site itself for the dyseidetics. And the stronger power at P_3 relative to P_4 actually reflects a stronger voltage difference between P_3 and C_z as compared to P_4 and C_z and is therefore the result of weaker power at the P_3 site itself for the dysphonetics.

There are several possibilities which might explain why ERP measures did not more fully discriminate between dyslexics and normals and among subgroups of dyslexics.

A. The subjects in each of the experimental and the control groups might have been inadequately screened clinically and/or too few to fully maximize the rationale of this study, especially since extremely subtle lateralized hemispheric dysfunctioning is implied. Handedness and sex were not used as clinical criteria for further subject subgrouping in this study.

B. Aspects of the experimental design might not have been sufficiently sensitive to permit detection of differences.

1. Based on grand-averaging techniques and subsequent visual inspection (Figures 5 and 6), predetermined and fixed latency bands were chosen as dependent variables for both the visual and auditory ERPs, eliminating some potential bias but losing some flexibility.

2. The assumption was made, perhaps incorrectly, that the P_3 and P_4 electrode sites reflect electrical activity from the left angular gyrus and from its homologous site in the right hemisphere, respectively. The assumption was made, perhaps incorrectly, that these two sites of the cortex, the left angular gyrus and its homologous site in the right hemisphere are involved in the information-processing dysfunctions of dysphonetics and dyseidetics, respectively.

3. The tasks assigned, that of silently counting soft (target) from loud (standard) clicks and counting dim (target) from bright (standard) flashes may not actually differentially engage the two hemispheres. Given the clinically noted problems with <u>word</u> processing, it might have been more appropriate, in the design, to use tachistoscopically-presented and dictated known and unknown words.

4. Other task variables which were not considered in this study but which have been shown to have significant effects on the ERP (left-right asymmetries) include word versus flash differences (Preston et al., 1977), meaningfulness of stimuli (Matsumiya et al., 1972), and effects of stimulus delivery rate-selective attention-information load (Schwent et al., 1976), and response to stimulus intensity (Buchsbaum, 1974).

5. In spite of seemingly adequate controls, there might have been flaws in the measurement techniques.

A review of the previous ERP dyslexia studies showsthat group differences and lateralized ERP differences were found in some; at times, however, the differences and their explanations were in opposite directions both for amplitude and reasoning.

Presenting visual and auditory stimuli, Fenelon (1978) found that Contingent Negative Variation was generated weakly in the left parietal region in problem readers but only for auditory stimulation conditions. Fenelon stressed that in view of the small sample (7 problem readers and 7 normal readers) it was prudent to withhold attempts at explanation until more data were available.

Conners (1971) presented data from four studies, all indicating significant results but not all of a convergent nature. Visual stimuli were presented but with eyes closed for all four studies. Study 1 showed noticeably attenuated left parietal (P_3) visual ERPs at N200 (negative component at

200 msec) for the poor readers in a family. Studies 2 and 3 showed that good reading achievement was related to amount of negativity (voltage) of N200 at the P_3 site. Study 4 showed that low verbal-high performance subjects had higher amplitudes of P140 (positive component at 140 msec) at P_3, P_4 and O_2. High verbal-low performance subjects showed significantly increased latencies of N200 at O_1 and O_2. Conners supported the genetic and neurophysiological bases for some forms of reading disorders. He noted that some of his studies showed that both left and right parietal and occipital late waves manifested changes among poor readers and suggested that an attempt be made to classify these subjects as having unilateral or generalized diminution of late wave activity. He felt that these two "types" of visual ERP abnormalities might provide clues to the differential etiologies of dyslexia. It would be of special interest to determine if some poor readers who clinically exhibit space-form perceptual deficits, might show right-sided diminution of activity.

Shields (1973) presented several different types of visual stimuli (flashes, pictures, designs, words and nonsense words) with no task required. He found that in the learning disabled group, the latencies of all the component peaks of the visual ERPs were longer than in normals. However, peaks P_1 and P_3 (not specified as to msec from stimulus) were larger in amplitude in the learning disabled group. Shields explained his results by suggesting that the longer latencies in the learning disabled group indicated that these children require more time to process information "because their nervous systems may operate more slowly than those of normal children". The larger ERP amplitudes found in the learning disabled group suggest that these children must focus greater attention toward the stimuli than normals.

Preston et al. (1974) in an attempt to replicate Conners' (1971) findings, used two control groups, one matched for age and I.Q. and the other matched for reading level and I.Q. Their findings which they felt confirmed Conners' (1971) results, were that disabled readers showed substantially smaller negative amplitudes than the control groups at the P_3 site at 180 msec for light flashes and words. The stimulus "cat" produced larger negative amplitudes than the light flash for all three groups. Preston et al. imply in their conclusions that P_3 voltage reflects activity at the left angular gyrus and that reduced amplitude there reflects a more inadequate mode of neural processing. They stress that the fact that the effect can be noted for non-linguistic (flashes) stimuli as well as linguistic stimuli ("cat") suggests that "the neurological deficit is general in nature rather than specific to the categories of stimuli involved in reading." Because there was no task, however, their conclusion that greater amplitude of the N180 response to the word "cat" as opposed to the flash stimuli reflects a greater degree of processing, should be accepted with caution. In addition, there is no mention of a comparison of P_3 to P_4 and so it is not known if the effect is specific for P_3 only.

Preston et al. (1977) - This study was with adult disabled readers and controls presenting flashes and different words, the task being to count silently certain words. The interaction of stimulus by hemisphere by placement by group showed that the reading disabled subjects showed smaller word-minus-flash differences only at the P_3 site compared to normals for both types of visual ERPs only for P200 and for the late positive component measures. Preston et al. explain their findings in that word stimuli may have a negative affective association for disabled readers <u>or</u> that these results reflect neurophysiological differences between normal and disabled readers which differentially affect the way the two groups process written material.

Weber and Omenn (1977) presented visual and auditory stimuli to dyslexics and family controls. A comparison of hemispheric ERPs showed no consistent differences between the two groups in amplitude for both visual and auditory ERPs. However, dyslexics showed longer latencies (both in visual and auditory ERPs) confirming Shields' (1973) study. Weber and Omenn attempted to subgroup their dyslexics via spelling errors or most affected sensory modality (auditory or visual), yet still found no group differences. However, it appears that there was little standardization in the clinical subgrouping. Weber and Omenn explain their inability to replicate Conners' work as perhaps due to the fact that Conners used a C_z reference while they used linked mastoids.

Sobotka and May (1977) compared visual ERPs and reaction time in dyslexics and controls in four different age groups. The task was to respond to dim flashes per a response key (with eyes closed). Dyslexics exhibited an increased amplitude to unattended stimuli and a slower reaction time to attended stimuli. The authors suggested that differencesin selective attentional ability might be expected to result in greater visual ERP amplitudes for unattended stimuli in dyslexics. Sobotka and May offer several explanations as to why their results might have differed from that of Conners (1971). One had to do with different methods of measuring amplitude (Conners measured amplitude from the baseline while Sobotka and May used peak to trough). In addition, they suggest clinical reasons in that the procedures used to define dyslexia might have been different in the two studies. A main unresolved problem in both the studies by Conners and Sobotka and May is that the subjects were instructed to respond motorically only to the dim flashes but the visual ERPs measured were those which occurred to the bright flashes (non-signal stimuli).

Lux (1977) calculated a learning disability score using only the Wide Range Achievement Test, which has reading, spelling and arithmetic components, for 9 subjects in regular classes with no controls. Visual ERPs to checkerboard patterns were obtained from both hemispheres and then a right-sided minus left-sided latency score derived. Lux felt that reading is processed in the right parietal area because longer latencies were noted there in dyslexics. On the other hand, he felt that arithmetic computation is handled in the left hemisphere as evidenced by longer latencies there in those subjects with dyscalculia.

Symann-Louett et al. (1977) studied wave form differences in visual ERPs in 10 reading disabled and 12 normal children. Sixteen frequently used words were flashed. No discrimination task was required but the subjects were told that they would be questioned later as to what words they had seen. Grand averaged curves were calculated and compared. The reading disabled subjects showed two peaks between 200 and 350 msec as compared with the single one in the controls. Then, by a count of individual curves, the control group showed more early components (before 200 msec) than the disabled group at P_3 and W_1 (Wernicke's Area). Symann-Louett et al. interpret their results as in accordance with Conners (1971) and Preston et al. (1974), in that the significant differences are at P_3 and W_1 and not at the right-sided homologous leads. The authors explain the more complex wave forms found before 200 msec in the normals as perhaps being due to the longer latencies seen in the reading disabled. Another possible explanation is that perhaps neuronal activities present in the normals may be absent in the reading disabled, resulting in fewer waves in the latter group.

Njiokiktjien et al. (1977) studied 58 children with learning disorders, but of varied clinical backgrounds, and compared them to six adults of a previous study. The visual

ERPs of the learning disordered children showed significantly longer latencies in four waves between 139 and 306 msec and the amplitudes of two of these waves were significantly higher. The authors explain the increased amplitudes as possibly indicating a neuronal disorder.

Shelburne (1978) studied 9 male children with reading disabilities and compared them with normals used in previous studies. The task was to respond motorically after discrimination between a nonsense syllable and a word in a consonant-vowel-consonant trigram. Previous studies had shown that those normal children who performed well on this problem-solving task showed greater positive amplitude of visual ERPs from the third position stimuli than visual ERPs from the first or second position stimuli. Dyslexics showed poor performance on this discrimination task; the absence of visual ERP position differences was seen in the dyslexic children but also in those normals who had trouble with the task.

Musso and Harter (1978) worked with two groups (each with 9 subjects) who were diagnosed clinically as having visual perceptual problems or auditory perceptual problems, and a control group of 9 subjects. Only visual ERPs however were studied. All children showed larger visual ERPs to relevant as opposed to irrelevant stimuli. Those with visual perception problems showed greater relevant-irrelevant differentiation in the visual ERPs recorded from O_z than the normal group; this suggested to the authors that the former group was selectively attending more perhaps as a compensatory mechanism for their deficiency. The latency of P300 was longer in the children with visual perceptual problems when compared to those with auditory perceptual problems who in turn showed longer latencies than the normals. The authors concluded that the reading disabled child processed information at a slower rate than the normals.

Fried et al. (In press) studied five dysphonetics, six dyseidetics and two "mixed type" as discriminated by the Boder Diagnostic Screening Test but only auditory ERPs were recorded to words and musical chords. No task was required. ERPs were recorded from F_7, F_8, W_1 and W_2 and referenced to paired ears. Using a cross-correlational comparison method of word and musical chord ERP waveforms from 50 to 400 msec after stimulus onset, the authors found that the data from W_1 and W_2 showed:

A. There were significant differences between normal and dysphonetic subjects in terms of auditory ERPs over the left hemisphere.

B. There were significant differences between normal and dyseidetic subjects in terms of auditory ERPs over the right hemisphere.

C. "Mixed subjects" showed these effects over both hemispheres.

The authors interpret their results as suggestive that subgroups of dyslexics have failed to develop hemispheric specialization functions.

It is difficult to compare previous dyslexia-ERP studies because of the great variations in the experimental designs regarding criteria for group selection, task (independent) variables, the parameters of the EEG used as dependent variables, montage, measurement techniques and data quantification and analysis. Still differences have been elicited which manifest some convergence. Increased ERP latencies have been noted in dyslexics in the studies by Shields (1973), Weber and Omenn (1977), Sobotka and May (1977), Symann-Louett et al. (1977), Njiokiktjien et al. (1977) and Musso and Harter (1978). The explanation has usually pertained to diminished neural capacity resulting in the need for more time to process information. Generally, smaller ERP amplitudes have been found in dyslexics, usually in the left hemisphere in the studies by Fenelon (1978), Conners (1971), Preston et al. (1974, 1977), Symann-Louett et al. (1977) and Shelburne (1978). The explanation has usually pertained to diminished (selective) neural capacity implying that in some sense, amplitude <u>is</u> related to functional power. Several studies have found increased ERP amplitude in dyslexics (Shields, 1973; Sobotka and May, 1977; Njiokiktjien, 1977). The explanation has usually pertained to diminished (selective) neural capacity resulting in a greater work effort or greater focusing of attention which is manifested by greater ERP amplitude. It is noteworthy that in several studies, either because of contradictory results (Conners, 1971; Symann-Louett et al., 1977) or because of clinically-based hypotheses (Weber and Omenn, 1977; Musso and Harter, 1978; Fried et al., In Press), suggestions had been made that subgroups of dyslexics with differential dysfunctions might exist.

This study, because of its experimental design, had predetermined latency bands as dependent variables (based on grand-averaging - Figures 5 and 6).

A reason why most of the ERP studies of dyslexics have shown decreased amplitude at P_3 only may have to do with the percentage distribution of subgroups. Boder (1971) and anecdotal evidence from educational sources have indicated that in a population of dyslexics, there are about 60% dysphonetics, 20% dyseidetics, and 20% "mixed". Given that percentage distribution and the relatively few subjects in previous experimental groups, it is possible to suspect that most of these subjects were dysphonetics with dysfunctions in an area of the left hemisphere, the electrode site for which was usually P_3. Interestingly, in the present study, the four groups were almost equal in numbers of subjects (dysphonetics, 12; dyseidetics, 11; mixed, 10; controls, 12).

In the present study, the significant differences were found in the 250-450 msec latency band, which encompasses the P300, wherein categorization and decision-making processes are presumed to occur. Previous studies, except those of Symann-Louett et al. (1977), Njiokiktjien et al. (1977) and Fried et al. (In press) have noted ERP amplitude differences, when they occur, at earlier latencies. A possible reason for this is that in the present study, three states, two modes, and two conditions were factors, with a task of silent counting involved, via a bimodal presentation of visual and auditory stimuli. Given the complexities inherent in this design, it is expected that if differences involving group and lead were to occur, these differences would be at or about the P300 since higher order processes beyond just gating and channel selection are probably involved.

A major purpose of this study was to assess possible ERP evoked hemispheric asymmetries in a dyslexic population. Cumulative and convergent data from clinical studies (Johnson and Myklebust, 1967; Bateman, 1968; Smith, 1970; Boder, 1971), neurological studies (Hecaen, 1967; Critchley, 1970a; Luria, 1973), diverse scientific studies (Sperry and Gazzaniga, 1967; Bakker, 1969; Ingvar and Schwartz, 1974) and electrophysiological studies (Tables I-XVII) supported a concept of at least two subgroups of dyslexia, one based upon language-symbolic dysfunction in the left hemisphere, the other based on spatial-Gestalt dysfunction in the right hemisphere. Notwithstanding much previous clinical evidence for the existence of subgroups of dyslexics, this was not a testable hypothesis until a measuring instrument which could subgroup dyslexics were constructed, which satisfied the scientific requirements of reliability, validity and replicability. Such a test is the Camp and Dolcourt (1977) Modification of the Boder Diagnostic Screening Test which was used in this study.

Noting the recent ERP studies in the more subtle aspects of information-processing and dysfunctions thereof, future research might focus on tachistoscopically-presented and auditorally-presented known and unknown words to carefully defined subgroups of dyslexics in an attempt to differentially engage the left and right hemispheres. If electrophysiological measures can allow for an early non-invasive and predictive diagnosis of dyslexia from the other reading incompetencies and can also infer hemispheric utilization in subgroups of dyslexia, especially in younger children, then:

A. Early detection can establish <u>early differential remedial education</u>.

B. Early detection can establish understanding and diagnosis in a hitherto amorphous area and in doing so, aid in the prevention of the psychopathologies which are frequent sequelae in those subjects with primary developmental dyslexia.

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FIGURE 1. SYSTEM OVERVIEW OF THE MODIFIED SCHWENT-HILLYARD SELECTIVE ATTENTION PARADIGM FOR RECORDING VISUAL AND AUDITORY ERPs

