76-19,416

MUSSO, Mario F., 1946-
PSYCHOPHYSICAL PERFORMANCE, CONTINGENT NEGATIVE VARIATIONS, VISUALLY EVOKED CORTICAL POTENTIALS, AND SELECTIVE ATTENTION: A BEHAVIORAL AND NEUROPHYSIOLOGICAL ASSESSMENT OF LEARNING DISABILITIES IN CHILDREN.

The University of North Carolina at Greensboro, Ph.D., 1975
Psychology, experimental

Xerox University Microfilms, Ann Arbor, Michigan 48106

PSYCHOPHYSICAL PERFORMANCE, CONTINGENT NEGATIVE VARIATIONS, VISUALLY EVOKED CORTICAL POTENTIALS, AND SELECTIVE ATTENTION: A BEHAVIORAL AND NEUROPHYSIOLOGICAL ASSESSMENT OF LEARNING DISABILITIES IN CHILDREN

by

Mario F. Musso

A Dissertation Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Greensboro
1975

Approved by

M. Russell Harter

Dissertation Adviser

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of the Graduate School at The University of North Carolina at Greensboro.

Dissertation Adviser M. Russell Harter

Committee Members Robert G. Eason

Walter L. Salinger

Rosemary O. Nelson

Robert B. Muir

October 17, 1975
Date of Acceptance by Committee

MUSSO, MARIO F. Psychophysical Performance, Contingent Negative Variation, Visually Evoked Cortical Potentials, and Selective Attention: A Behavioral and Neurophysiological Assessment of Learning Disabilities in Children. (1975) Directed by: Dr. M. Russell Harter. Pp. 93.

The present experiment was designed to assess whether any attentional, perceptual, or neurophysiological differences exist between children classified as reading disabled and normal. A visual discrimination task was employed, which required attentional and perceptual capabilities; wherein the children were required to selectively attend and respond to one stimulus of a pair and to ignore the other stimulus. Four pairs of stimuli (colors, line orientations, letters, and words) of different levels of complexity were discriminated in order to provide clues as to the possible level of neural processing accounting for the reading disability. The children's ability to attend and to discriminate each stimulus in a pair was measured both behaviorally by psychophysical measures of response accuracy (d') and reaction time, and also electrophysiologically by visually evoked cortical potentials (VEPs) and contingent negative variations (CNVs). A secondary purpose of the study was to examine whether the learning disability was restricted to one sensory modality. Children who were diagnosed as having either a visual or an auditory disability participated in the experiment so as to determine whether only the visual learning disability children would have difficulty with the visual discrimination task. Therefore, three groups of subjects, matched for age, sex, and IQ, were employed: normal controls (NC), visual learning disabled (VLD), and auditory learning disabled (ALD).

Behavioral measures revealed that both the VLD and ALD groups had greater difficulty, as indicated by lower d' scores, on the word discrimination problems than the NC group. No other significant differences in

behavioral performance as a function of diagnosed reading disabilities were observed. Response accuracy scores were sensitive to the effects of problem type across all subjects with color and line orientation discriminations yielding higher d' scores than letter or word discriminations. The general lack of group differentiation by the behavioral measures was discussed in light of the nature of the perceptual task and also, in terms of the high levels of motivation maintained in all subjects.

While VLD subjects tended to have the largest CNV responses, measures of CNV amplitude revealed no significant group differences. This suggests that all subjects, despite their level of reading proficiency, were highly motivated to perform well on the discrimination tasks. Across all subjects the amplitude of the CNV was related to the type of problem, with word discriminations yielding the largest CNV responses.

The effects of selective attention were manifested in the VEPs recorded from the occiput for all subjects: significantly larger amplitude peak-to-trough measures of the $\overline{N}200$ and $\overline{P}300$ components prevailed in the responses to attended stimuli compared to the responses to non-attended stimuli. Additionally, the VLD subjects showed greater selective attention differentiation in their VEPs than either the ALD or NC subjects. It was concluded from the observed differences in selective attention across the three groups that the VLD subjects were expending more effort into the visual discrimination tasks than the other subjects. This greater perseverence on the part of the VLD subjects was interpreted as a compensation for their perceptual and neurophysiological deficits. Also, it was concluded that the LD children in the present study did not have any apparent attentional deficits.

The latency of the $\overline{P}300$ component from the VEPs recorded from both the vertex and occiput reflected significant group differences. The VLD subjects had longer latencies than the ALD subjects, who, in turn, had longer latencies than the NC subjects. Latency measures of the VEP components suggest that the LD child has a predisposition for processing sensory information at a slower rate of speed than the normal child, which may be indicative of an immature nervous system.

The VEP measures of selective attention and component latencies, which yielded significant group differences, support the notion of a sensory specific deficit in the reading disability syndrome. On the visual discrimination tasks, in this investigation, the VLD subjects tended to show the greatest behavioral and neurophysiological deficits. The separation of reading disabled children according to modality-specific perceptual capabilities is ameanable to the present study's findings.

ACKNOWLEDGMENTS

This dissertation was possible only through the extended efforts of the many people who volunteered their services and support to this project. To these individuals who shared many of the memorable experiences behind the project the author wishes to express his most sincere gratitude.

Deepest appreciation is extended to Dr. M. Russell Harter, Committee Chairman, for his invaluable assistance and guidance throughout all stages of this dissertation. Gratitude also is conveyed to Drs. Robert G. Eason, Rosemery O. Nelson, Robert Muir, and Walter Salinger for serving as committee members.

Cooperation of the Guilford County School System by way of Sarah Smith, Director of Exceptional Child Services, and Ed Bowles, School Psychologist, is most gratefully appreciated. The efforts of Ed Bowles in selecting subjects and soliciting parental cooperation were of crucial importance. Special thanks is given also to the principals, teachers, and parents for their full cooperation.

Fellow students who provided the majority of the manpower behind this study are deserving of special recognition. For their help in various capacities gratitude is expressed to Pat Santoro, Tali Hoenigmann, Sandy Harvey, Roberta Sadler, Art Peoples, Vernon Odom, and Leo Towle. Special thanks are extended to Debbie Nixon and Robie McFarland for skillfully assisting as co-experimenters. To the closest of friends, Linda

Hay, Bill Hay, Tommi Johnsen, and Dave Lipinski, who expended immeasurable amounts of time, effort, and thought into this project, words of appreciation would be quite inadequate.

Drs. John R. Bourne, H. Earl Ginn, and Paul E. Teschan and the Uremia Project (NIH-NIAMDD-72-2211) at Vanderbilt University are responsible for providing the time and facilities necessary to prepare this manuscript. This support is gratefully acknowledged.

The assistance of Vanderbilt students, Sammie Walker, Morris Johnston, Baruch Hamel, and Howard Johnston, also is gratefully appreciated.

The secretarial services provided by Judy Lipinski and Loretta Nance are deeply appreciated.

Particular gratitude is extended to the 27 children who served as subjects and provided many an enjoyable and unforgettable experience. Special thanks are extended to Mel Newby and Jeff Harter for serving as pilot subjects. And to the many children confronted with a learning disability problem this dissertation is dedicated in the hopes that knowledge through future research will help to lessen their struggle.

This study was partially supported by NSF Grant GB 8053.