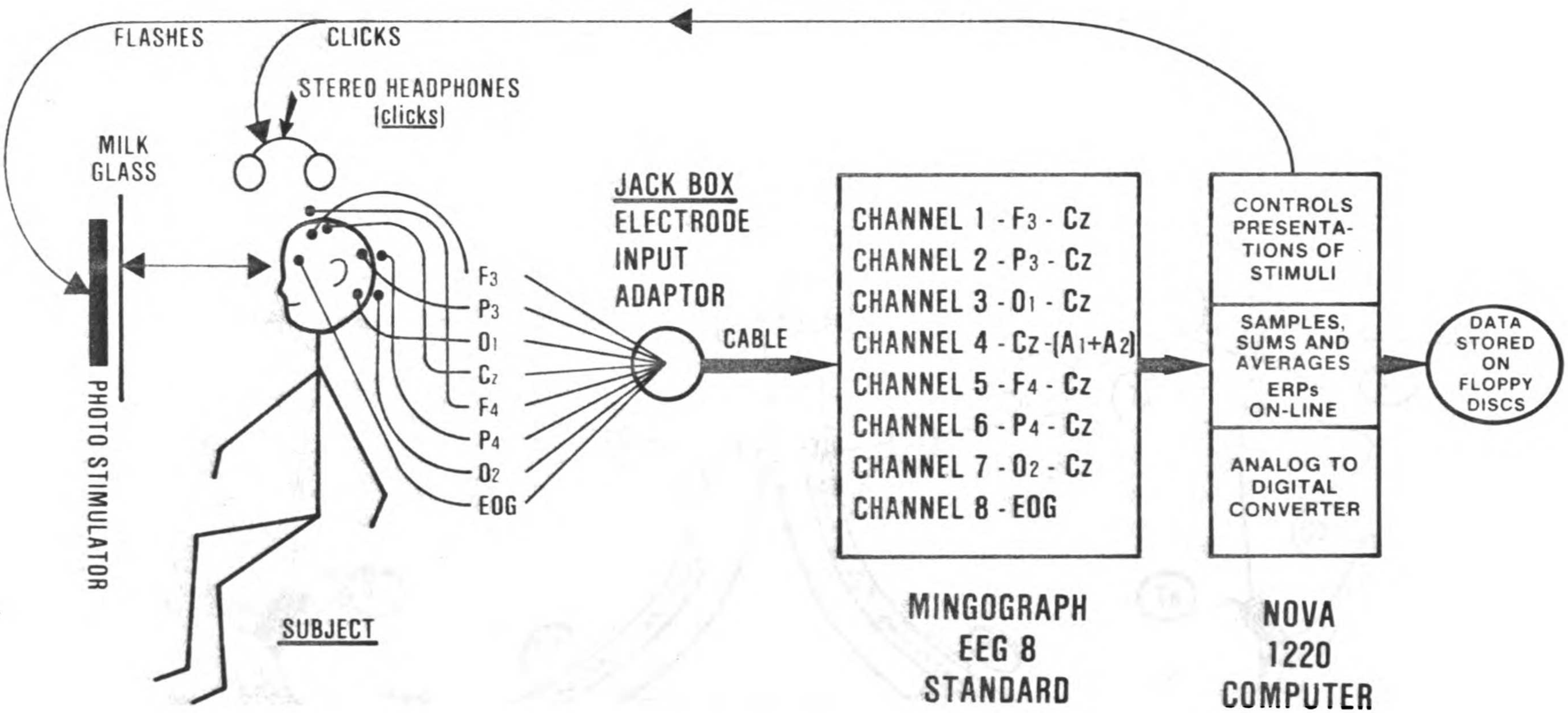


FIGURE 2. ELECTRODE LOCATION AND NOMENCLATURES FOR INTERNATIONAL 10-20 EEG SYSTEM

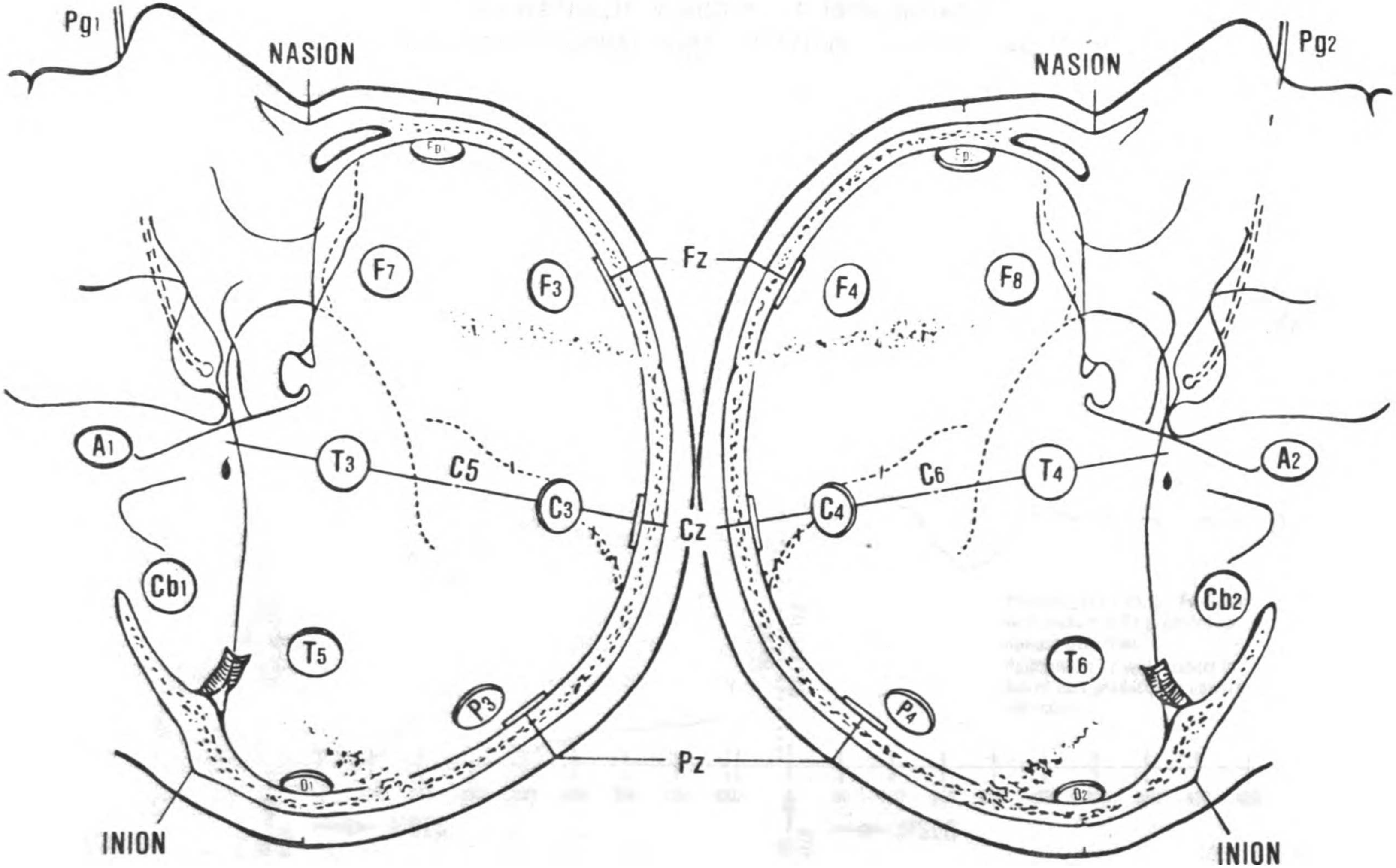


FIGURE 3. MODIFIED SCHWENT-HILLYARD SELECTIVE ATTENTION PARADIGM GRAND AVERAGED ERPs

DP=DYSPHONETIC SUBGROUP T=TOTAL SUBJECTS

AA=AUDITORY ATTENDING STATE CONDITION 1=AUDITORY TARGET

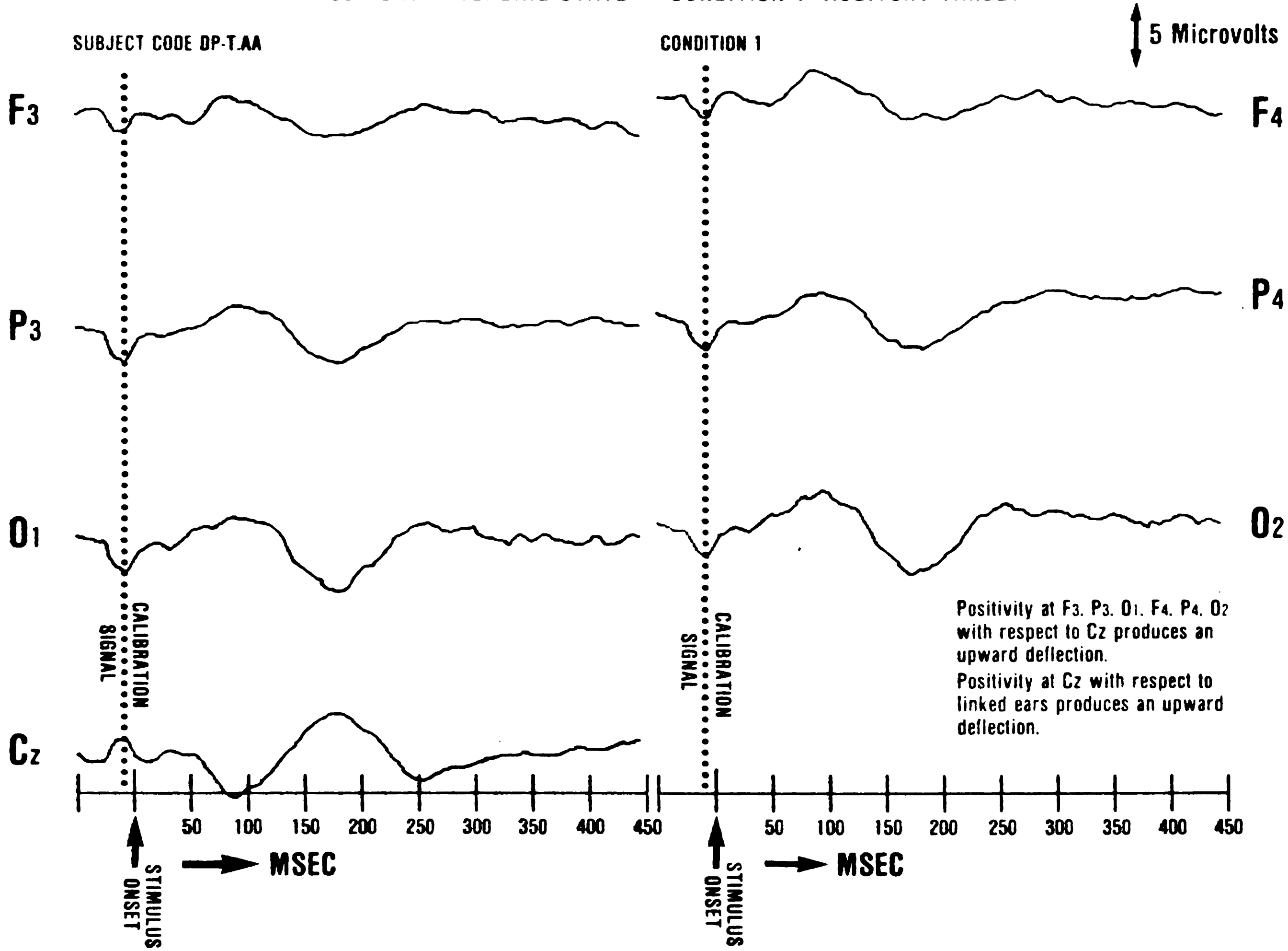


FIGURE 4. MODIFIED SCHWENT-HILLYARD SELECTIVE ATTENTION PARADIGM GRAND AVERAGED ERPs

DE=DYSEIDETIC SUBGROUP T=TOTAL SUBJECTS
VA=VISUAL ATTENDING STATE CONDITION 3=VISUAL TARGET

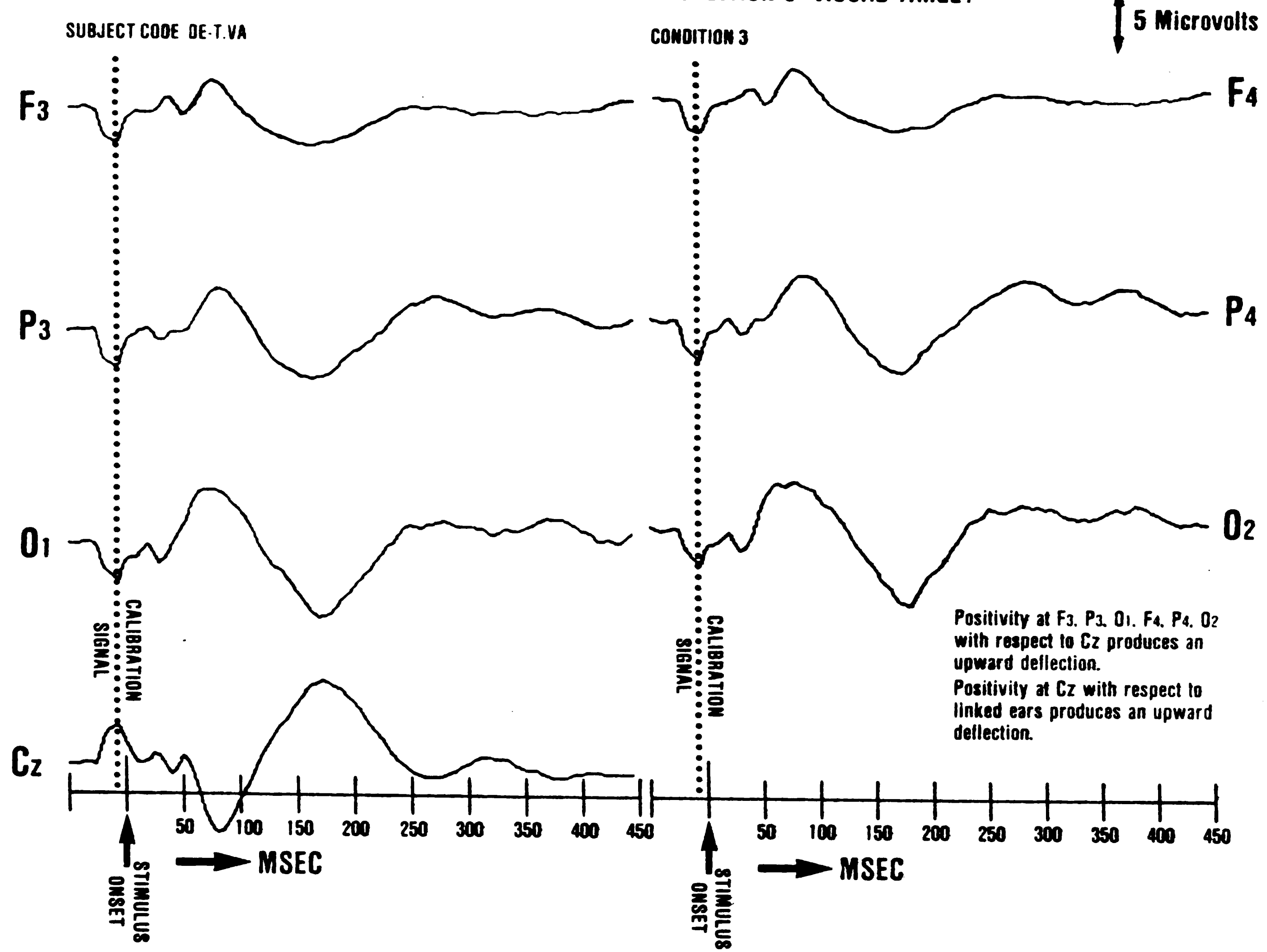


FIGURE 5. GRAND AVERAGING FOR VISUAL ERPs
GROUPS: DP=DYSPHONETIC, DE=DYSEIDETIC, MI=MIXED, CO=CONTROLS
STATES: VA=VISUAL ATTENDING, AA=AUDITORY ATTENDING, PA=PASSIVE
CONDITIONS: VT=VISUAL TARGET, VS=VISUAL STANDARD

FIGURE 6. GRAND AVERAGING FOR AUDITORY ERPs

GROUPS: DP=DYSPHONETIC, DE=DYSEIDETIC, MI=MIXED, CO=CONTROLS
STATES: VA=VISUAL ATTENDING, AA=AUDITORY ATTENDING, PA=PASSIVE
CONDITIONS: AT=AUDITORY TARGET, AS=AUDITORY STANDARD

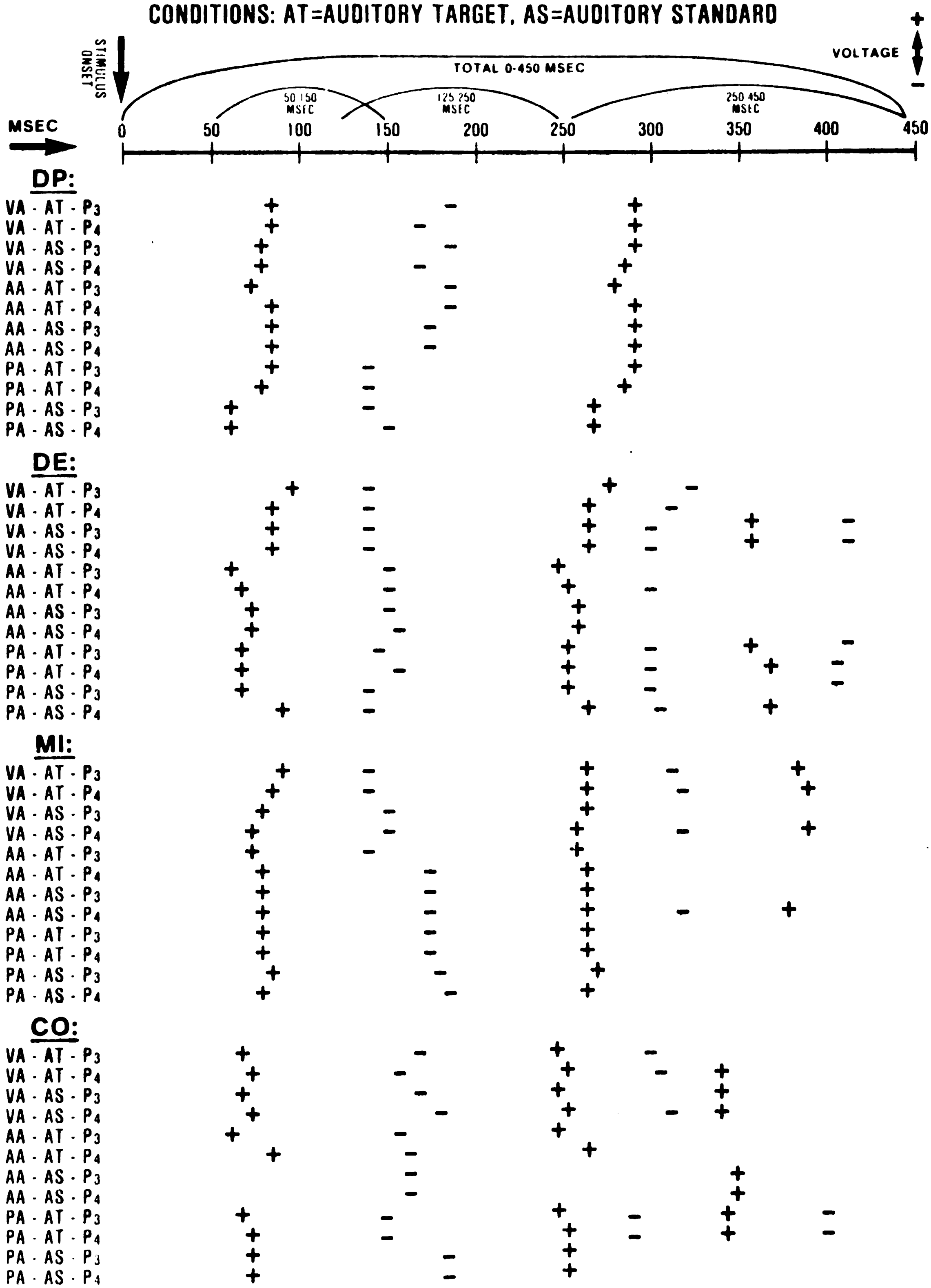


FIGURE 7. ANOVA

2 FACTOR INTERACTION FOR TOTAL (0-450 MSEC) LATENCY BAND
STATE - MODE P=.001

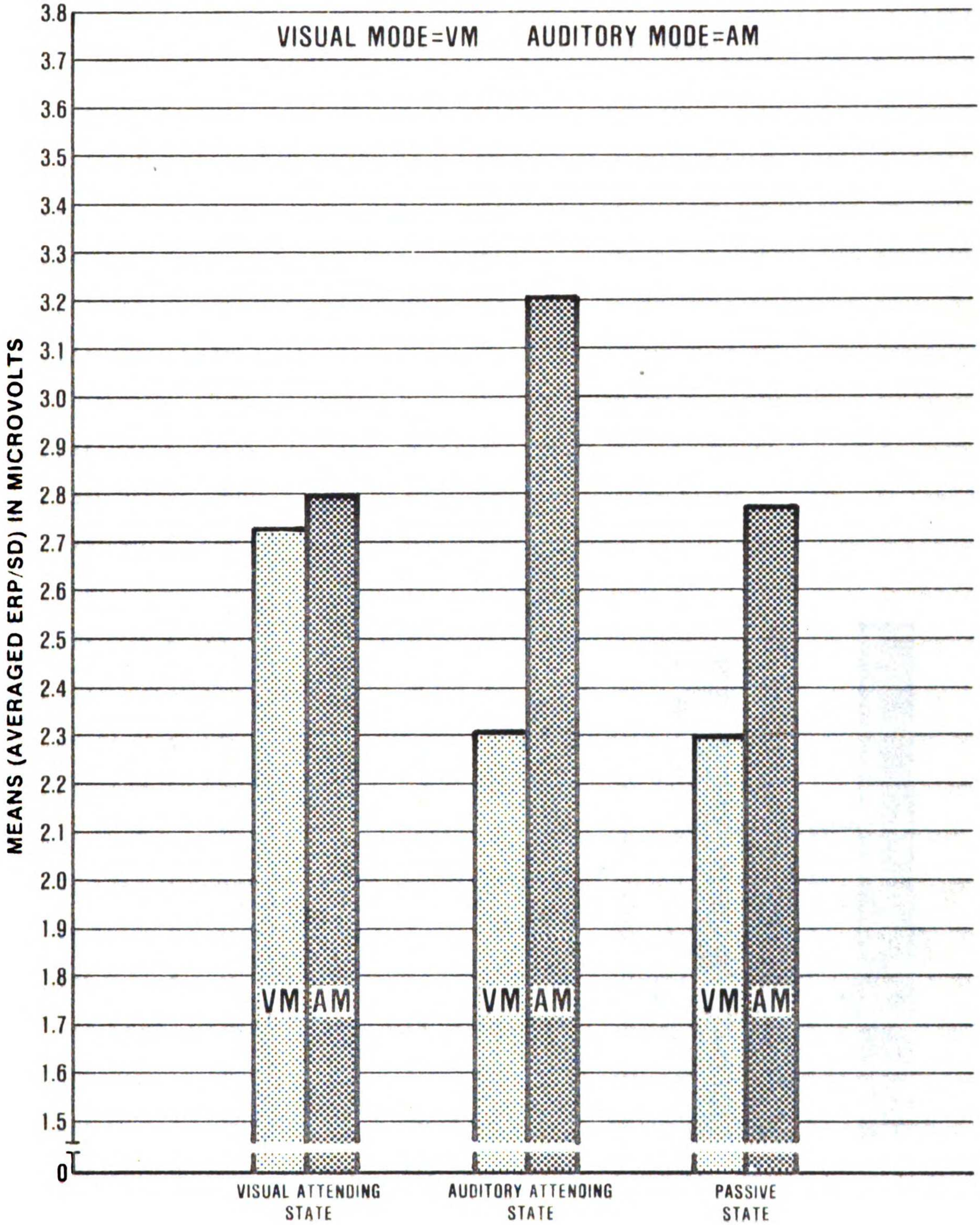


FIGURE 8. ANOVA

2 FACTOR INTERACTION FOR TOTAL (0-450 MSEC) LATENCY BAND (P=.007)
AND FOR 125-250 MSEC LATENCY BAND (P=.044)
MODE - CONDITION

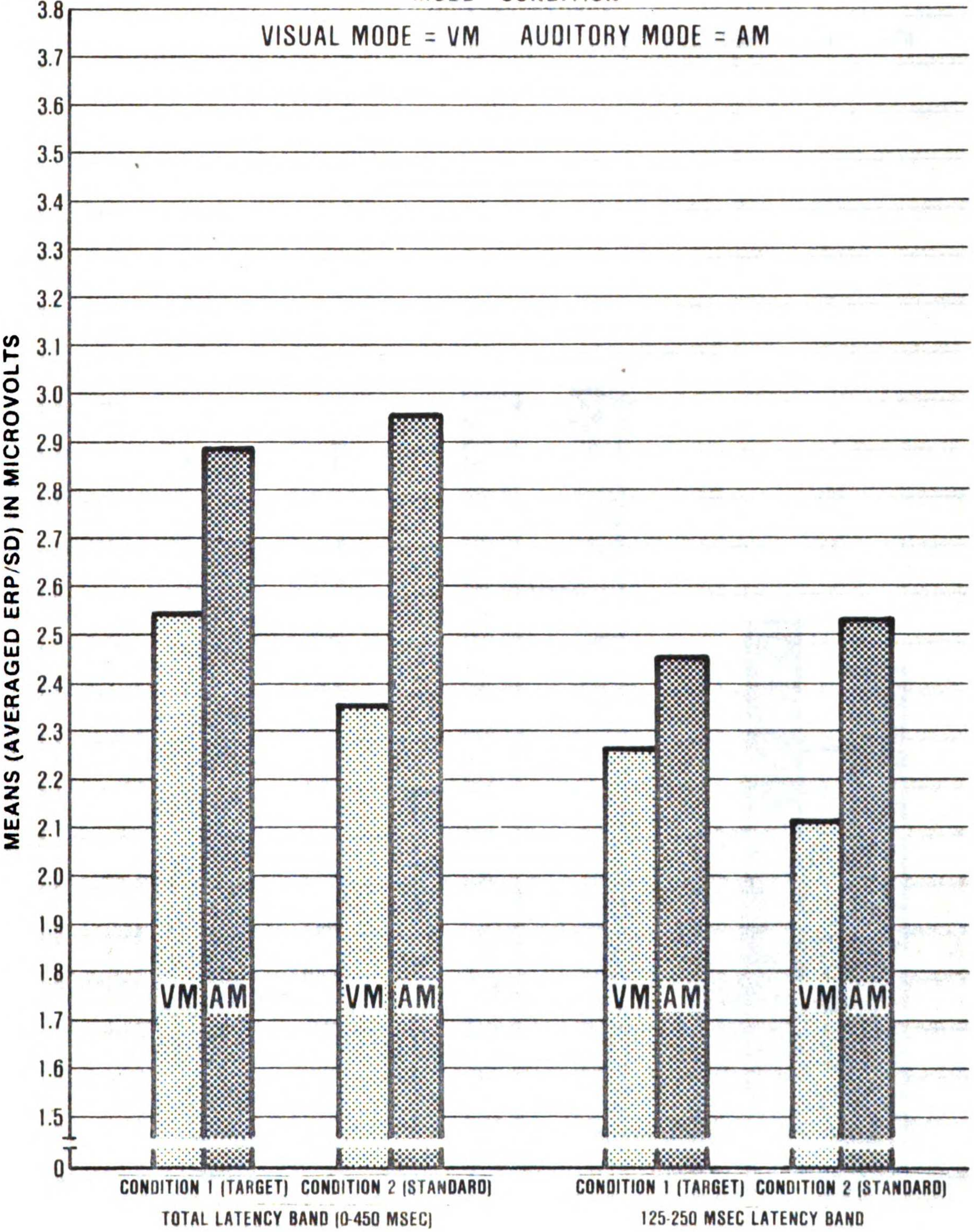


FIGURE 9. ANOVA

2 FACTOR INTERACTION FOR TOTAL (0-450 MSEC) LATENCY BAND (P=.048) 50-150 MSEC LATENCY BAND (P=.002) AND 125-250 MSEC LATENCY BAND (P=.037)