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CHAPTER I

INTRODUCTION

Children with a normal intelligence who, nevertheless, have great difficulty acquiring specific academic skills have been classified as Learning Disabled (LD). The present study dealt with one particular type of learning disability: reading disabilities. Probably the most widely accepted and employed operational definition of a reading disability is "the failure to learn to read with normal proficiency despite conventional instruction, a culturally adequate home, proper motivation, intact senses, normal intelligence, and freedom from gross neurological effects" (Eisenberg, 1964, p. 65). Although LD children seem to possess all the prerequisite capabilities to acquire specific academic skills, their performance falls quite short of their expected achievement. Therefore, classification into an LD grouping is often based on an observed discrepancy between some measure of academic performance (i.e., low reading ability) and expected capacity score (i.e., above normal intelligence) (Hallahan & Cruickshank, 1973; Johnson & Myklebust, 1967).

A problem confronted in assessing the etiology behind learning disabilities is that the specific component skills that the LD child is lacking have not been identified and defined. Capobianco (1964) claimed that assessment procedures for learning disabilities are in the "infancy stage of development." The diagnostic label "perceptually handicapped" has little or no specific meaning beyond a loose description of observable deficiencies. A profile is required based on normative comparisons of the perceptual and psychomotor skills for which the LD child is deficient. If specific component skills can be delineated, comprehension of the problem appears more feasible.

The present investigation attempted to specify some of the component attributes which contribute to learning disabilities. With the aid of the visually evoked cortical potential (VEP) and contingent negative variations (CNVs), differences in the perceptual and neurophysiological capacities of children classified as reading disabled were examined.

Before the present experiment is described, a review of the previous research and literature which deals with perceptual and neurophysiological variables, as they relate to learning disabilities, will be presented. First, the variables which have been thought to be responsible for learning disabilities will be discussed. Next, the electrophysiological measures (VEPs and CNVs) employed in the present investigation will be described. It will then be shown how these measures, in conjunction with the behavioral psychophysical indices, may help resolve some of the controversies over what factors do contribute to learning disabilities.

Subject Variables Related to Learning Disabilities

Perceptual and psychomotor abilities. The literature suggests that perceptual incapacities may contribute to learning disabilities (Ayres, 1964; Frostig, 1961; Gibson, 1969; Wold, 1969). LD children have been characterized as having difficulty translating sensory input into meaningful percepts and cognitions. Perceptual disorders in LD children are described by Johnson and Myklebust (1967) as disorders or disruptions in the identification, discrimination, and interpretation of sensations. These problems are viewed in terms of decoding and receptive processes.

For example, poor visual decoding is manifested in figure-ground confusions, letter reversals and inversions; while disorders in auditory decoding would result in difficulties in sound discrimination. Since concept formation and symbolic behavior are based on adequate perceptual processes, disorders at such levels may result in reading or language deficits.

There have been numerous investigations which have examined the differences in perceptual capacities between normal and reading disability 'hildren. Spring and Hopkins (1972) found reading disability children to have longer and more variable reaction times than normals in a task entailing the identification of whether or not two simultaneously presented letters of the alphabet were identical. Katz and Wicklund (1971) also observed longer response times in reading disabled children in a word scanning task where subjects were to decide whether or not a series of three words contained a word which was previously presented. In a subsequent study (Katz & Wicklund, 1972), difference in performance between normal and LD children was observed when letters of the alphabet rather than words were employed. The reading disabled subjects in the Blank, Higgins, and Bridger (1971) investigation also had longer response times than normals in a visual discrimination task, especially when the physical difference in the stimuli was extreme. Sykes, Douglas, Weiss, and Minde (1971) found hyperactive LD children to have fewer correct responses than normals in a simple visual discrimination task. These studies in toto provide evidence that LD children perform below normal on visual discrimination tasks entailing rapid and decisive responses.

Problems in terms of the temporal processing of sensory information in LD children have been elucidated by additional perceptual experiments. For example, reading disabled children tended to require longer inter-stimulus intervals before they could temporally distinguish two successive stimuli in a visual masking paradigm (Stanley & Hall, 1973). Guthrie and Goldberg (1972) reported slower information processing in the reading disabled child, and also reported the inability of such children to handle efficiently the temporal and sequential aspects of sensory processing. Since reading can be characterized as the sequential temporal processing of information, these conclusions deserve particular attention and further investigation.

One cannot be certain whether these differences are due to perceptual, motivational, or psychomotor deficiencies. Lewis, Bell, and Anderson (1970) observed significantly poorer motor performance in the LD child compared to normals as indicated by the Lincoln-Osteretsky Motor Development Scale. Deficiencies were reported in locomotion, bilateral movements, synchrony and sequential movements. When a child has longer reaction times in a visual discrimination task, is his problem perceptual or motor? In order to circumvent this problem, multiple behavioral and electrophysiological measures could be obtained in a perceptual task; these measures could indicate the influence of both the perceptual and motor aspects of the task.

Sensory interaction: single or multiple modality deficits. One question raised by a number of studies (Birch & Belmont, 1965; Rudnick, Sterritt, & Flax, 1967; Sterritt & Rudnick, 1966) is whether the perceptual deficiency in a given child is a disorder restricted to one sensory modality or involves several modalities. Regarding specific reading disabilities, Johnson and Myklebust (1967) differentiate between disabilities attributable to the visual as opposed to the auditory modality.

Children who cannot differentiate, interpret, or remember words, are classified as having visual problems and display the following characteristics:

> 1) They have visual discrimination problems and confuse letters and words which appear similar. Some fail to note internal detail and confuse words such as beg and bog; others cannot see the general configuration of words such as ship and snip.
>
> 2) Rate of perception is slow. Although accurate in discriminations, some scrutinize words slowly and cannot rapidly recognize them as being the same or different.
>
> 3) Many show reversal tendencies both in reading and writing, tending to read and write dig for big.
>
> 4) Some have inversions tendencies and misread u for n or m for w.
>
> 5) They have difficulty following and retaining visual sequences. If they see the word pan and are given letters to arrange in the same way, they distort the order and spell the word pna or apn. Some follow the sequence when a model is provided but cannot revisualize the sequence from memory.
>
> 6) Some have many visual memory disorders, in that they cannot remember either verbal or nonverbal experiences.
>
> 7) Drawings tend to be inferior and lacking in detail.
>
> 8) Many have problems with visual analysis and synthesis. Some have difficulty doing jigsaw puzzles indicating that they cannot relate the parts to the whole. (Johnson & Myklebust, 1967, p. 153)

Children with learning disabilities attributable to auditory deficits display the following characteristics:

1) They have numerous auditory discriminations and perceptual disorders which impede the use of phonetic analysis. For example, they are unable to hear the similarities in initial or final sounds of words. Similarities in the words boy and big or cat and mat are not perceived. Discrimination of short vowel sounds is also a prevalent difficulty in such children. While the words pin, pan, and pen may be understood in context, the child is unable to hear the differences between them when they are heard in isolation.

2) Difficulties in auditory analysis and synthesis also arise. Although the child's spoken language may be good, he may not be able to break a word into syllables or into individual sounds. Those with problems of synthesis cannot combine parts of words to form a whole.

3) Many cannot reauditorize sounds or words. When these children look at a letter, they cannot remember its sound, or when they look at a word they are unable to say it, although they know its meaning. This child can probably read silently better than orally.