MODE - LEAD

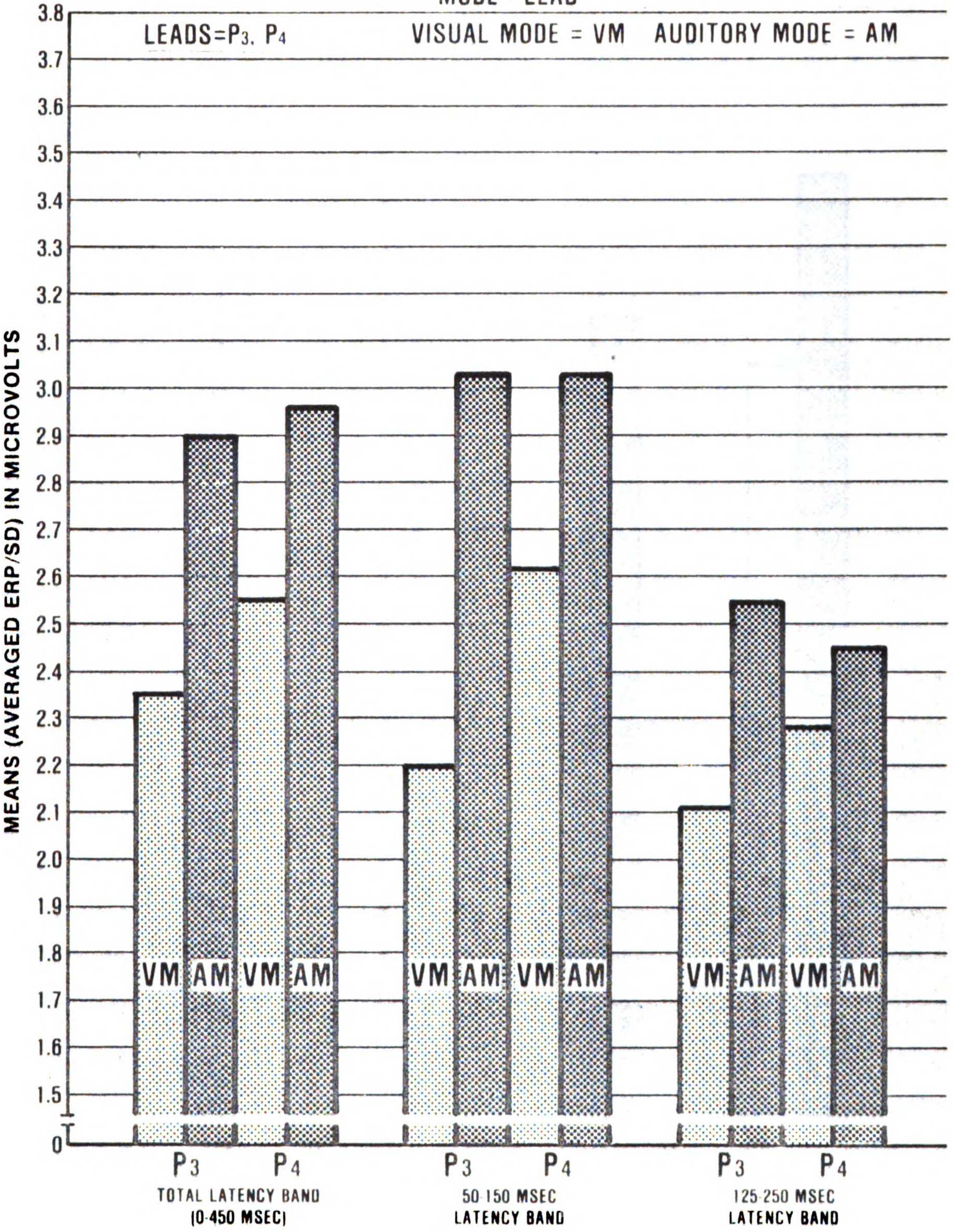


FIGURE 10. ANOVA

2 FACTOR INTERACTION FOR 250-450 MSEC LATENCY BAND
GROUP - LEAD P=.035

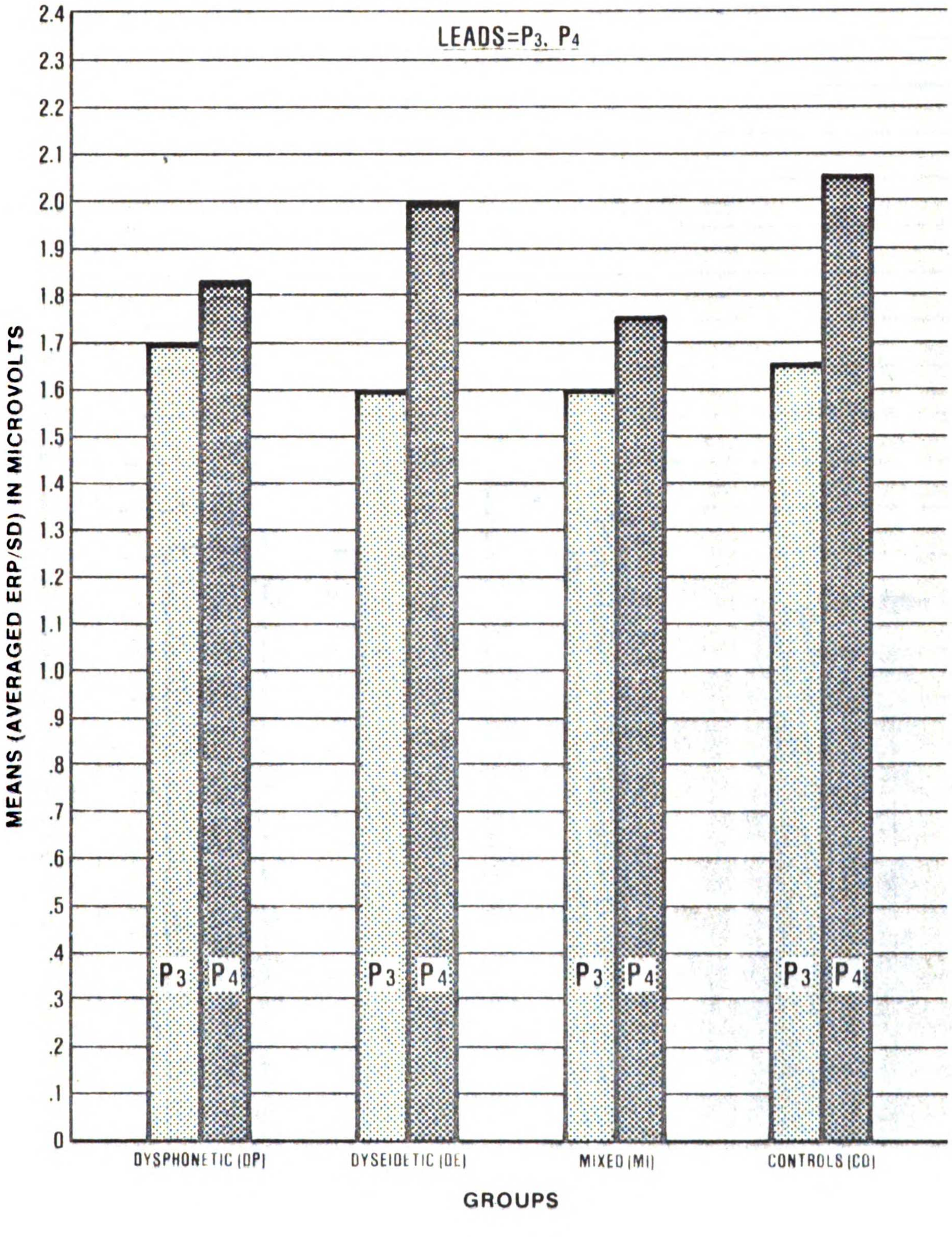


FIGURE 11. ANOVA

3 FACTOR INTERACTION FOR TOTAL (0-450 MSEC) LATENCY BAND
STATE - CONDITION - LEAD   P=.028 (MULTIVARIATE)

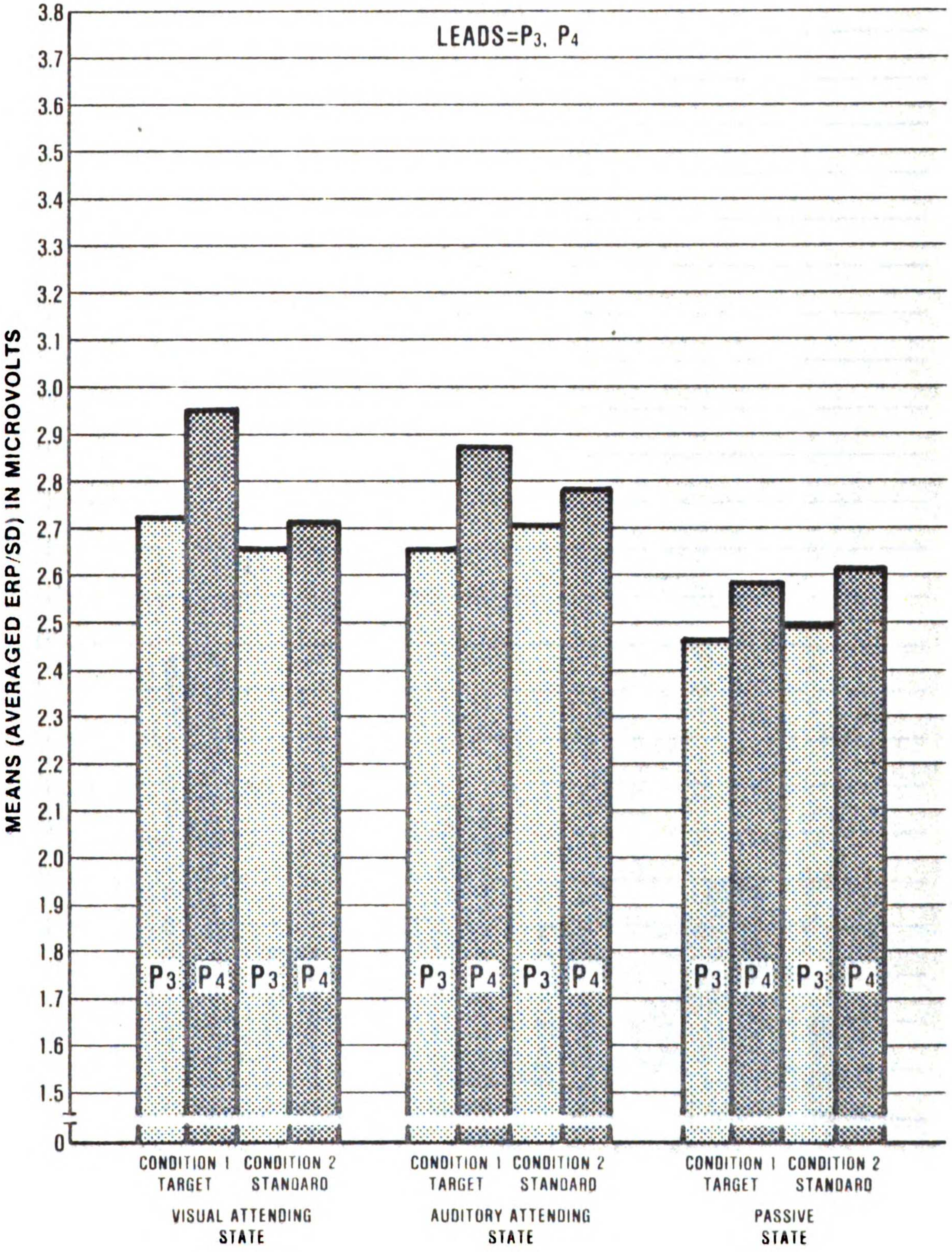


FIGURE 12. ANOVA

3 FACTOR INTERACTION FOR 250-450 MSEC LATENCY BAND
STATE - CONDITION - LEAD P=.001

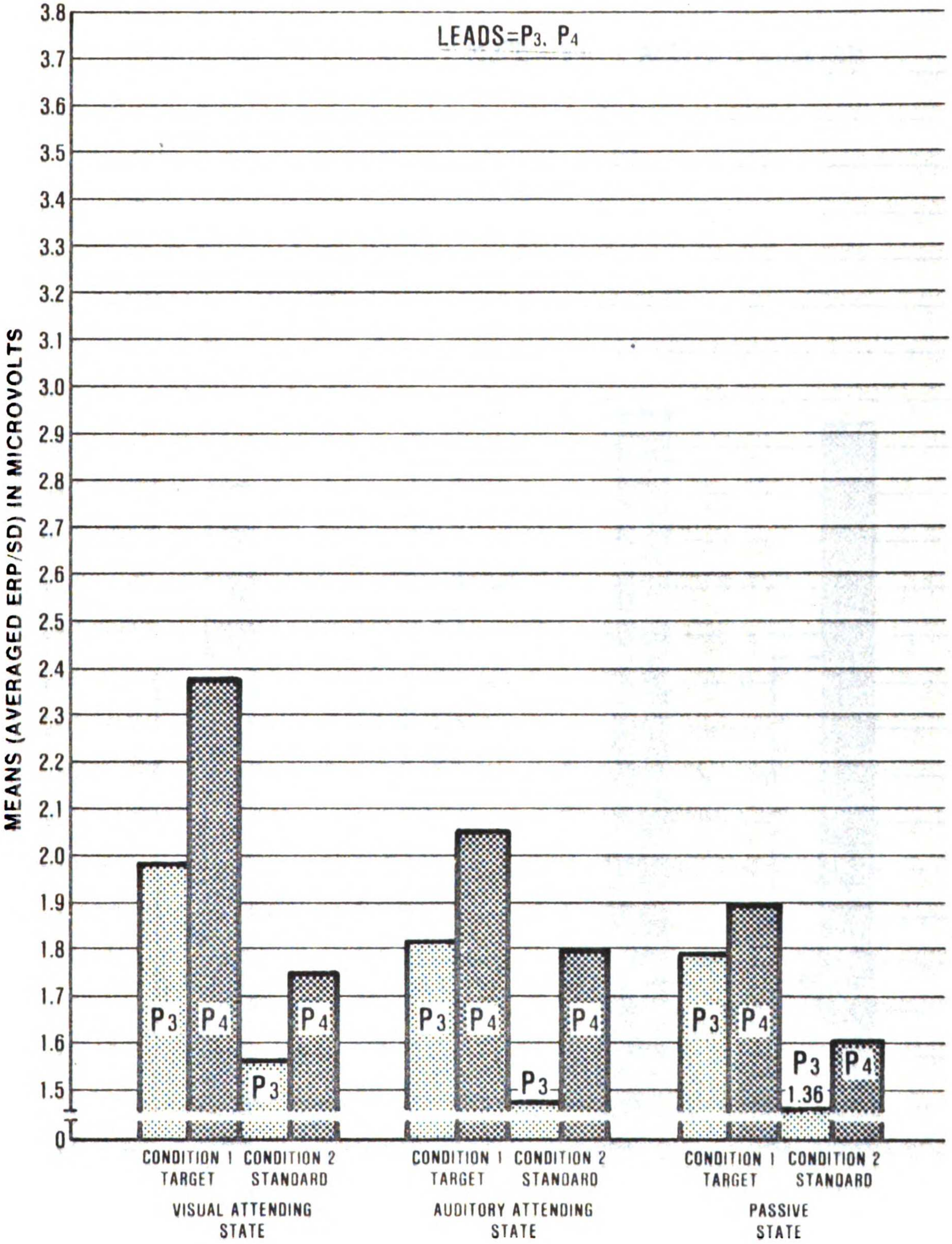


FIGURE 13. ANOVA

3 FACTOR INTERACTION FOR TOTAL (0-450 MSEC) LATENCY BAND

MODE - CONDITION - LEAD P=.026

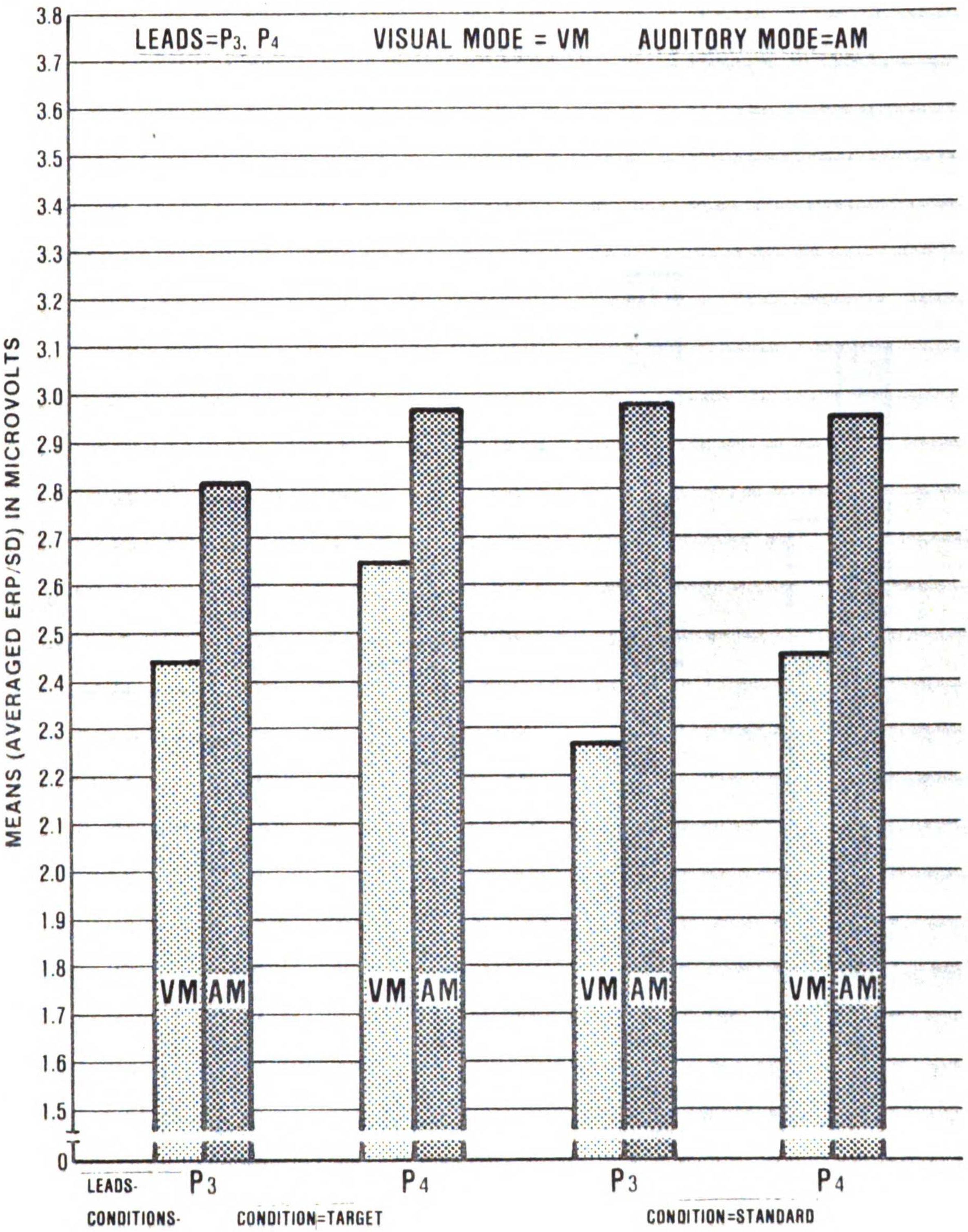


FIGURE 14. ANOVA

3 FACTOR INTERACTION FOR 50-150 MSEC LATENCY BAND
MODE - CONDITION - LEAD   P=.004

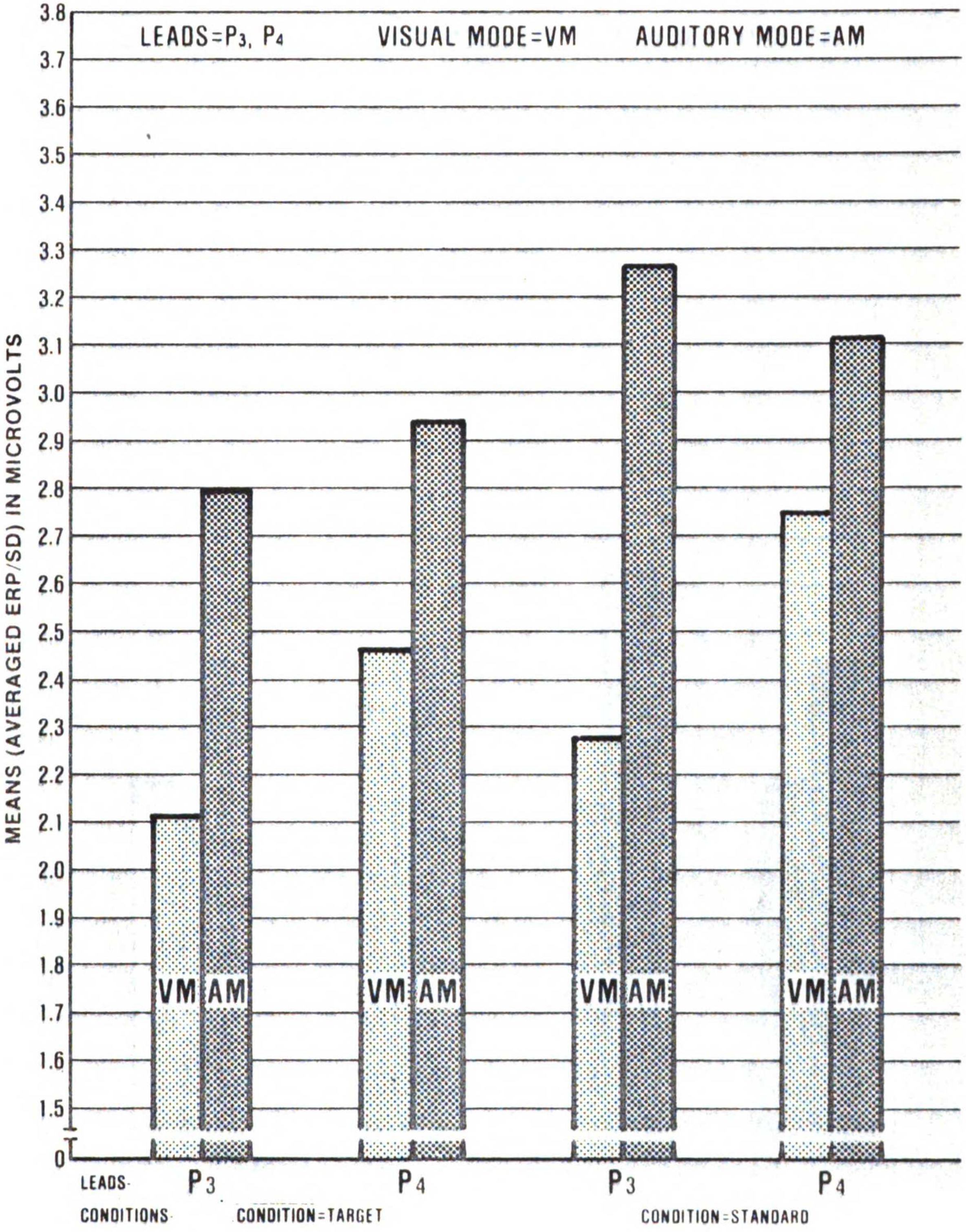


FIGURE 15. ANOVA

3 FACTOR INTERACTION FOR 125-250 MSEC LATENCY BAND

MODE - CONDITION - LEAD P=.047