4) Some have disturbance in auditory sequentialization. They may distort the pronounciation of words; or when writing, they may transpose letters because they cannot retain a sequence of sounds. (Johnson & Myklebust, 1967, pp. 174-175)

Since the acquisition of reading skills involves both the auditory and visual senses, one may ask whether the etiology of a reading problem in a given child is related to one or to both sensory modalities. Resolution of this question has implications not only for delineating the genesis of learning disabilities but also for prescribing effective remedial procedures. If the problem is restricted to one sensory modality (i.e., auditory), greater emphasis on the other modality (i.e., visual) when teaching the child to read may provide an effective means of circumventing his sensory deficit.

While either the auditory or visual modalities separately could impede reading proficiency, several investigators (Birch & Belmont, 1965; Rudnick et al., 1967; Sterritt & Rudnick, 1966) contend that the reading disability problem is related to the audio-visual sensory interaction involved in reading acquisition. Birch and Belmont (1965), for example, found reading disability children had great difficulty in translating temporally-presented sequences of sounds into a spatially-presented series of visual dot problems.

Several investigators in subsequent studies have attempted to discredit the findings and interpretations of Birch and Belmont. These studies (Blank & Bridger, 1967; Blank et al., 1971; Voort, Senf, & Benton, 1972) found LD children do just as poorly on intramodal integration tasks as on cross modal tasks. These latter investigations thus contended that while the LD child may have sensory interaction deficits, the initial studies may simply reflect a deficit restricted to one modality.

Neurological impairments. Terms such as "brain damage," "minimal brain dysfunction," and "neurological impairment" have been widely used to categorize LD children. Such designations are sometimes based on little or no empirical physiological or anatomical data. Due to the inaccessibility of the brain for examination, methods are limited for investigating human brain function and its relation to complex cognitive activities. Neurological examinations, which are primarily concerned with lower levels of the nervous system,do report that often the LD child displays "soft neurological" signs of impairment (Bowley, 1969; Ingram, 1971; Penn, 1966). Since these neurological symptoms are quite variable across subjects with comparably the same low level of reading proficiency, their direct relationship to the reading disability problem becomes quite tenuous.

Studies attempting to relate abnormal EEG patterns to reading disabilities have been inconclusive (Benton & Bird, 1963; Capute, Niedermeyer, & Richardson, 1968; Hartlege & Green, 1971, 1973; Hughes & Parks, 1969; Kris, 1969, 1970; Oettinger, Nekonishi, & Gill, 1967; Torres & Ayres, 1968; Tuller, 1966). The equivocal results and the variability in the incidence of EEG abnormalities found in reading disability children across these studies can be attributed to the different criteria used for defining an EEG as abnormal and to the selection of cases which are investigated in each particular study. Because knowledge about the EEG in regard to its genesis and its relationship to specific sensory and cognitive processes is relatively minimal, information gained by stating a child has an abnormal EEG is quite limited in terms of understanding and specifying the problem.

Attentional variables. In addition to perceptual difficulties, learning disabilities are often attributable to attentional deficits (Anderson, Halcomb, & Doyle, 1973; Dykman, Walls, Suzuki, Ackerman, & Peters, 1970; Luria, 1961, 1966a, 1966b). Clinical descriptions of LD children include distractibility and inability to focus attention appropriately. Johnson and Myklebust (1967) describe attentional disorders either as attention being deficient (unable to attend to a task for a specified amount of time) or excessive (unable to change focus of attention to a new task at the appropriate time). Insufficient attention is sometimes labeled as distractibility, hyperawareness, hyperirritability, or short attention span. The child is unable to filter out irrelevant stimuli and attend to the appropriate task. Excessive attention occasionally occurs with a child who attends to unimportant details of a stimulus while the relevant details are ignored.

In many of the studies (Anderson et al., 1973; Dykman et al., 1970) which have shown attentional deficits in the LD child, whether these deficits are inherent to the child or are merely related to the task with which the child is involved is not certain. With many of the tasks, it is possible to mistake attentional deficits for motivational deficits in the child. If a given child in the past has met only failure and frustration with certain types of tasks, it is possible that this child would have difficulty committing his full efforts and attention to a similar task. Therefore, when specifying attentional differences between individuals on a given task, one must be certain that these individuals are equally motivated.

Possible Contributions of the Visually Evoked Cortical Potential and Contingent Negative Variations Toward Understanding Learning Disabilities

Sensory processes and the VEP. If neurological and perceptual anomalies in brain functioning of the LD child do exist, they most certainly are subtle and complex and will require sensitive physiological and behavioral methods of investigation. The physiological measure employed in the present study is the visually evoked cortical potential (VEP), which is a computer-averaged electrical potential recorded off the scalp and elicited by visual stimulation. The VEP, which has been shown to be sensitive to various stimuli, subject and psychological variables (Regan, 1972), is a powerful tool for investigating the relationship between perceptual and neurophysiological parameters in the same "intact" subject.

Several investigations have employed the VEP to assess the electrophysiological differences between normal and reading disability children. Conners (1970) found the amplitude of VEPs recorded from the left parietal areas to be comparatively reduced when contrasted to VEPs from other locations in the reading disability subject. An impressive correlation prevailed in this study between reading proficiency and the relative amplitude reduction of the VEP at this electrode location. Preston, Guthrie, and Childs (1974) conducted a similar evoked potential investigation which essentially corroborrated Conners' findings. Shields (1973) observed that reading disability subjects had VEP components which had longer latencies and smaller amplitudes than those of normals.

The results of these studies tend to indicate that the VEP may be a potentially useful means of assessing the neurophysiological functioning of the reading disability child. The VEP has been related to various perceptual and integrative processes within the central nervous system (Eason & White, 1966). This allows the examination of the joint neurophysiological and psychophysical processes required of an individual while partaking in a particular perceptual or cognitive task.

In addition to the VEP being related to perceptual processing, its employment as a dependent measure when investigating learning disabilities affords several advantages. One is able to compare the neurophysiological capacities, as reflected in the VEP, with the perceptual capacities, as reflected in the behavioral measures. The VEP, which presumably is more indicative of sensory then motor processes, enables the assessment of the LD child's behavioral deficits as they are related to sensory capacities independent of the motor aspects of the disorder. Additionally, by simultaneously recording electrophysiological and behavioral data while a subject is performing a perceptual task, a multivariate statistical assessment of the learning disability syndrome becomes possible. The multivariate approach to specifying the component attributes which account for learning disabilities not only reveals the interrelationships between various attributes, both behavioral and neurophysiological, but also provides a more encompassing perspective of the problem.

The VEP also may be very useful in specifying sensory deficits in the LD child. The averaged sensory evoked response has proved to be a powerful diagnostic tool for examining the capacity of various sensory modalities (Regan, 1972). The VEP has already been used to study human pattern vision and its physiological basis (Clynes & Kohn, 1967; Eason, White, & Bartlett, 1970; Harter, 1971; Harter, Seiple, & Musso, 1974; Rietveld, Tordoir, Hagenouw, Lubbers, & Spoor, 1967). For example, the VEP reflects and, thus, may be used to measure visual characteristics such as refractive error (Harter & White, 1968), visual acuity (Harter, 1971; Harter & White, 1970), astigmatism (White, 1969), eye dominance and amblyopia (Lehman & Fender, 1968; Shipley, 1969) and binocular interactions (Harter et al., 1974; Harter, Seiple, & Salmon, 1972; White & Bonelli, 1970).