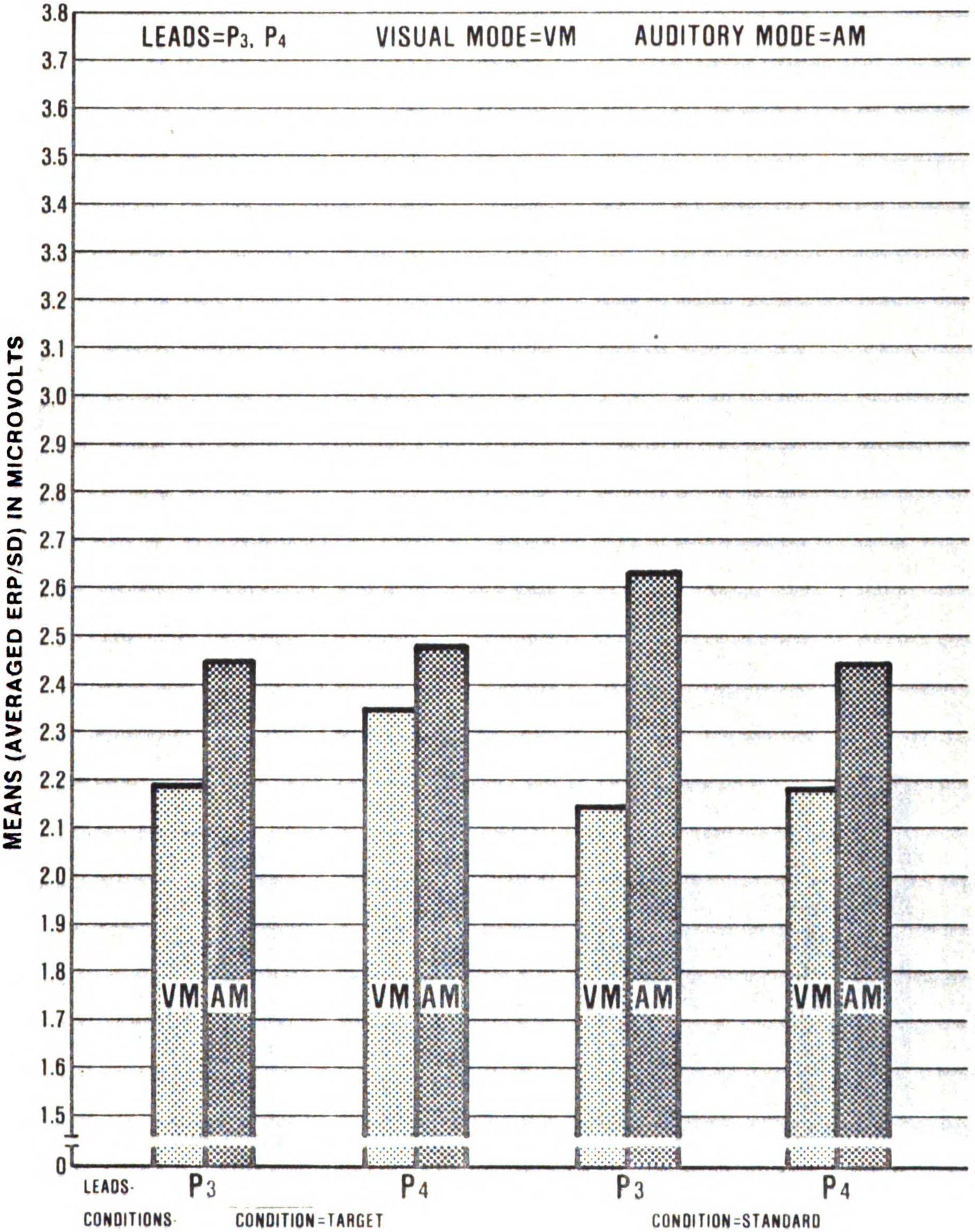


FIGURE 16. ANOVA

3 FACTOR INTERACTION FOR 250-450 MSEC LATENCY BAND

GROUP (DP, DE) - STATE - LEAD P=.042

STATE=VISUAL ATTENDING

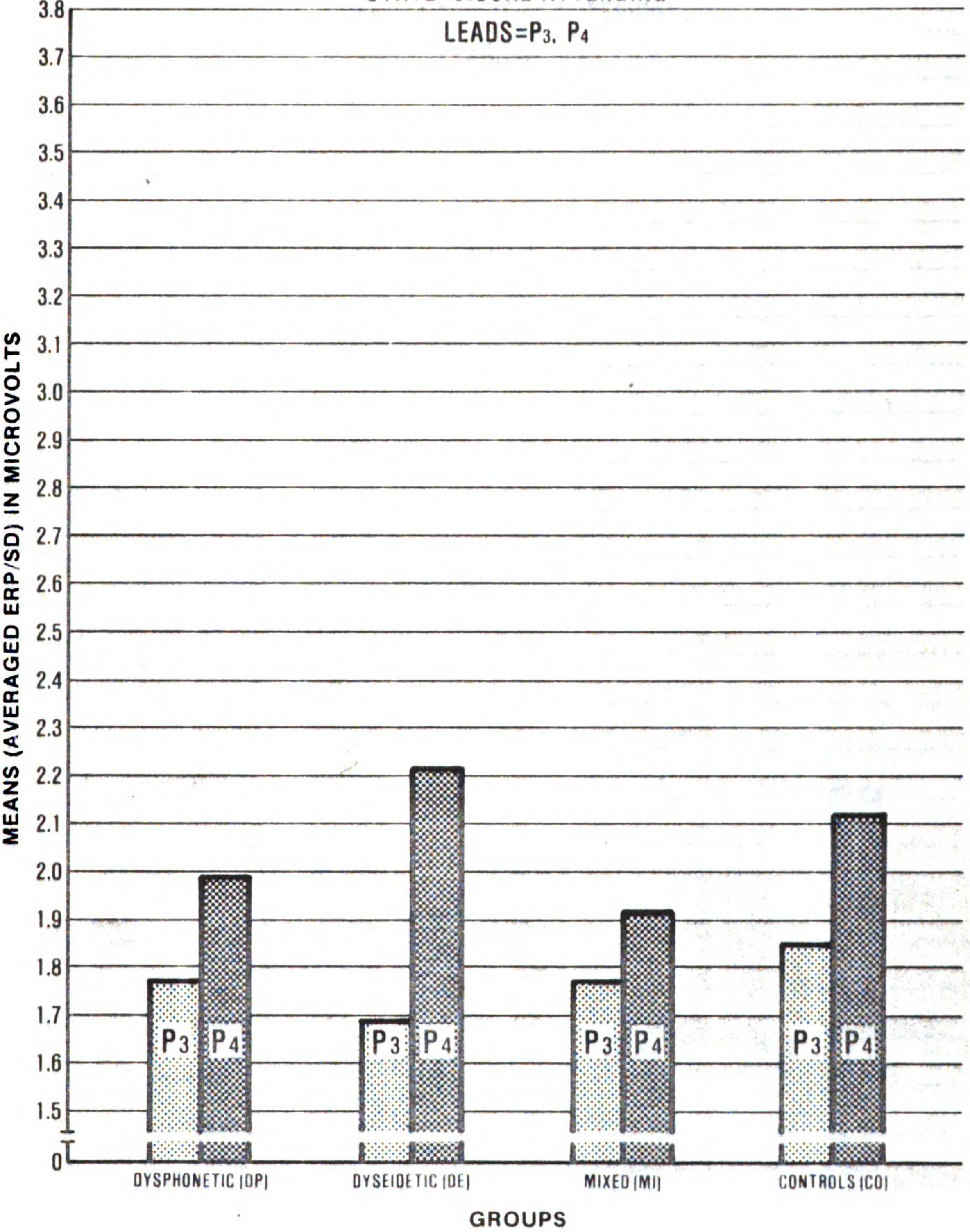


FIGURE 17. ANOVA

3 FACTOR INTERACTION FOR 250-450 MSEC LATENCY BAND

GROUP(DP, DE) - STATE - LEAD P=.042

STATE - AUDITORY ATTENDING

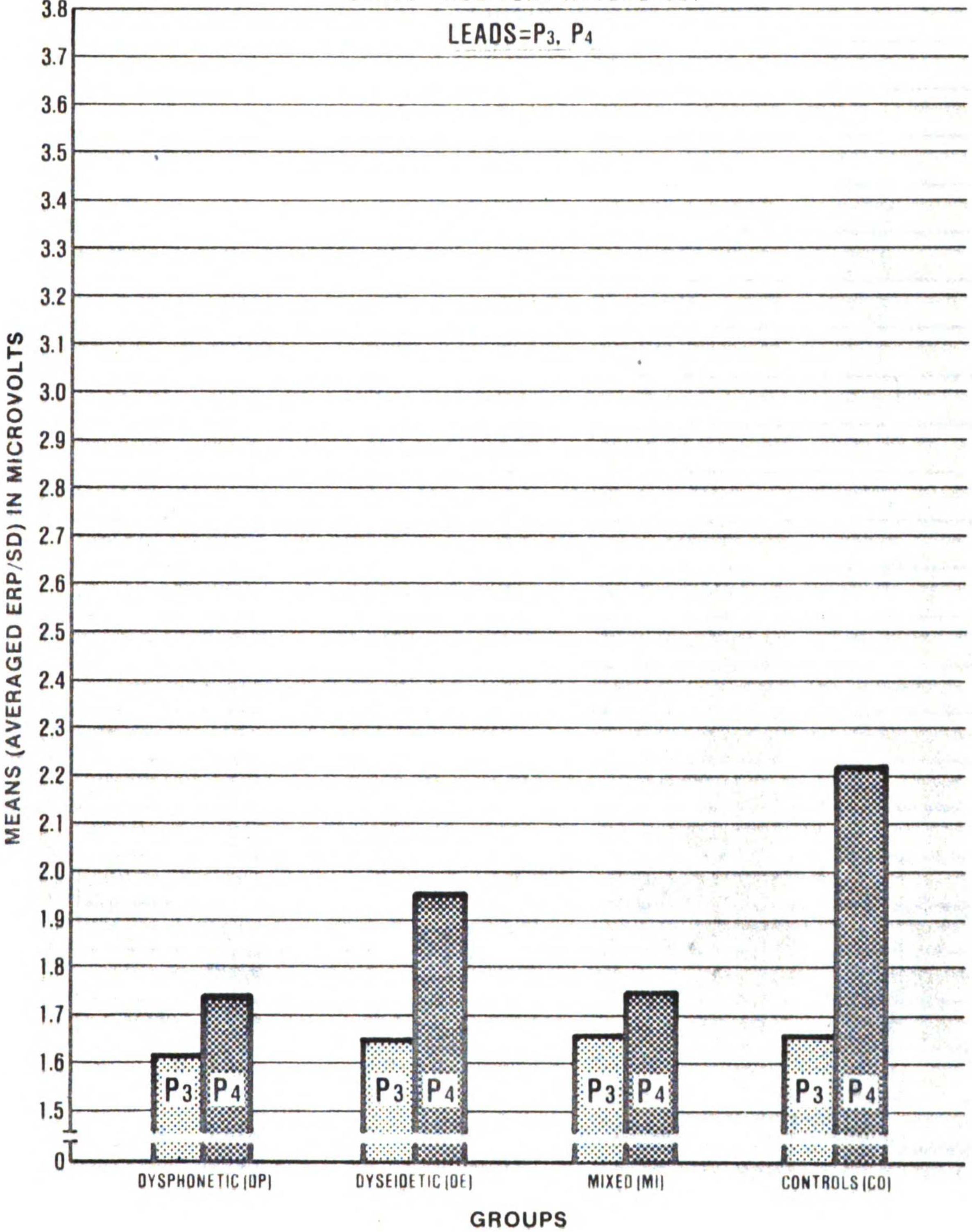


FIGURE 18. ANOVA

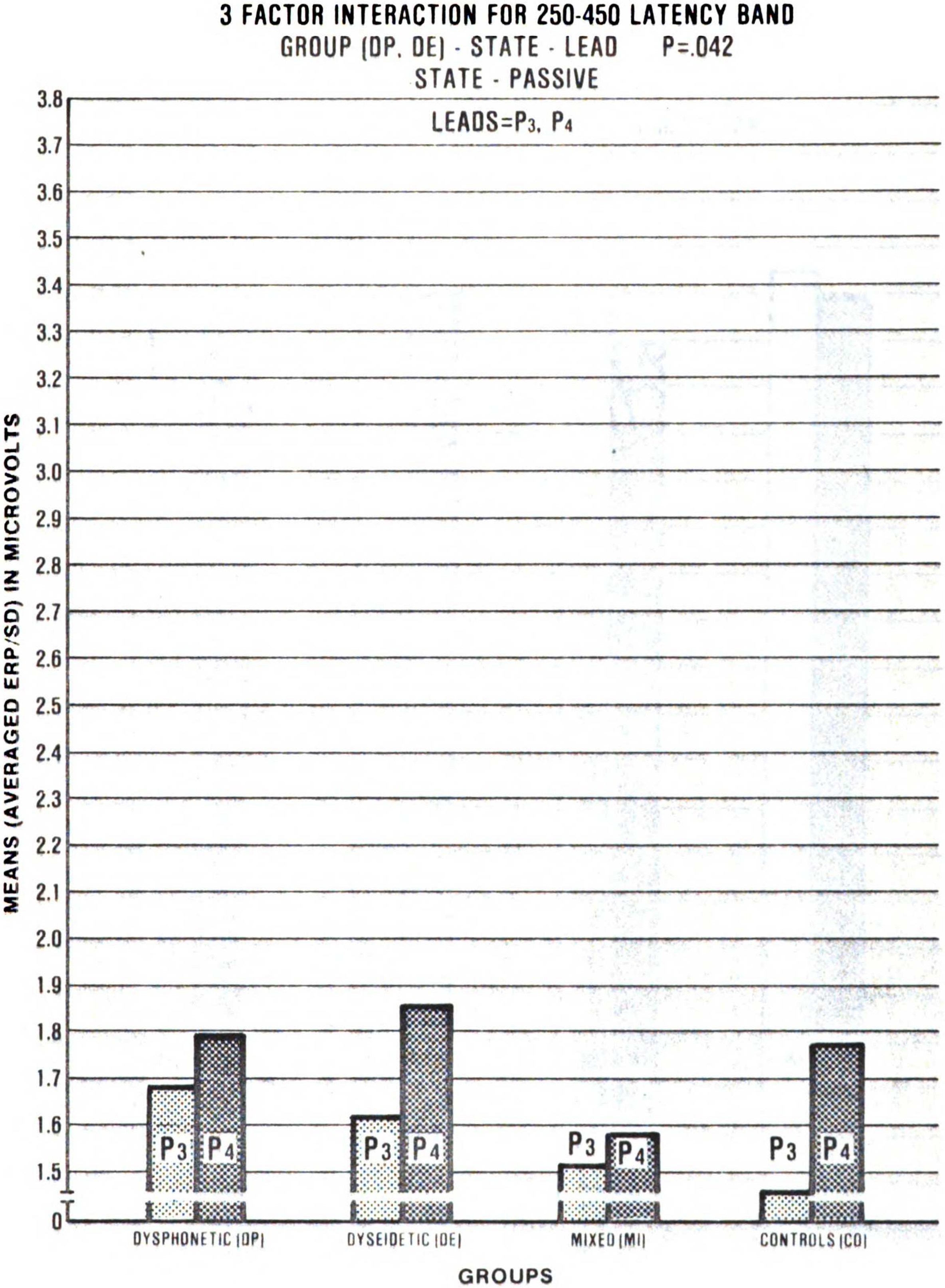


FIGURE 19. ANOVA

3 FACTOR INTERACTION FOR 250-450 MSEC LATENCY BAND
GROUP (DP, DE) - MODE - CONDITION
P=.037 CONDITION=TARGET

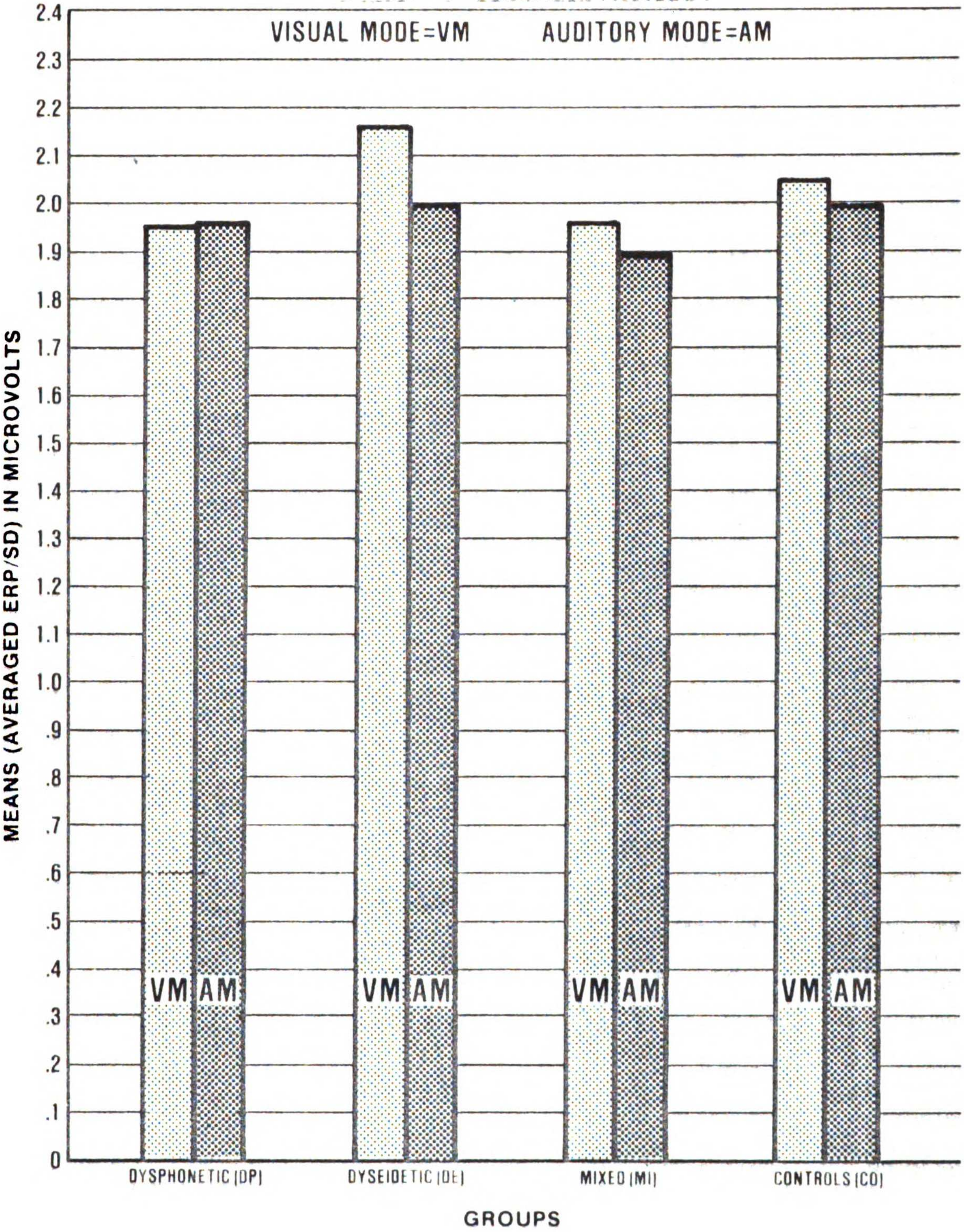


FIGURE 20. ANOVA

3 FACTOR INTERACTION FOR 250-450 MSEC LATENCY BAND
GROUP (DP. DE) - MODE - CONDITION
P=.037 CONDITION=STANDARD

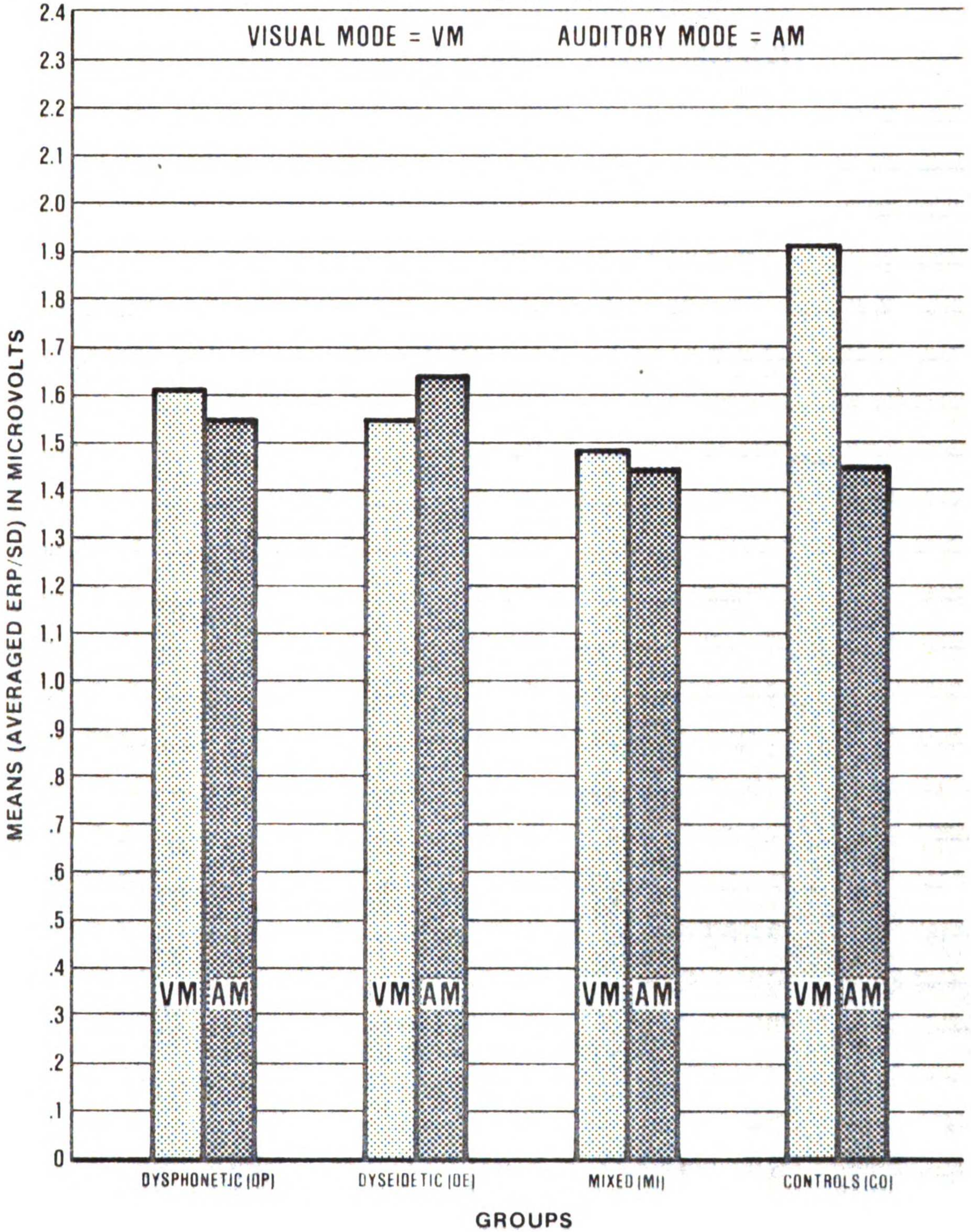


FIGURE 21. ANOVA

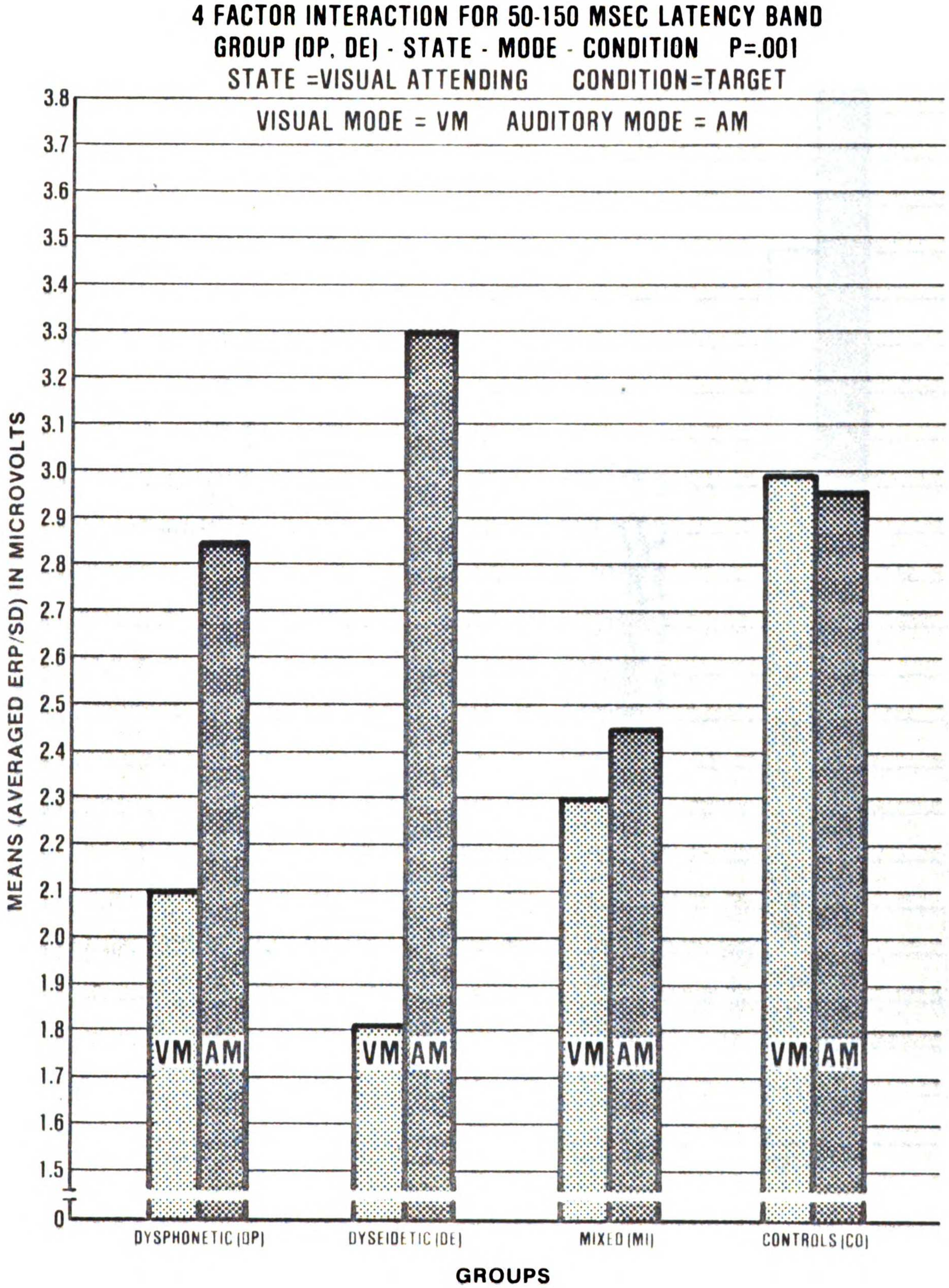
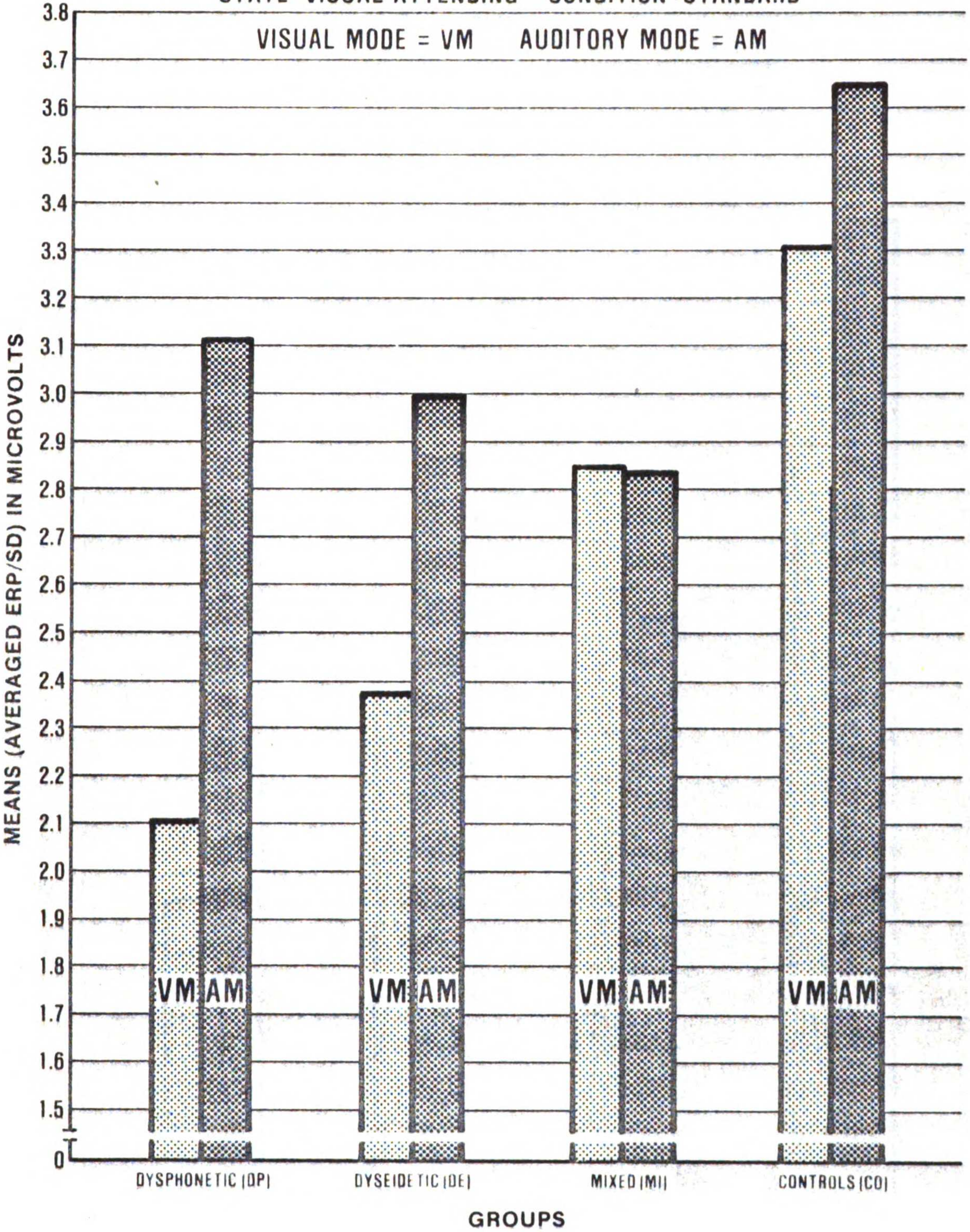


FIGURE 22. ANOVA

4 FACTOR INTERACTION FOR 50-150 MSEC LATENCY BAND

GROUP (DP, DE) - STATE - MODE - CONDITION P=.001

STATE=VISUAL ATTENDING CONDITION=STANDARD



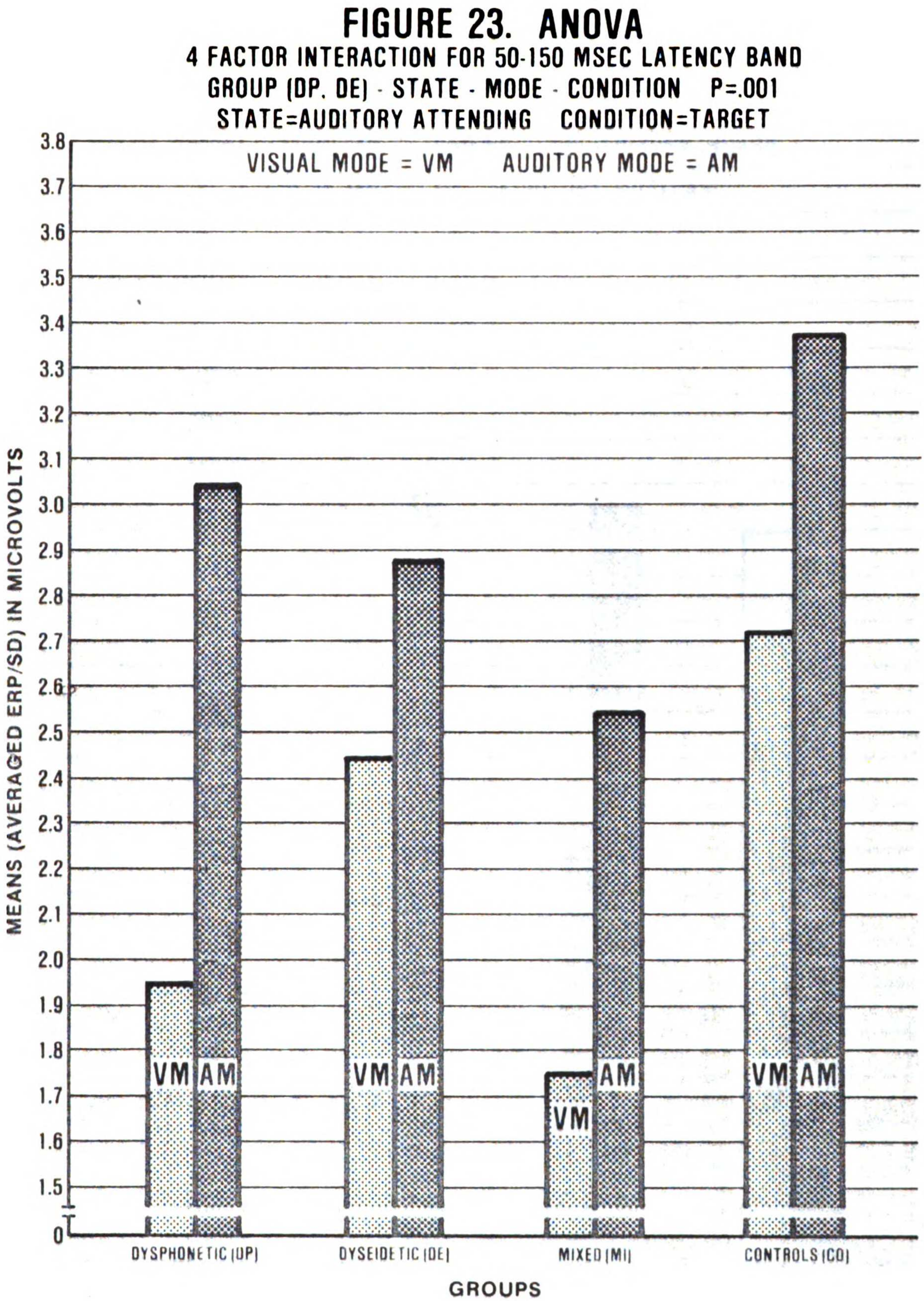


FIGURE 23. ANOVA
4 FACTOR INTERACTION FOR 50-150 MSEC LATENCY BAND
GROUP (DP, DE) - STATE - MODE - CONDITION P=.001
STATE=AUDITORY ATTENDING CONDITION=TARGET
VISUAL MODE = VM AUDITORY MODE = AM
MEANS (AVERAGED ERP/SD) IN MICROVOLTS
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
0
VM
AM
DYSPHONETIC (DP)
DYSEIDETIC (DE)
MIXED (MI)
CONTROLS (CO)
GROUPS

FIGURE 24. ANOVA

4 FACTOR INTERACTION FOR 50-150 MSEC LATENCY BAND

GROUP (DP, DE) - STATE - MODE - CONDITION P=.001

STATE=AUDITORY ATTENDING CONDITION=STANDARD

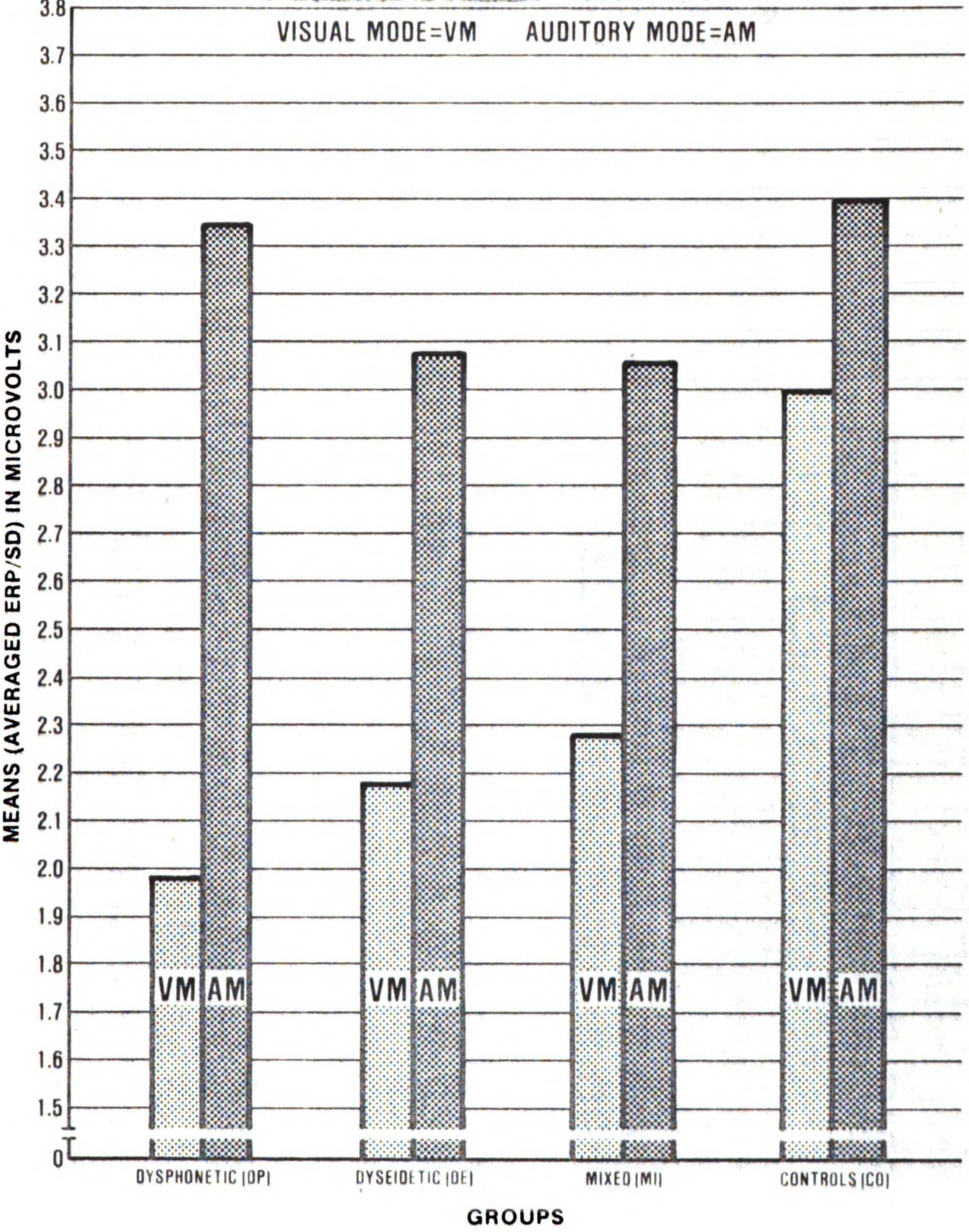


FIGURE 25. ANOVA

4 FACTOR INTERACTION FOR 50-150 MSEC LATENCY BAND
GROUP (DP, DE) - STATE - MODE - CONDITION P=.001

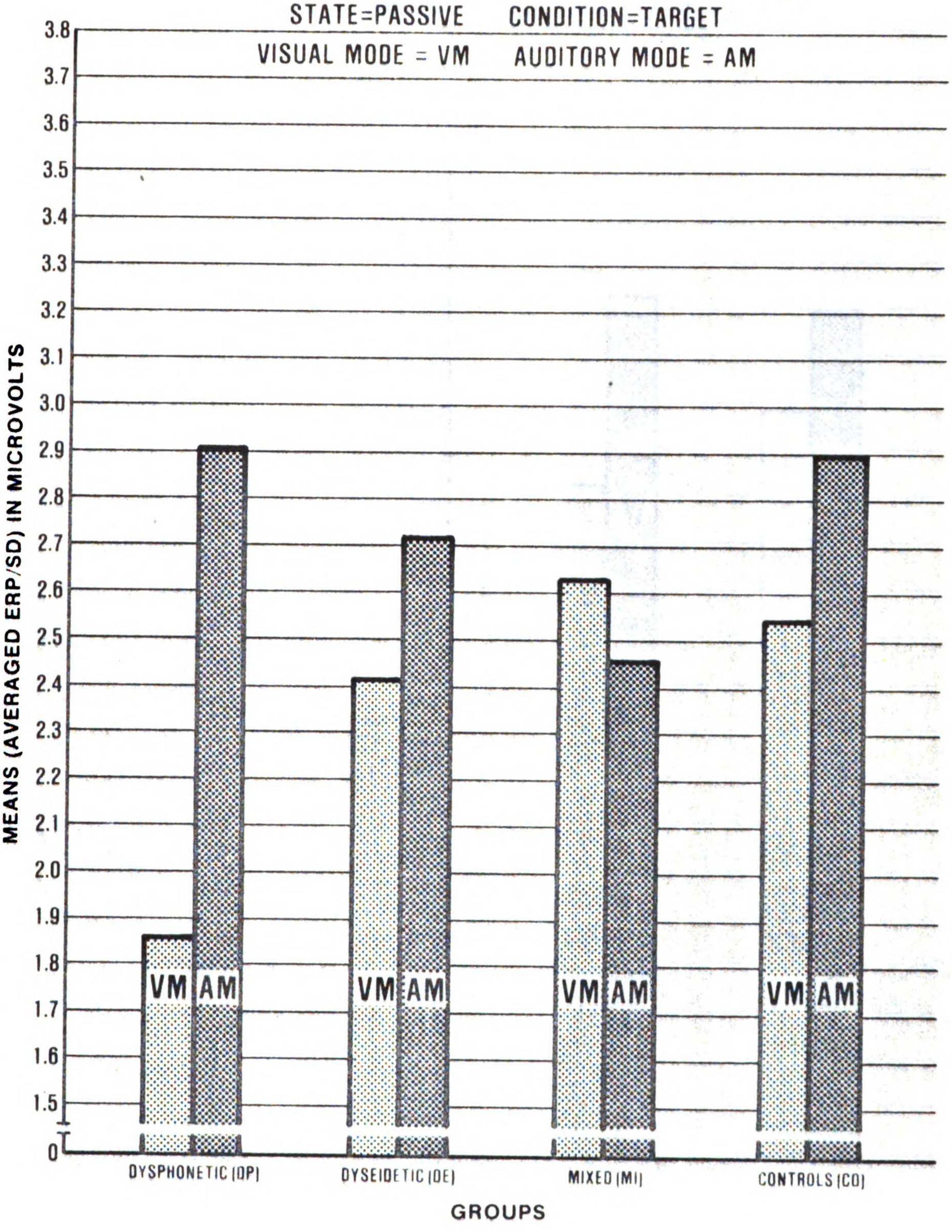


FIGURE 26. ANOVA

4 FACTOR INTERACTION FOR 50-150 MSEC LATENCY BAND
GROUP (DP, DE) - STATE - MODE - CONDITION P=.001
STATE=PASSIVE CONDITION=STANDARD

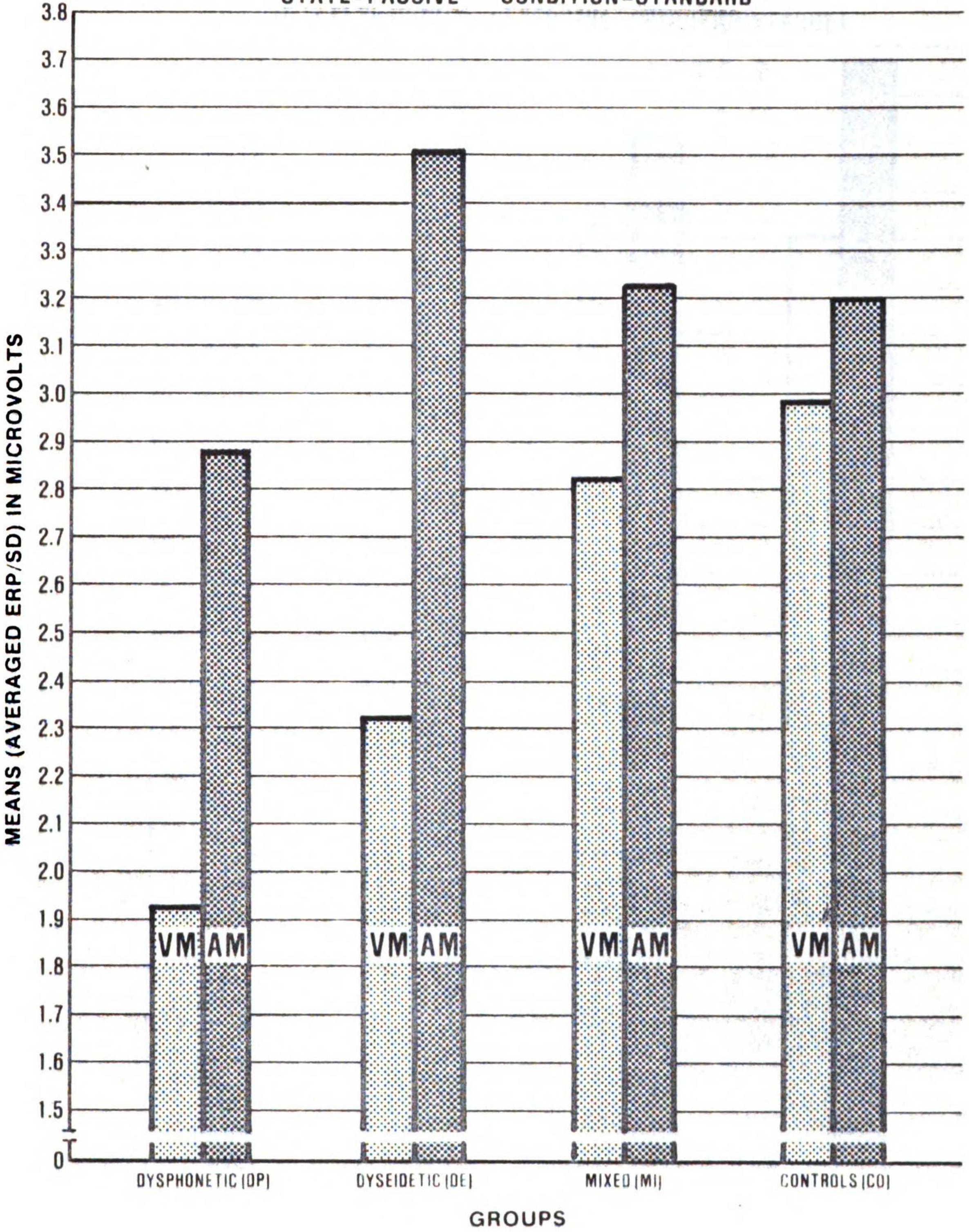


FIGURE 27. ANOVA
4 FACTOR INTERACTION FOR 250-450 MSEC LATENCY BAND
GROUP(DP, DE) - STATE - CONDITION - LEAD
P=.036 STATE=VISUAL ATTENDING CONDITION=TARGET