While it is generally agreed that the LD child may suffer from a perceptual disorder, it is not certain whether this problem is directly attributable to optical or sensory neurophysiological factors. Little or no relationship has been reported between reading disabilities and visual deficits as diagnosed by optometric procedures (Anapolse, 1971; Rubino & Minden, 1971). The visual anomalies in the LD child, however, may be so subtle that they go undetected by the usual diagnostic methods. The VEP may prove to be a more discriminative diagnostic procedure since it is an objective, accurate indicant of both the refractive and acuity parameters involved in the processing of visual information.

The question of whether the LD child has a sensory interaction deficit also may be examined with the aid of the VEP. Shipley and Jones (1969) have presented some interesting, yet incomplete, electrophysiological data to suggest the presence of a sensory-interaction problem in LD children. Bimodally evoked audio-visual responses showed a slight reduction in amplitude compared to unimodal evoked potentials in LD children. Shipley and Jones assumed that facilitation rather than reduction of responses to bimodal stimuli is usually the case in normal children, although such control data were not presented. In a separate experiment reading disabled children tended to be more distracted than normals by an auditory stimulus in a visual memory recognition task. While the results of both of these experiments can be interpreted in terms of sensory interaction differences, an alternative explanation would be based on attentional differences between the children.

Selective attention and the VEP. Birch and Belmont (1965), Katz and Wicklund (1971), Rudnick et al. (1967), Spring and Hopkins (1972), and Sterritt and Rudnick (1966) have shown that LD children have inferior abilities, when compared to normal children on perceptual tasks. They have not, however, separated attentional from perceptual contributions to the obtained difference in performance levels. In previous studies, the amplitude of VEP components has been shown to be sensitive to the meaningfulness (Chapman & Bragdon, 1964), the task relevance (Davis, 1964; Donchin & Smith, 1970; Shelburne, 1973) and the uncertainty reducing properties (Friedman, Hakerman, Sutton, & Fleiss, 1973; Sutton, Tueting, & Zubin, 1967) of the eliciting stimulus. More directly, the VEP has been shown to reflect attentional states per se; VEP components to a stimulus tend to be larger when the subject is asked to selectively attend and respond to rather than ignore the stimulus (Donchin & Cohen, 1967; Eason, Harter, & White, 1969; Harter & Salmon, 1972; Salmon, 1973). Changes in the VEP amplitude as a function of selective attention would provide electrophysiological data which, in conjunction with behavioral data, could indicate the attentional and perceptual capabilities of the children.

CNV and the effects of motivation, attention, and arousal. When an individual is presented with two sequentially paired stimuli, such that the first stimulus (S_1) serves to signal the occurrence of the second stimulus (S_2), a slow negative D-C drift, the contingent negative variation (CNV), occurs during the S_1-S_2 interstimulus interval. The amplitude of the CNV response has been related to a number of psychological variables.

Walter and his associates (Walter, Cooper, Aldridge, McCallum, & Winter, 1964), who were the first to discover this phenomenon, considered the CNV an index of expectancy. In other words, the subject held some level of expectancy in terms of the subjective probability that S_2 would follow S_1. Subsequent investigators (Low, Borda, Frost, & Kellaway, 1966) felt that conation, or the intention to respond, was a more accurate description of the psychological state conveyed by the CNV response. Several studies have shown that CNV amplitude is directly related to the level of motivation which was manipulated by the instructions to the subject (Waszak & Obrist, 1969), by contingent reinforcement (Rebert, 1972), or by the threat of shock (Irwin, Knott, McAdam, & Rebert, 1966). The amplitude of the CNV also has been shown to reflect the meaningfulness or relevance of the task to subject (Cohen & Walter, 1966; Pincton & Low, 1971).

Tecce (1971, 1972), who has made a comprehensive review of investigations dealing with CNV, has concluded that CNV amplitude is related to both attentional and arousal states of the subject. The level of attention is directly related to the resultant CNV amplitude. Arousal, on the other hand, is related to CNV amplitude in terms of an inverted-U function; when arousal states are varied from low to moderate to high, CNV amplitudes vary from small to large to small. While the exact nature of these posited functional relationships are yet to be substantiated, the effects of arousal and attention on CNV are well-founded.

The CNV also has been shown to reflect individual differences (Tecce, 1971, 1972). Cohen and Offner (1967) found that normal CNVs occurred in dyslexic children when S_1 and S_2 were light and sound, respectively. However, Fenelon (1968) observed the disappearance of CNV in reading disability children when the imperative stimulus was a word or trigram.

Purpose of the Present Study

The purpose of the present investigation was to assess whether any attentional, perceptual, or neurophysiological differences exist between children classified as reading disabled and normal. A visual discrimination task was employed, which required attentional and perceptual capabilities; wherein the children were required to selectively attend and respond to one stimulus of a pair and to ignore the other stimulus. Four pairs of stimuli of different levels of complexity were discriminated in order to provide clues as to the nature and possible level of neural processing accounting for the reading disability. The children's ability to discriminate each stimulus in a pair was measured both behaviorally and electrophysiologically (by VEPs and CNVs). A secondary purpose of the study was to investigate whether the learning disability was modality specific. Children who were diagnosed as having either auditory or visual disabilities participated in the experiment so as to determine whether only the visual LD children would have difficulty with the visual discrimination task.

CHAPTER II

METHOD

Subjects

Twenty-seven children, divided into one of three groups, took part in this study. All children were free from gross neurological damage and physical disabilities according to medical records. Children on any form of medication were not used. All children had been solicited through the Guilford County School System and had parental consent to partake in the study. Also, parents were encouraged to be present in the laboratory during the experiment. All 27 subjects initially selected completed all aspects of the study.

Two of the three groups of children had learning disabilities. They had been classified as LD by the school system based on (a) average and above IQ (Slossen Intelligence Test), (b) two or more years behind in academic achievement (Wide Range Achievement Test), and (c) displaying language or reading disabilities as indicated by 20 or more errors on subtests of the Slingerland Screening Test for Identifying Children with Specific Language Disabilities. The two LD groups differed in terms of whether their disability appeared to be attributable to visual as opposed to auditory perceptual problems, as reflected in the scores of the subtests of the Slingerland. The third group of subjects served as controls and had no diagnosed reading or language disability as indicated by the test battery listed above.

There were nine children in each of the three groups: LD-visual (VLD), LD-auditory (ALD), and normal controls (NC). Groups were matched on a subject-by-subject basis for age (7-12 years), grade (second to fifth), IQ score (90 and above), and sex.

Vision Screening Procedure

Both VEPs and the more traditional subjective screening procedures were employed on the child's first visit to the laboratory in order to assess each subject's vision. Spherical refractive error was assessed by recording the VEPs to a transient visual pattern viewed through a series of spherical lenses. Visual acuity, vertical and lateral phorias, and color blindness were evaluated by subjective reports in conjunction with an Ortho-Rator and Ishihara color plates.

A method described by Harter and White (1968) was used to evaluate visual processes utilizing the VEP. Briefly, a square display (subtending a visual angle of 14.5 x 14.5 degrees), composed of a black and white checkerboard pattern (individual checks subtending a visual angle of 19 min), was back-illuminated by a PS-2 Grass photostimulator (intensity setting at 1). The patterned flash was presented once every 550 msec and had a flash duration of 10 microsec. Visually evoked potentials were recorded while subjects looked through the various refractive lenses.

Visually evoked potentials were recorded monopolarly with a gold-cup electrode placed 2.5 cm above the inion and the reference electrode attached to the right earlobe. Responses were averaged for 500 msec after stimulus onset. A total of 100 responses, collected in a counterbalanced fashion, composed each VEP. The details of the VEP recording procedures are described below.

In order to maintain an equally high attentional state to all stimulus presentations under the VEP refraction procedures, children were required to take part in a simple reaction time task. They were asked to release a microswitch as fast as possible whenever the stimulus display stopped flashing. If subjects responded within 1000 msec after the presentation of the last flash in the train, they were rewarded with a token. Tokens consisted of plastic poker chips. The chips were delivered by means of a Ralph Gerbrands Token dispensor, which was located outside of the subject's cubicle, through a large dryer vent hose. Tokens were redeemable for money at the conclusion of the daily session. Also, in order to restrain the children from unnecessary movements and fidgeting when recording, subjects were rewarded with tokens for sitting still and attending.

Binocular refractive error was assessed by having the child view the flashing checkerboard pattern through an American Optical Company Phoropter with various sperical lenses. Initially, the spherical lens which resulted in the clearest and sharpest image for each eye, based on subjective report, was determined and set. Next, both eyes were opened and VEPs were obtained in a counterbalanced order while the following diopter values were added to the initial settings: +12, +3, +2, +1, 0, -1, -2, and -3 diopters. After each VEP had been recorded for a particular lens setting, the subject was asked to report the perceptual clarity of the visual pattern, in order that the subjective and electrophysiological responses might be compared. The +12 diopter setting resulted in a perceptually diffuse flash, which should have elicited a "diffuse-like" VEP. It was assumed that this diffuse VEP would be most different from the pattern VEP that resulted under optimal viewing conditions (when the correct spherical lens was in place). Therefore, the lens that resulted in the VEP most different from the diffuse VEP (+12 D) was considered the optimal spherical correction. Particular attention was paid to the 100 and 200 msec latencies of the VEP which previously have been shown to reflect both pattern and refractive error parameters in adults (Eason et al., 1970; Harter, 1971; Harter & White, 1968; 1970; Reitveld et al., 1967).

After assessment employing the VEP was complete, each child was requested to view the first five tests on the Bausch and Lomb Ortho-Rator. These tests provided an assessment of vertical and lateral phorias, and visual acuity (binocular, right-eye, and left-eye). A check for the presence of color blindness was made with the Ishihara color plates.

Visual problems detected which were not indicated in the child's prescription lenses were documented and reported to the parents. If such problems would interfere in any way with the child's performance on the subsequent visual discrimination tasks, they were alleviated, when possible, by means of corrective lenses; otherwise, the child was dismissed from the remainder of the study.

<u>Visual Discrimination Attentional Task</u>

One trial of the discrimination task, which is represented in Figure 1, consisted of presenting a warning stimulus, S_1 (clown's face), followed 1100 msec afterwards by either one of two stimuli, S_{2rel} or S_{2irrel}. Visual discrimination was assessed and selective attention manipulated by asking the subjects to respond (see below) to the S_{2rel} (i.e., red) and to withhold the response to the S_{2irrel} (i.e., green). Both S_{2rel} and S_{2irrel} were presented 32 times each in a random, unpredictable sequence, so that a given problem consisted of at least 64 trials.

On a given problem the subject responded by releasing his finger from the microswitch key within a given time period after the presentation of S_{2rel}. This critical time interval was attuned to each subject's capability so that an approximate 50% hit rate would result. Prior to the actual collection of data, the subject was allowed to practice the task so as to minimize experiential factors and to assure that the subject understood the task. Behavioral data consisted of reaction times to each S_{2rel} (measured by Hewlett-Packard Model 5325B universal Counter and Model 526A Digital Recorder), correct responses, and incorrect responses (see Results for definition).

For each trial a response contingent outcome was imposed in terms of dispensing or retrieving rewards. A token was delivered immediately to the subject either when a correct response to S_2 within the critical time period occurred or when a response was withheld to S_{2irrel}. When an incorrect response occurred, an auditory click provided negative feedback. In addition, the number of incorrect responses was registered on a counter located next to the subject and one token was taken from the subject for every two errors. At the end of each problem (64 trials), the subjects were rewarded with an additional one to five tokens for sitting still and giving clean, muscle-activity-free EEGs.

Four different types of problems were employed in the study, each problem type involving separate pairs of S_2 stimuli: red and green diffuse light; vertical and horizontal lines; the letters _b_ and _d_; and the words _was_ and _saw_. Each stimulus of the pair served as both an S_{2rel} and S_{2irrel} for one condition, thus giving a total of eight different conditions, two for each problem. These eight conditions were presented to each subject twice, so that each type of problem was presented four times (replications).

Table 1 delineates the employed experimental design in terms of the order of condition presentation for each subject. Two replications, or a total of eight conditions, were conducted on each separate recording session. The nine sets of matched subjects from each group were assigned to one of four condition sequences which were established by a Latin Square design (Winer, 1971), so as to counterbalance the order of conditions across subjects. The order of presentation of each sequence of eight conditions comprising the two replications of each problem type was counterbalanced according to problem type within each subject on a given recording session. Order of problems also was counterbalanced across the two recording sessions.

Visual stimuli were presented on a LVE Model 1346 Multiple Stimulus Projector. Stimuli were 40 msec in duration, were projected on a 28 mm in diameter circular screen (subtending a visual angle of 2.5 degrees), and were surrounded by a white background. Previous research (Hillyard & Galambos, 1970; Tecce, 1972; Waszak & Obrist, 1969) has suggested that ocular potentials arising from eyeblinks and vertical eye movements can contaminate CNV recordings. Such contamination was minimized in the present investigation by having subjects fixate on a specific target during the S_1- S_2 interval. In order to verify that subjects maintained fixation during the visual discrimination tasks, a control recording session was administered to each subject. In this session both vertical and lateral eye movements were monitored by electro-oculograms which were recorded and signal averaged while the subject was partaking in a series of problems.

The projection screen was mounted on the backside of a three-sided partition, in order to keep all extraneous visual stimulation at a minimum. For each problem the stimulus to be attended (S_{2rel}) was pictured on a 3 x 5 white card and placed immediately below the projection screen. This was done (a) to help facilitate the subject's comprehension of the instructions, (b) to make the visual discrimination task independent of variables such as memory or familiarity with the stimuli, and (c) to minimize the carry-over and transfer effects from the previous problem.

VEP Recording Techniques

Cortical responses were recorded monopolarly from the occiput (2.5 cm above the inion at approximately O_z) and from the vertex (approximately C_z) with Grass gold-cup electrodes. A reference electrode was attached to the right ear lobe. Skin resistance was kept below 10,000 ohms with the aid of Redux Electrode Paste. Responses were amplified by means of a Grass 7P5A Pre-amplifier in conjunction with a 7DAC Amplifier. One-half amplitude low and high frequency filters were set at 0.15 and 35 hz, respectively.

A Fabritek Model 1062 or Datacom minicomputer system was used to average cortical activity. The computer was set to record and average activity 2048 msec after S_1 onset so that the VEP to S_1, the VEP to S_2, and any CNV activity occurring within the 1100 msec S_1-S_2 interval would be sampled. In order to evaluate the effects of selective attention on the VEPs to S_2, evoked responses from both O_z and C_z to S_{2rel} and S_{2irrel} were sorted into four separate channels of the computer. An average VEP for each condition was based on a total of 32 responses. After each problem, the four averaged potentials were recorded on paper with a Hewlett-Packard 7035-B XY plotter and also on magnetic tape with an Ampex Model SP300 seven-channel FM tape recorder.