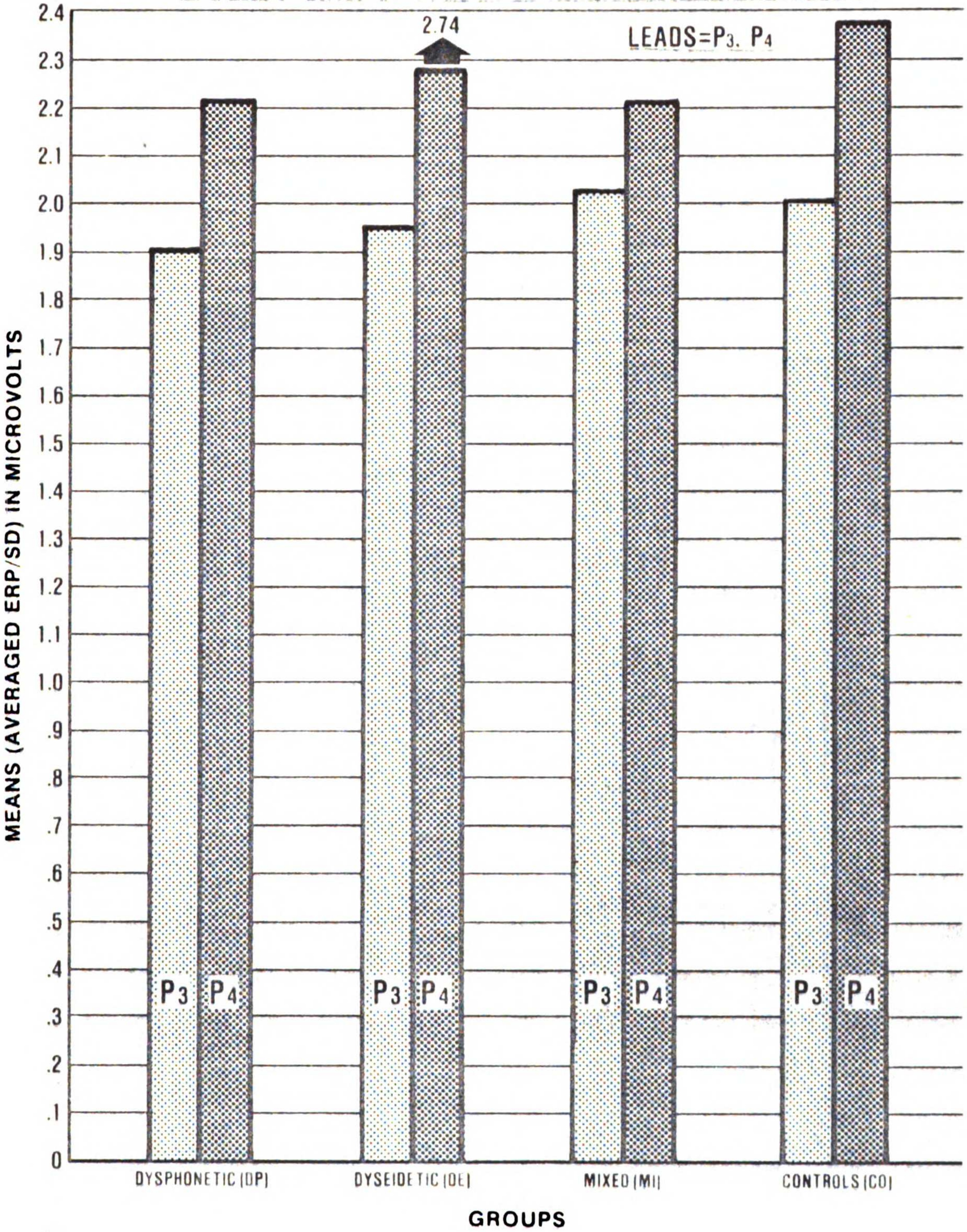


FIGURE 28. ANOVA

4 FACTOR INTERACTION FOR 250-450 MSEC LATENCY BAND

GROUP(DP, DE) - STATE - CONDITION - LEAD

P=.036 STATE=VISUAL ATTENDING CONDITION=STANDARD

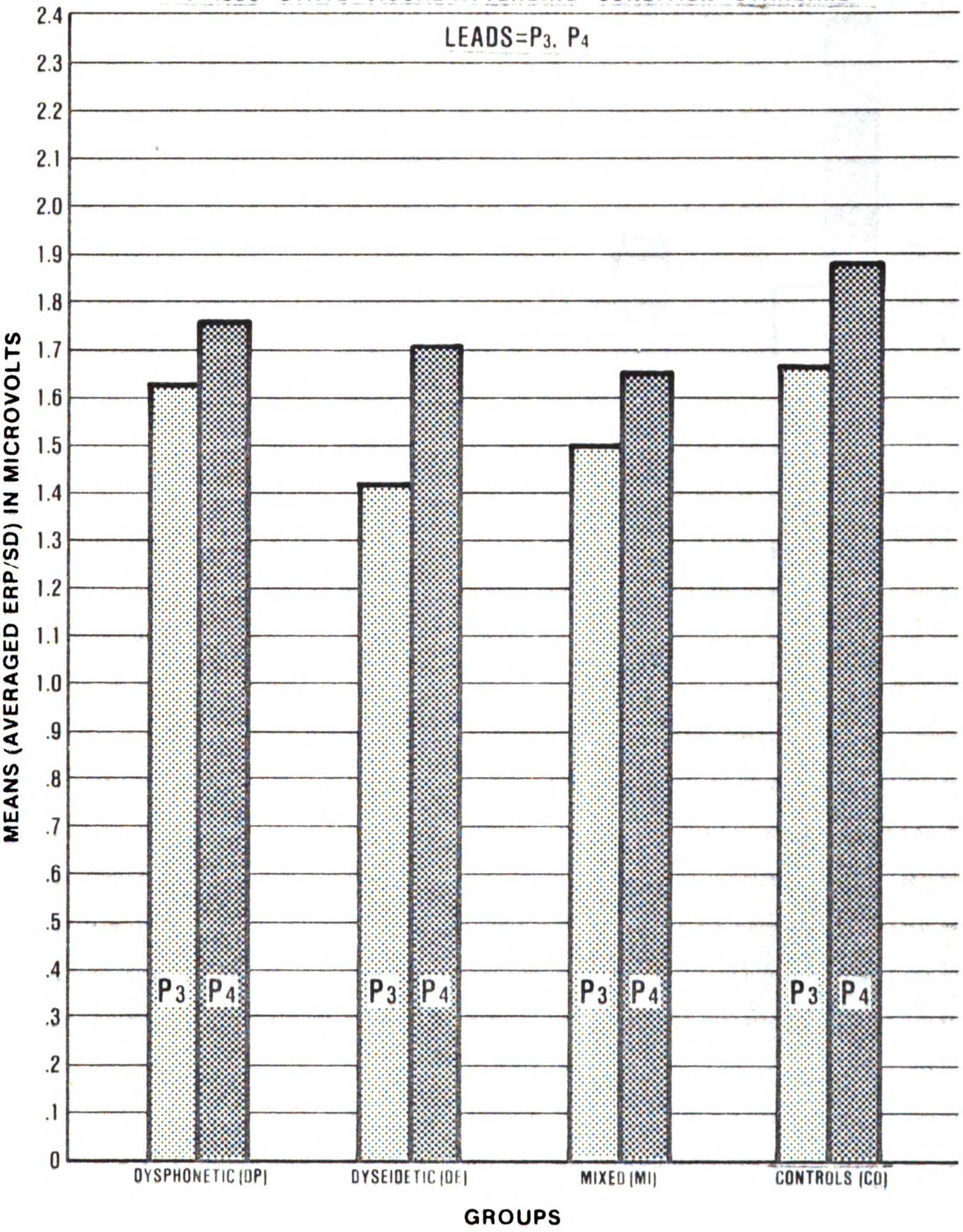


FIGURE 29. ANOVA

4 FACTOR INTERACTION FOR 250-450 MSEC LATENCY BAND

GROUP(DP, DE) - STATE - CONDITION - LEAD

P=.036 STATE=AUDITORY ATTENDING CONDITION=TARGET

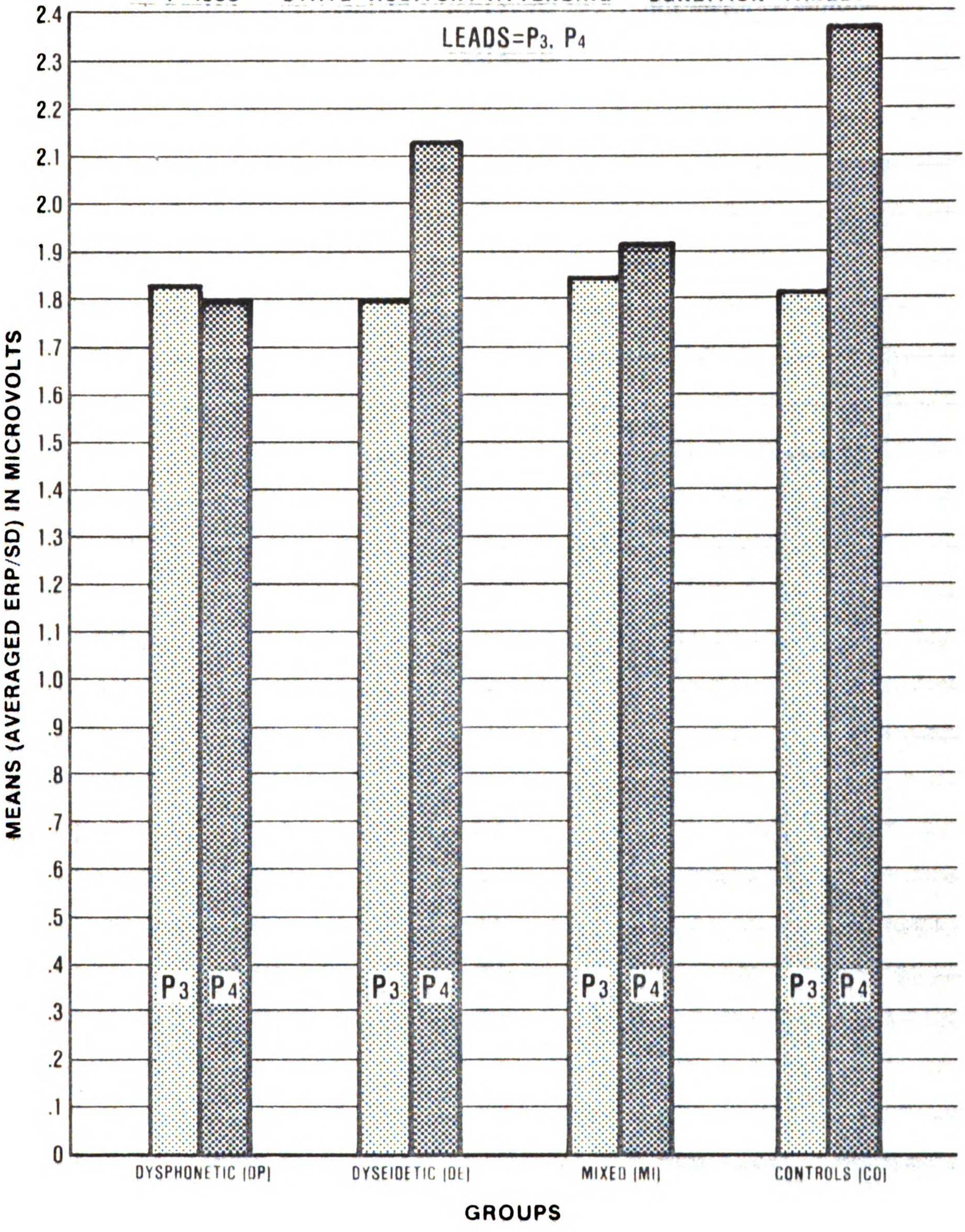


FIGURE 30. ANOVA

4 FACTOR INTERACTION FOR 250-450 MSEC LATENCY BAND
GROUP(DP, DE) - STATE - CONDITION - LEAD
P=.036 STATE=AUDITORY ATTENDING CONDITION=STANDARD

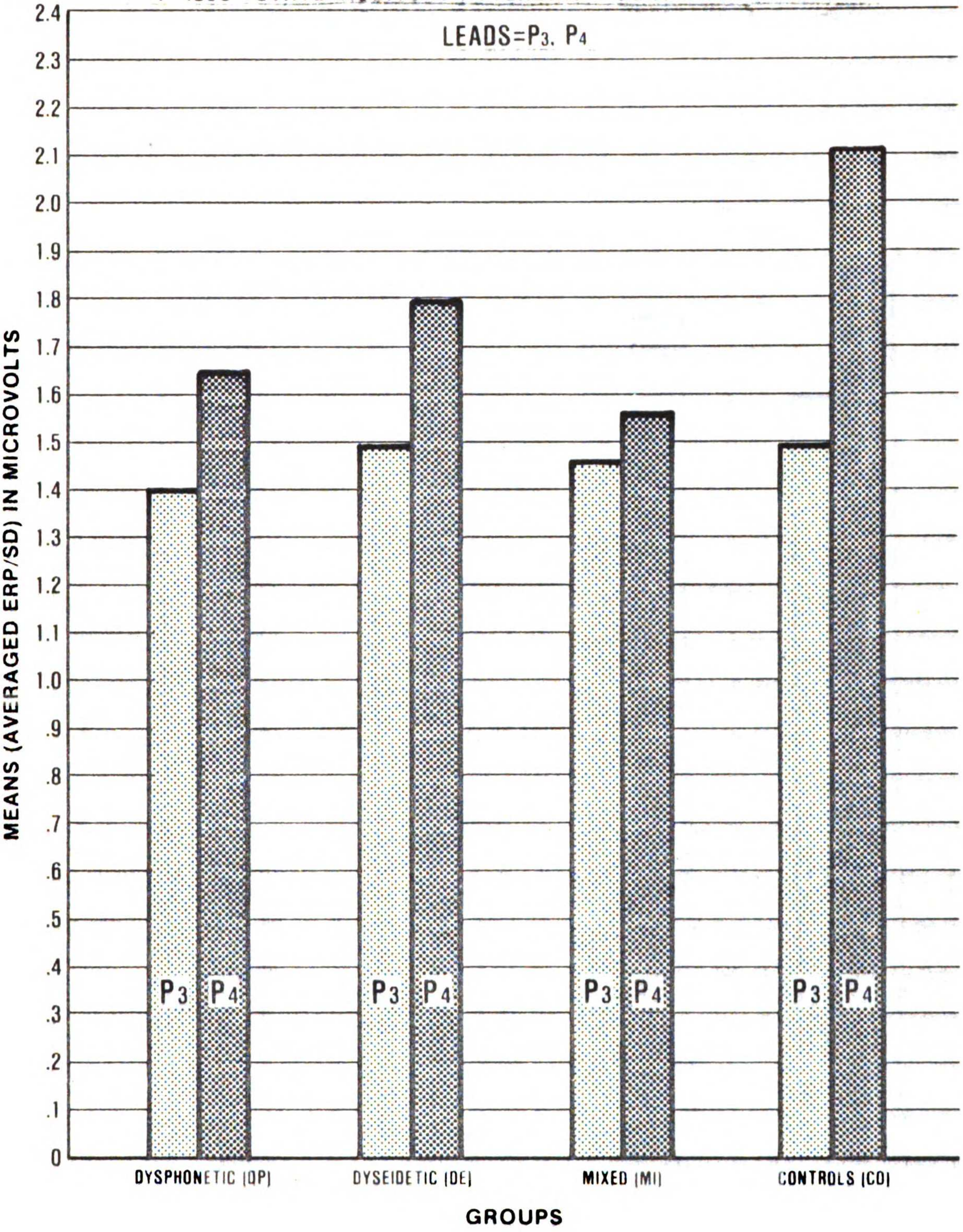


FIGURE 31. ANOVA

4 FACTOR INTERACTION FOR 250-450 MSEC LATENCY BAND
GROUP(DP, DE) - STATE - CONDITION - LEAD
P=.036 STATE=PASSIVE CONDITION=TARGET