The recording of evoked potentials to stimuli in the visual discrimination task took place in a sound-attenuated electrically shielded cubicle. The experimenter was located outside the cubicle and monitored the equipment and recordings, while a co-experimenter was placed inside the cubicle with the child. The purpose of this co-experimenter was (a) to allay any fears or doubts in the child, (b) to monitor the child for comfort, fatique, and restlessness, and (c) to encourage attention and diligence. This second experimenter had a switch to start and stop the presentation of stimuli at any time during the session in order to assure that the child's full attention was directed at the task.

CHAPTER III

RESULTS

Visual Screening Examinations

Table 2 summarizes the results of the diagnostic screening procedures for each of the 27 subjects. Results of the Ortho-Rator tests, which assess visual acuities and phorias, are included in the first five columns of Table 2. The sixth column represents the results of the Ishihara color blindness test.

The optimal diopter settings, as determined by the VEPs, for each subject are included in the last column of Table 2. Induced refractive error influenced both the subjective reports and the VEP waveform. The polarity of the VEP at the 120-150 msec latency appeared most sensitive to these refractive error changes. As the spherical error was reduced, as indicated by subjective reports, the polarity at this latency became more and more negative. These changes in VEP waveform as a function of refractive error and visual acuity corroborate previous research (Harter, 1971; Harter & White, 1968, 1970). The VEPs to pattern flashes viewed under the various diopter settings are presented in Figure 2 for three subjects. In two of these three subjects (NC-5 and ALD-8) the voltage at the 120-150 msec latency was most negative at the 0 diopter lens setting, indicating the presence of no refractive error, which was confirmed by subjective reports. However, for one subject (ALD-3), who was diagnosed as having less than normal visual acuity by the Ortho-Rator (20:29), the -1 diopter setting yielded the optimal VEP and resulted in the sharpest image.

For the 27 subjects screened, the frequency of the detected visual anomalies were relatively small in occurrence and evenly distributed across the three groups of subjects. It was decided that visual anomalies were not serious enough to hamper the child's performance on the visual discrimination tasks.

Dependent Variables

The visual discrimination task employed in this investigation yielded a variety of psychophysical and electrophysiological indices. A summary of the definitions and procedures required to quantify each of these dependent measures is provided below.

Signal Detection Response Accuracy (d'). In order to assess the proficiency on the visual discrimination tasks, a signal detection analysis of response accuracy was utilized. Given the heterogeneity of individual response strategies in terms of response impulsivity, an isosensitivity function (d') was specified for each problem based on the false-alarm and hit rates of each problem (Swetts, 1964).

On a given trial any one of the sequences of events delineated in Figure 3 might occur. Despite the actual reaction time criteria interval, which varied from subject to subject, any response occurring within 1000 msec after the presentation of the relevant S_2 was considered a hit in this analysis. This made the response accuracy measure independent of the actual response speed. Likewise, any response within the 1000 msec interval following the S_2 was considered a false-alarm. Trials in which a response occurred 1000 msec after the S_2 presentation were discarded from the analysis, since one could not be certain whether these responses (which were very infrequent, occurring on less than 5% of the trials) were in any way related to the occurrence of S_2. The hit rate was defined as the ratio of hits to the number of relevant S_2 presentations, and false-alarm rate was the ratio of false-alarms to the number of irrelevant S_2 trials. Given the hit and false-alarm rates for a particular problem the response sensitivity, d', was determined. It may be noted that hits and correct misses were considered "correct responses" and misses and false-alarms were considered "incorrect responses" for purposes of feedback (tokens and clicks).

Psychophysical Response Latency (MRT). The reaction times from all trials on which a hit occurred were averaged into one mean reaction time (MRT) for each problem. In order to ensure the sensitivity of the response latency measures, trials where a miss or a late response (response latency greater than 1000 msec) occurred were discarded from the analysis.

Reaction Time Critical Interval (RTC). Short reaction time to the relevant S_2 was encouraged by providing a critical time interval within which the subject had to respond in order to be reinforced. An attempt was made to employ an interval wherein on 50% of the relevant S_2 trials the subject would respond within the allocated time. The RTC would vary both across subjects and within subjects across the various test problems. Since the RTC level was based on RT performance under the various experimental conditions, it was included as a dependent measure in the subsequent data analyses.

Contingent Negative Variation ($CNVO_z$ and $CNVC_z$). CNV activity occurring within the S_1-S_2 interval was recorded from both the occiput ($CNVO_z$) and the vertex ($CNVC_z$). Tecce (1972) reports three methods used in previous research for quantifying CNV magnitude. The most popular method is to determine the maximum negative voltage reached by the CNV deflection within the S_1-S_2 interval, relative to the averaged EEG baseline prior to S_1. A second and similar method entails the measurement of the mean negative voltage for a defined epoch within the S_1-S_2 interval relative to an averaged EEG epoch prior to S_1. One limitation of both of these two measures is the establishment of the pre-S_1 baseline which in many studies is determined subjectively. However, a third method requires measuring the area under the CNV deflection in terms of a voltage-time dimension. This latter method which tends to provide a more robust indice of CNV activity by taking the entire CNV response within the S_1-S_2 period into account was adopted for the present investigation.

Figure 4 graphically illustrates the procedural steps involved in obtaining this integrated CNV measure from a typical subject's VEP records. Note that the CNV waveform illustrated in Figure 4 is somewhat atypical of the majority of CNVs which were observed in the present study. While this subject's record revealed an initially large CNV deflection, the CNV appeared to terminate prematurely, prior to the presentation of S_2. Initially, a baseline is computer-established by setting the average arithmetic integrated voltage within the 700 msec epoch preceding S_2 equal to zero (tracing II, Figure 4). The CNV measure is then defined as the absolute integrated voltage of this 700 msec pre-S_2 epoch (tracing III, Figure 4). The first 400 msec in the S_1-S_2 interval does not enter into the measure, since VEP components related to S_1 fall within this interval. Secondly, Rebert and Knott (1970) have shown that CNV activity did not prevail any sooner than 400 msec after S_1 in a similar CNV paradigm.

VEP Latency Measures (O_zLAT and C_zLAT). The rate of electrophysiological visual processing was assessed by means of the latency of the prominent positive VEP component prevailing after S_2 for both the O_z and the C_z electrode derivations (O_zLAT and C_zLAT). For all subjects, this component fell between 270 and 345 msec and between 350 and 435 msec for the O_z and C_z VEPs, respectively. While other VEP components could have been assessed, this positive component, termed $\overline{P}300$, was selected because it was the most discernible component across all subjects. These components were measured by the computer in terms of milliseconds after S_2 onset.

Differential Selective Attention Effects on the VEP (DAEO_z and DAEC_z). One method used in the present investigation to quantify the differential responsiveness of the VEPs to S_2 attributable to selective attention was adapted from the procedures of Harter and Salmon (1972). This procedure entails subtracting with the aid of the computer the averaged evoked response to a stimulus when it was not attended from the response to the stimulus when it was attended. It is assumed that the magnitude of this difference response (VEP_{att} - VEP_{natt}) will reflect the effects of selective attention which should be the only variable differentiating the two responses.

A similar procedure, graphically illustrated in Figure 5, was employed in this investigation. Visually evoked potentials to S_2 were sorted on-line into separate channels of the computer based on whether they were elicited by S_{2rel} or S_{2irrel}. The magnitude of the VEP difference was quantified by first setting the baselines for each individual VEP. The baselines established for the CNV measures were used for these purposes. Next, the VEP to the irrelevant S_2 was subtracted from the VEP to the relevant S_2, and the 350 msec epoch after S_2 of the resultant differential response was quantified in terms of the average absolute integrated voltage. A 350 msec epoch was chosen since most VEP activity related to stimulus parameters tend to lie within this interval while motor response artifacts to the reaction time task lie outside this interval. This measure was obtained for each problem for both the occiput ($DAEO_z$) and the vertex ($DAEC_z$) responses.

Differential Selective Attention Effects on VEP Components (O_zNP, C_zNP, $DAEO_zNP$, and $DAEC_zNP$). The effects of selective attention in terms of peak-to-trough amplitude changes in specific VEP components also were assessed. Previous research (Donchin & Smith, 1970; Eason et al., 1969; Friedman et al., 1973; Harter & Salmon, 1972; Sutton et al., 1967) has indicated that amplitudes of both the negative-going component at about the 200 msec latency ($\overline{N}200$) and the positive-going component at about the 300 msec latency ($\overline{P}300$) of the VEP are sensitive to changes in attentional states. In an attempt to get a comprehensive measure of the changes in

VEP components attributable to selective attention and to avoid the problem of gauging component amplitudes from a reference baseline, a peak-to-trough measure of $\overline{N}200$ to $\overline{P}300$ components was employed. Since the actual latency of the $\overline{P}300$ component varied from subject to subject (270 to 345 msec for O_z and 350 to 435 msec for C_z), the $\overline{P}300$ component was operationally defined for a given subject as the most prominent and consistent positive component falling between 250 and 450 msec after S_2. The $\overline{N}200$ component was defined as the first negative deflection prevailing before $\overline{P}300$ and falling between 170 and 370 msec after S_2. Figure 5 illustrates how the four peak-to-trough measures for each problem were obtained: two from each electrode location for both the relevant and irrelevant S_2 (O_zNP_{rel}, O_zNP_{irrel}, C_zNP_{rel}, and C_zNP_{irrel}). These four measures were then converted into difference scores in order to specify the effects of selective attention ($O_zNP_{rel} - O_zNP_{irrel} = DAEO_zNP$ and $C_zNP_{rel} - C_zNP_{irrel} = DAEC_zNP$).

<u>Multivariate Analysis</u>

A three factorial (Group x Problem x Replication) repeated measures analysis of variance (ANOVA) was the basic statistical paradigm used to elucidate the various group and treatment effects. Nine subjects were nested under each of three clinical groups (NC, VLD, ALD); and there were four levels in each of the two within-subject variables: problem (colors, line orientations, letters, and words) and replications (first, second, third, and fourth exposure to a given problem).

Given the multitude of dependent measures obtained in this investigation and the uncertainty of the orthogonality of these multi-dimensional indices, a multivariate analysis of variance (MANOVA) was conducted initially. The rationale for doing such an analysis is that when several dependent measures are obtained from the same subjects and, thus, are intercorrelated in some unknown way, the univariate F tests on the individual dependent variables are not independent, which inflates the probability of either a Type I or II error. Based on multiple regression analysis, the MANOVA takes the intercorrelation of the variables into account and provides an overall statistical significance test of the orthogonal facets of each of the dependent variables taken jointly (Kerlinger & Pedhazur, 1973, pp. 352-360; Tatsuoka, 1971, pp. 194-214).

Twelve variables which included d', MRT, RTC, $CNVO_z$, $CNVC_z$, $DAEO_z$, $DAEC_z$, $DAEO_zNP$, $DAEC_zNP$, O_zLAT, C_zLAT, and age of the subjects were entered as dependent variables into the MANOVA. The results of this analysis, summarized in Table 3, indicated that the group, problem, and replication main effects were all statistically significant ($p < .01$). In addition, there was a significant group by replication interaction effect ($p < .01$).

In an effort to clarify the nature of these significant effects, univariate analyses of variance were performed on the individual dependent measures. Relationships among the variables also were assessed by means of intercorrelations and factor analysis procedures.

Psychophysical Measures

For each subject the visual discrimination task consisted of sixteen separate conditions (four problems x four replications). Each problem provided two behavioral indices of a psychophysical nature: response accuracy (d') and response speed (MRT). In the analyses of these two measures, attention was also directed at one of the motivational variables involved in each particular problem: the RTC. Pooled covariance correlations among these three variables revealed several interesting relationships. First, there appeared to be a trade-off between d' and MRT ($\underline{r}$ = .402, $\underline{p}$ < .0001). This relationship, which is graphically illustrated in Figure 6, indicates that as most subjects tended to respond faster, they became less accurate in their responses. However, for a few individual subjects, the relationship between MRT and d' could be characterized as curvilinear: as reaction times went from short to medium to long, response accuracy tended to go from low to high to low. Likewise, MRT was significantly related to the RTC ($\underline{r}$ = .551, $\underline{p}$ < .0001). However, whether the RTC directly modulates the MRT is unclear, since for a given problem the RTC was determined by the subject's previous problem performance. Given the relationship between the variables, it is safe to say that the RTC was able to maintain a high level of response speed.

Response accuracy (d') tended to be the most discriminative behavioral measure in terms of the independent variable manipulations. The univariate ANOVA of d' revealed a significant main effect across the four types of problems: colors, lines, letters, and words, $\underline{F}$ (3, 72) = 26.30, $\underline{p}$ < .001. Based on a post hoc analysis of the main effect of problem type,subjects taken as a whole performed significantly superior on the color discrimination problems as compared to the other three types of problems ($\underline{p}$ < .01). Secondly, proficiency of response accuracy for the problems involving line orientations was significantly greater than for problems involving words ($p < .01$) or letters ($p < .01$). There was no significant difference between the problems involving letters and words, for which d' scores were the lowest.

Additionally, variability in both d' and MRT scores was attributable to the main effects of replication: d' -- F (3, 72) = 18.49, $p < .001$; MRT -- F (3, 72) = 15.07, $p < .001$. Since the majority of subjects were given the first two replications on one day and the second two replications on a separate day, replication effects may be viewed in light of reflecting both experiential and fatigue factors. Changes in the MRT and d' scores as a function of replication are shown in Figure 7 along with the post hoc analyses. Across the first three replications there was a successive and significant shortening of response times ($p < .01$) which was maintained through the fourth replication. Along with this decrease in MRT came a concomitant decrease in response accuracy. There was a significant decrement in d' scores in the last three replications when compared to the first ($p < .01$). These replication effects indicate that response strategies tended to change for the majority of subjects; changes in performance in terms of these two behavioral measures did not provide much evidence for subject fatigue within the paired replication experimental sessions (One vs. Two and Three vs. Four), since the second replication of the pair (Two and Four) was equal or superior to the first (One and Three) in terms of the d' and MRT scores. However, there was some indication of learning effects across the last three replications. While response accuracy was essentially unchanged across these last three replications, response speed tended to improve significantly from replication Two to Three and Four ($p < .01$).