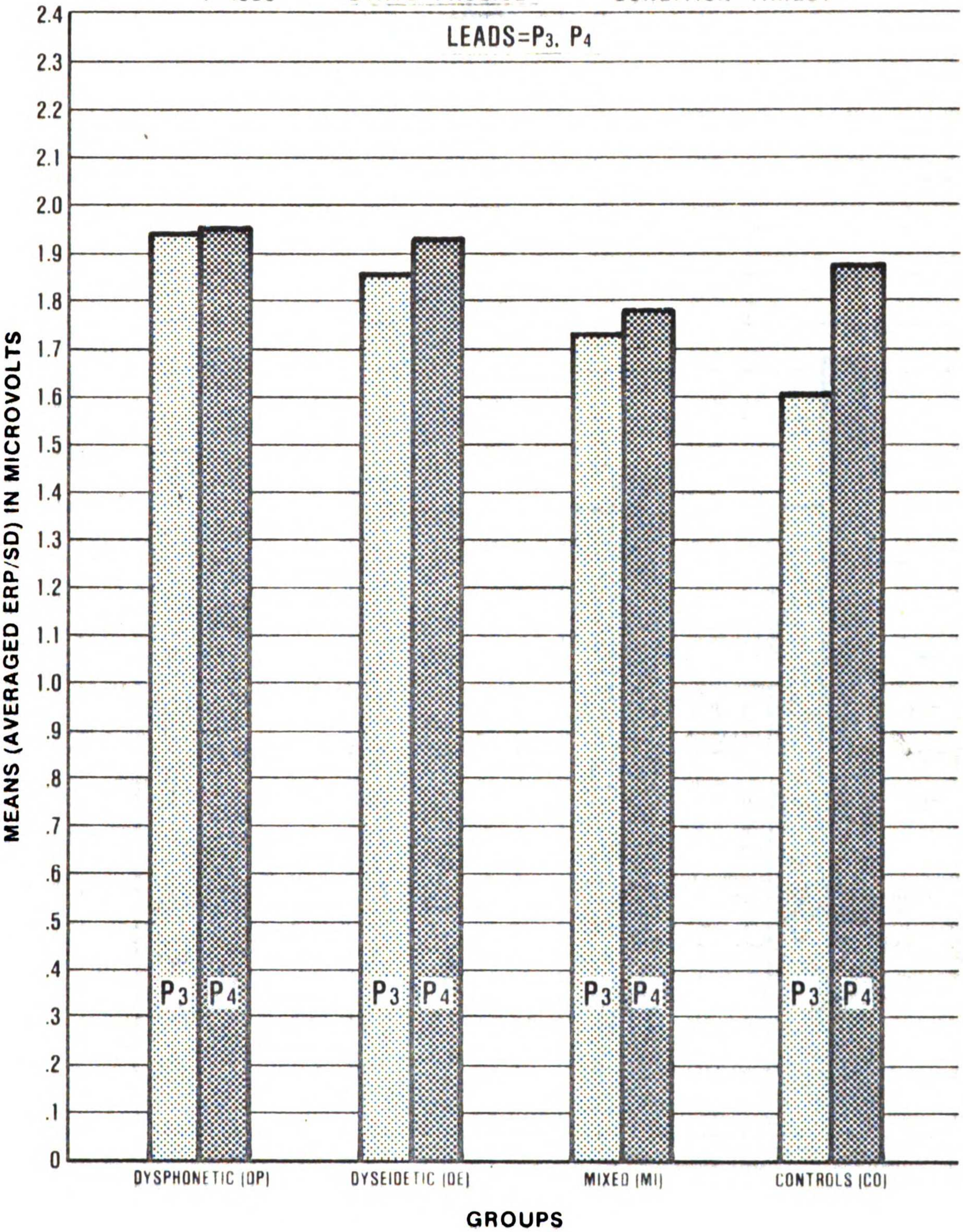


FIGURE 32. ANOVA

4 FACTOR INTERACTION FOR 250-450 MSEC LATENCY BAND

GROUP(DP, DE) - STATE - CONDITION - LEAD

P=.036 STATE=PASSIVE CONDITION=STANDARD

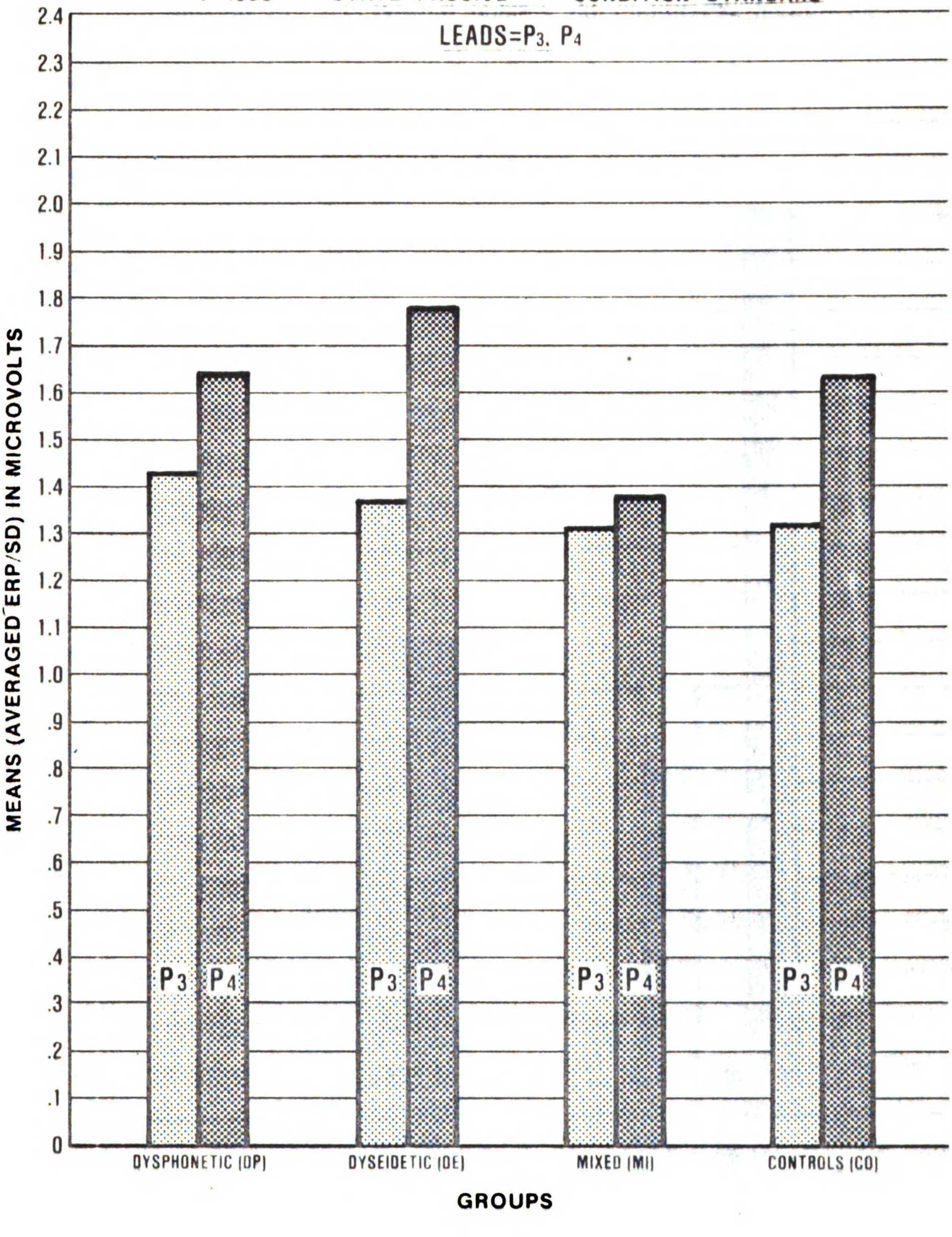


FIGURE 33. ANOVA

5 FACTOR INTERACTION FOR 250-450 MSEC LATENCY BAND
GROUP (DP, DE) - STATE - MODE - CONDITION - LEAD
$P_4 - P_3$ DIFFERENCES

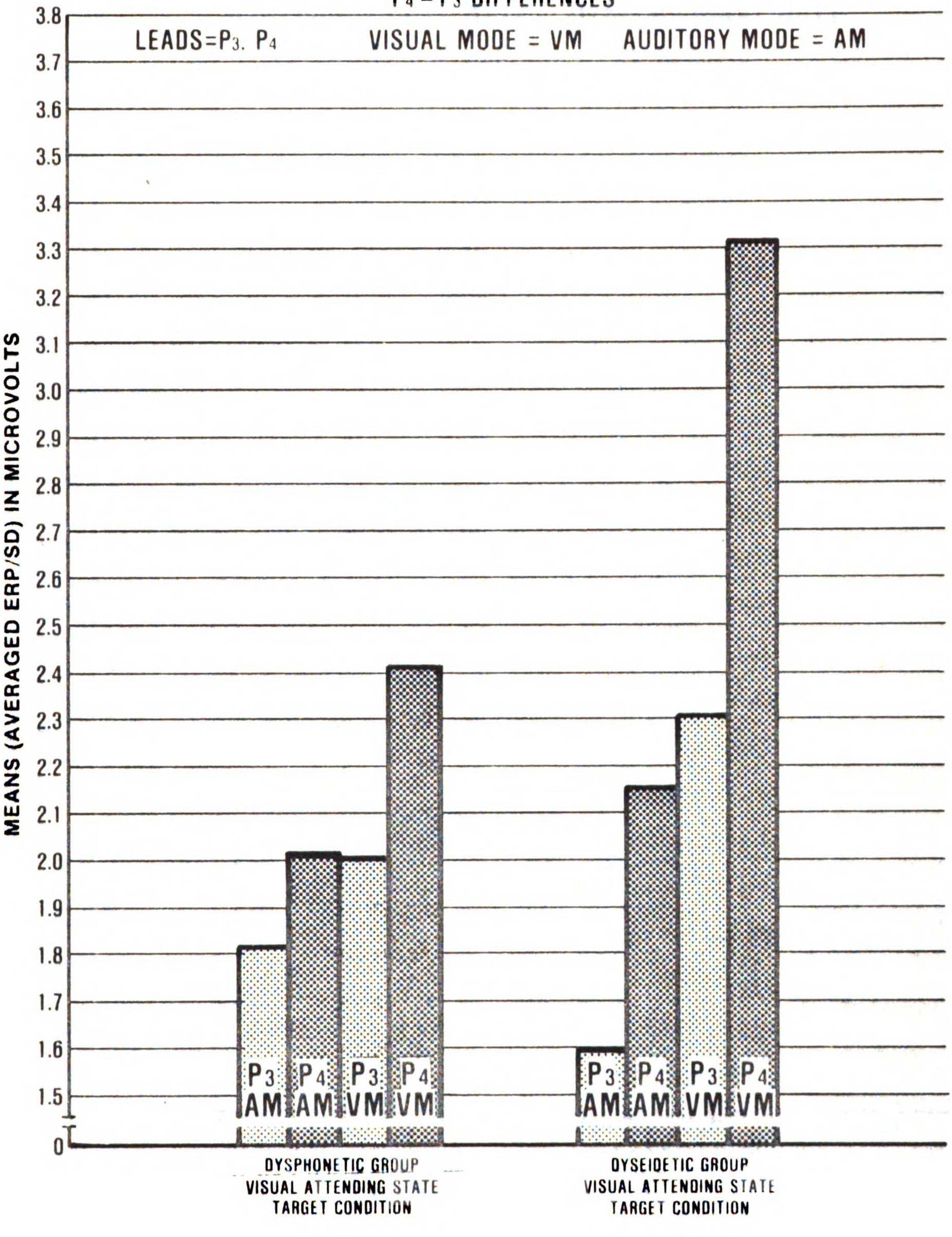


FIGURE 34. COMPARISON BETWEEN DYSPHONETIC AND DYSEIDETIC GROUPS
250-450 MSEC LATENCY BAND
P4 (VISUAL ATTENDING STATE-VISUAL TARGET)—P3 (AUDITORY ATTENDING STATE-AUDITORY TARGET)

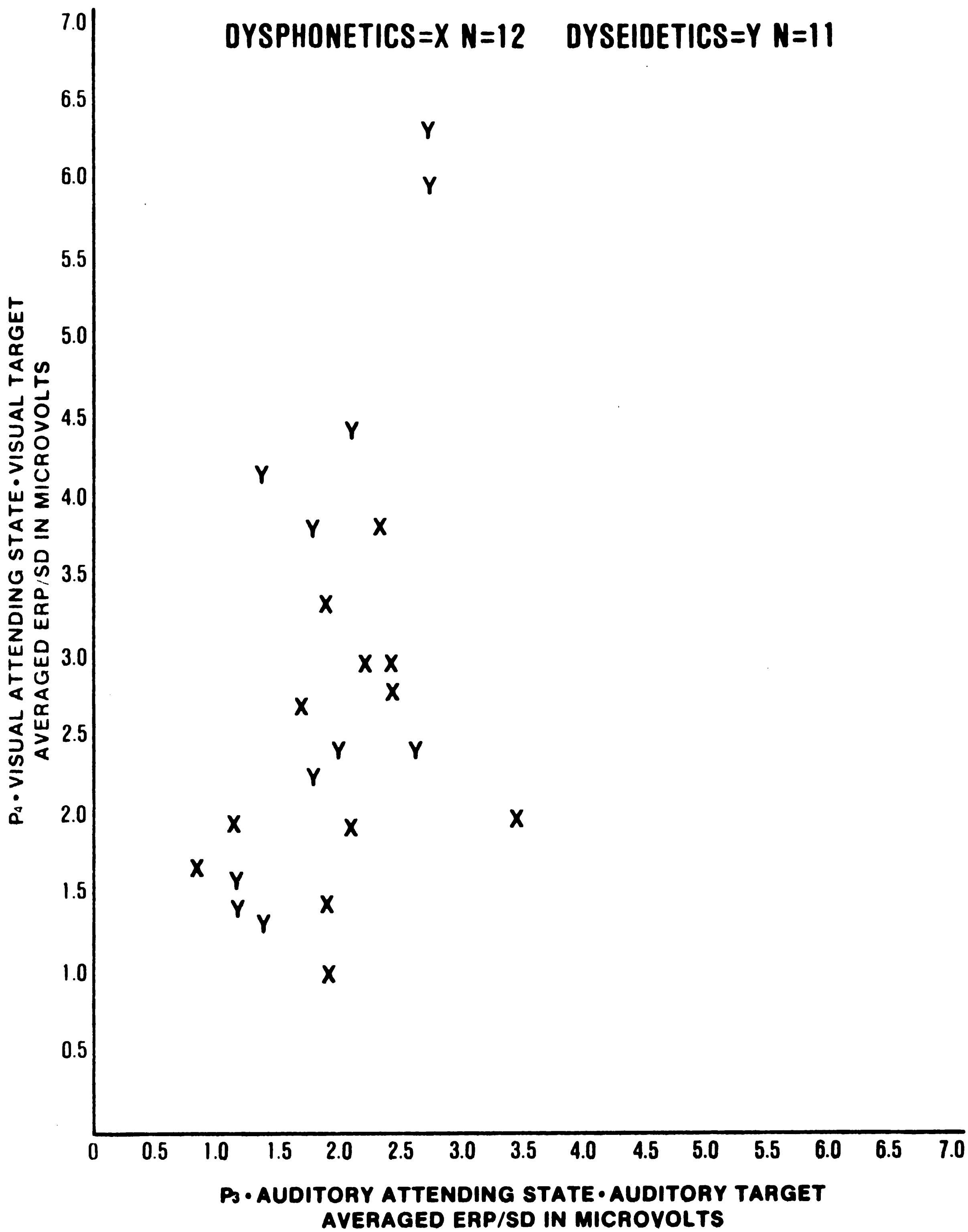


TABLE XVIII

GROUP COMPARISONS: P_4-P_3 DIFFERENCES
(FOR COMBINATIONS OF STATE-MODE-CONDITION)

FACTORS	GROUP	COMPARISONS . DP VS. DE
VA.VM.T	F(3,41) = 2.49, P = .073	F(1,41) = 3.26, P = .077
VA.VM.S	F(3,41) = 0.71, P = .554	F(1,41) = 2.12, P = .152
VA.AM.T	F(3,41) = 0.65, P = .594	F(1,41) = 1.18, P = .282
VA.AM.S	F(3,41) = 0.48, P = .698	F(1,41) = .001, P = .975
AA.VM.T	F(3,41) = 2.92, P = .045	F(1,41) = 3.57, P = .065
AA.VM.S	F(3,41) = 2.96, P = .043	F(1,41) = .068, P = .797
AA.AM.T	F(3,41) = 2.47, P = .075	F(1,41) = 1.70, P = .198
AA.AM.S	F(3,41) = 0.56, P = .650	F(1,41) = .000, P = .993
PA.VM.T	F(3,41) = 0.56, P = .649	F(1,41) = .657, P = .427
PA.VM.S	F(3,41) = 1.38, P = .259	F(1,41) = 3.23, P = .079
PA.AM.T	F(3,41) = 0.94, P = .437	F(1,41) = .077, P = .785
PA.AM.S	F(3,41) = 1.18, P = .325	F(1,41) = .098, P = .757

DP = Dysphonetics
DE = Dyseidetics
MI = Mixed
CO = Controls

VA = Visual Attending State
AA = Auditory Attending State
PA = Passive State

VM = Visual Mode
AM = Auditory Mode
T = Target Condition
S = Standard Condition

APPENDIX 1

P = Phonetic
NP = Nonphonetic

Basal Reader Vocabulary

Primer		Grade I		Grade II		Grade III	
work	NP	guess	NP	friendly	NP	canoe	NP
your	NP	school	NP	listen	NP	china	P
see	P	morning	P	miss	P	cave	P
come	NP	like	P	chick	P	calf	NP
is	P	dinner	P	bird	P	mud	P
big	P	again	NP	field	NP	fog	P
my	P	do	NP	caught	NP	chief	NP
help	P	please	NP	Christmas	NP	language	NP
I	P	bear	NP	ever	P	born	P
in	P	aunt	NP	bring	P	all right	NP
you	NP	faster	P	land	P	alarm	P
at	P	funny	P	talk	NP	already	NP
white	P	could	NP	full	P	eight	NP
me	P	away	P	feather	NP	crash	P
want	NP	babies	NP	across	P	cent	NP
can	P	laugh	NP	believe	NP	candy	P
we	P	pocket	P	beautiful	NP	knife	NP
what	NP	over	P	bought	NP	jar	P
red	P	stay	P	ask	P	island	NP
up	P	how	P	pull	P	led	P

APPENDIX 1 (Continued)

P = Phonetic
NP = Nonphonetic

Basal Reader Vocabulary

Grade IV		Grade V		Grade VI		Grades VII-VIII	
carriage	NP	conquer	NP	alfalfa	P	blunt	P
card	P	apricot	P	diesel	NP	achieve	NP
clay	P	cough	NP	alas	P	chaplain	NP
pal	P	alphabet	NP	bog	P	approval	NP
collection	NP	hurl	P	arena	P	antler	P
drag	P	fry	P	aviator	NP	bazaar	NP
double	NP	aisle	NP	adobe	P	chief	NP
carol	P	art	P	acquaint	NP	absurd	P
motion	NP	develop	P	drought	NP	blend	P
anchor	NP	cooperative	NP	affection	NP	adapt	P
board	NP	hymn	NP	conscious	NP	behold	P
cane	P	flesh	P	combat	P	acquire	NP
business	NP	import	P	argument	P	bonus	P
unless	P	chum	P	clamp	P	anvil	P
celebrate	NP	apiece	NP	artificial	NP	adviser	P
cot	P	craft	P	acid	NP	adolescent	NP
eighth	NP	hygiene	NP	gracious	NP	ambitious	NP
death	NP	beard	NP	bolt	P	allegiance	NP
acorn	P	charm	P	bond	P	affectionate	NP
den	P	liquid	NP	campaign	NP	ajar	P

APPENDIX 2

AGE AND SEX DISTRIBUTIONS FOR SUBJECTS IN DYSLEXIC AND CONTROL GROUPS

M = Male, F = Female

Dysphonetic Group N=12			Dyseidetic Group N=11			Mixed Group N=10			Control Group N=12		
Subjects	Age	Sex	Subjects	Age	Sex	Subjects	Age	Sex	Subjects	Age	Sex
1.	16.3	M	1.	17.2	M	1.	33.5	F	1.	28.9	M
2.	38.9	M	2.	16.5	M	2.	38.1	F	2.	45.1	F
3.	16.3	M	3.	17.0	M	3.	15.7	M	3.	27.1	F
4.	19.5	M	4.	37.3	M	4.	36.1	F	4.	34.6	M
5.	23.0	M	5.	17.6	M	5.	19.2	M	5.	29.2	M
6.	28.5	F	6.	20.7	F	6.	36.0	M	6.	31.0	M
7.	28.5	F	7.	38.6	M	7.	17.4	F	7.	16.5	M
8.	22.0	M	8.	23.1	M	8.	24.8	M	8.	23.5	F
9.	30.6	M	9.	22.8	M	9.	42.5	F	9.	18.2	M
10.	36.8	M	10.	17.9	M	10.	17.3	M	10.	18.6	M
11.	21.5	M	11.	18.3	M				11.	17.2	F
12.	20.7	M							12.	18.5	M
Age Range from 16.3 to 38.9			Age Range from 16.5 to 38.6			Age Range from 15.7 to 42.5			Age Range from 16.5 to 45.1		
Mean = 25.2			Mean = 22.5			Mean = 28.1			Mean = 25.7		
SD = 7.4			SD = 7.9			SD = 10.2			SD = 8.6		

APPENDIX 3

READING LEVELS AND IQ SCORES OF SUBJECTS OF DYSLEXIC SUBGROUPS

Reading Level (Grade Equivalent) = RL
IQ (WISC or WAIS)   FS = Full Score   VS = Verbal Score   PS = Performance Score

DYSPHONETIC GROUP
N = 12

Subjects	RL	IQ	
1	3	FS 81	VS 80 PS 85
2	7-8	FS111	VS100 PS123
3	6	FS114	VS115 PS109
4	5	FS108	VS100 PS118
5	6	FS 78	VS 84 PS 73
6	4	FS 99	VS 92 PS107
7	3	FS 67[1]	VS 63 PS 77
8	3	FS 62[2]	VS 63 PS 65
9	7-8	FS 96	VS 95 PS 98
10	1	FS103	VS101 PS106
11	2	FS 94	VS100 PS 87
12	7-8	FS102	VS 95 PS112

DYSEIDETIC GROUP
N = 11

Subjects	RL	IQ	
1	4	FS112	VS113 PS109
2	5	FS 98	VS 97 PS100
3	5	FS 98	VS 82 PS117
4	4	FS109	VS113 PS104
5	4	FS 96	VS 95 PS 98
6	7-8	FS 85	VS 91 PS 81
7	7-8	FS112	VS115 PS106
8	4	FS116	VS104 PS129
9	4	FS 93	VS 84 PS107
10	4	FS111	VS105 PS117
11	7-8	FS 95	VS 93 PS 99

MIXED GROUP
N = 10

Subjects	RL	IQ	
1	3	FS 96	VS 93 PS101
2	5	FS 89	VS 87 PS 93
3	4	FS104	VS 98 PS111
4	6	FS112	VS115 PS108
5	2	FS 90	VS 86 PS 97
6	7-8	FS108	VS118 PS 95
7	7-8	FS 69[3]	VS 66 PS 74
8	7-8	FS130	VS128 PS128
9	1	FS 87	VS 83 PS 95
10	4	FS119	VS118 PS117

1. Functionally not retarded; high school graduate and had three years of college.
2. Functionally not retarded; at age 11 years on the WISC - VS = 96, PS = 67.
3. Functionally not retarded; not highly motivated during testing.