Changes in d' scores can also be attributable to a significant problem by replication interaction effect, $F\ (9, 216) = 1.98$, $p < .042$. Analyses of the effects of problems within each replication and the effects of replications within each type of problem are documented in the right hand column of Tables 4 and 5, respectively. It can be concluded from these analyses in conjunction with the post hoc tests (also shown in Tables 4 and 5) that as one progresses from replications One through Four the magnitude of the simple main effect of problem type on d' scores diminishes progressively; that is, along with the general decline in d' across replications, d' also became less discriminative of problem type. The effects of replications within a problem type (Table 5) indicate that for problems involving colors and line orientations there was a significant decline in response accuracy from replications One to replications Two, Three and Four ($p < .01$). For the more difficult problems entailing letter and word discriminations, there was less change in d' scores across replications (word problems, $p < .05$; letter problems, $p > .05$).

The response accuracy scores indicated that performance across the different problems was related to the group with which the child was associated, $F\ (6, 216) = 2.29$, $p < .04$. This interaction effect is graphically presented in Figure 8. Comparisons of the performance of the three clinical groups for any one particular problem type revealed no significant differences. This interaction effect was attributable, therefore, to the effects of problem type within each clinical group (summarized in Table 6). As indicated in Figure 8, both the VLD and ALD groups showed a progressive decline in d' scores from color to line to letter and to word problems; the NC group differed in that it showed an increase in its level of performance from the letter to word problems. This significant interaction effect, as manifested in the response accuracy scores, was the only indication of differences between groups based on the behavioral measures generated by the prescribed visual discrimination tasks. Neither the MRT nor RTC scores revealed any significant between group differences.

Contingent Negative Variation

Contingent negative variations occurring within the S_1-S_2 interval were measured from both the occiput and vertex electrode locations and quantified in terms of an integrated voltage-time indice. An ANOVA on the $CNVO_z$ revealed a significant replication effect, F (3, 72) = 5.57, $p < .002$. A post hoc analysis indicated a significant reduction in CNV from replication One to replications Two, Three, and Four ($p < .01$). When concomitant CNV amplitude and MRT scores are compared across replications, a corollary reduction in both measures is observed. This relationship between CNV and MRT is also evidenced by the significant pooled covariance correlation between these two variables (r MRT-$CNVO_z$ = .223, $p < .001$). These correlated changes in MRT and CNV activity indicate that CNV activity may decline with more impulsive response strategies which were associated with the faster response times.

The amplitude of CNV varied significantly between the problems for both $CNVO_Z$ and $CNVC_Z$: $CNVO_Z$ -- F (3, 72) = 6.82, $p < .001$; $CNVC_Z$ -- F (3, 72) = 3.04, $p < .034$. Table 7 summarizes these effects along with a post hoc analysis. For both electrode derivations, CNV activity was greater for the word problems than for any other type of problem. This was the only significant separation of problem types in terms of CNV amplitude.

No other significant changes in CNV were obtained. The interrelationship between CNV activity from the occiput and vertex is of interest (r $CNVO_Z$ - $CNVC_Z$ = .659, $p < .0001$). Additionally, CNV activity was greater from the occiput than from the vertex, which is opposite to the findings typically reported based on adults (Tecce, 1971, 1972).

VEP Latency

The latencies of the principle positive component of the VEP was measured from both the occiput and vertex responses, O_ZLAT and C_ZLAT, respectively. Figure 9 illustrates how $\overline{P}300$ was significantly different in latency for the groups: O_ZLAT -- F (2, 24) = 3.51, $p < .045$; C_ZLAT -- F (2, 24) = 7.35, $p < .004$. The O_ZLAT measure of the NC subjects was significantly shorter (12.92 msec on the average) than that of the VLD subjects ($p < .05$). The latencies for the occiput VEP of the ALD group were at intermediate levels and did not differ significantly from either the NC or the VLD groups.

The C_ZLAT measure also indicated that the NC subjects had the shortest $\overline{P}300$ component latencies. Again, latencies progressively increased from the NC group to the ALD group, and then to the VLD group. In this case the NC subjects' latencies were significantly shorter than both the VLD group ($p < .01$) and the ALD group ($p < .05$). The ALD and VLD groups did not differ significantly from each other. The NC group's latencies were on the average 26.06 msec shorter than those of the VLD group. The magnitude of this group difference in absolute time is almost twice that found with the occiput recordings.

Selective Attention and the VEP

The behavioral visual discrimination tasks in conjunction with the VEP measures employed in this investigation provided the means for assessing the selective attention effects. The degree to which the VEP to an S_2 differed when the S_2 was attended as compared to unattended, attention being manipulated by the concomitant behavioral discrimination task and validated by d', was evaluated as a function of the clinical grouping of subjects, the specific discrimination problem, and replications. Two separate measures of the VEP were employed for this analysis: peak-to-trough measures of two specific VEP components (O_zNP and C_zNP) and 350 msec epoch VEP difference responses ($DAEO_z$ and $DAEC_z$).

The peak-to-trough measures were analyzed according to groups, problems, replications, and attentional states with a four factorial repeated measures analysis of variance (3 x 4 x 4 x 2 levels, respectively). There were two levels of attention: responses to a given S_2 when relevant and when irrelevant for a given problem and replication. Results of these analyses revealed VEPs were significantly larger when the eliciting stimulus was attended: O_zNP -- F (1, 24) = 24.19, $p < .001$; C_zNP -- F (1, 24) = 66.11, $p < .0001$. These VEP peak-to-trough amplitudes were

1.08 microvolts and 1.38 microvolts larger for the attended S_2 when compared to the unattended S_2 for the occiput and vertex VEPs, respectively. It cannot be stated from the present measures whether this change in peak-to-trough amplitude is attributable to a more positive $\overline{P}300$ component, a more negative $\overline{N}200$ component, or both.

Significant between-group differences for three of the selective attention measures prevailed, with the VLD group showing the greatest selective attentional differentiation: $DAEO_zNP$ -- F (2, 24) = 3.43, $p < .048$; $DAEO_z$ -- F (2, 24) = 4.75, $p < .018$; and $DAEC_z$ -- F (2, 24) = 8.48, $p < .002$. The group means for these three VEP measures are presented graphically in Figure 10.

Examination of the group scores for the $DAEO_zNP$ measure of selective attention revealed that the VLD group manifested greater attentional differences in the peak-to-trough amplitudes of the VEP than did the NC group ($p < .05$). The ALD group showed intermediate level differences, not being significantly different from either the NC or the VLD group. While the peak-to-trough attentional measures recorded from the vertex did not quite show significant group differences: $DAEC_zNP$ -- F (2, 24) = 2.41, $p < .073$; again, attentional differences progressively increased from the NC group to the ALD group and then to the VLD group.

The integrated attentional difference scores ($DAEO_z$ and $DAEC_z$) showed similar group differences: $DAEO_z$ -- F (2, 24) = 4.75, $p < .018$; $DAEC_z$ -- F (2, 24) = 8.48, $p < .002$. Post hoc analyses of the measures taken from both electrode locations indicated that the VLD group showed significantly larger attentional differences in the VEPs than either the normals or ALD group: $DAEO_z$ -- $p < .05$; $DAEC_z$ -- $p < .01$.

The type of problem influenced the magnitude of the selective attention effects on the peak-to-trough amplitude measures of the VEP: $DAEO_zNP$ -- F (3, 72) = 3.61, $p < .017$. This significant problem effect, which is graphically presented in Figure 11, can be attributed to the significantly larger attentional differences found in the problems involving color discriminations compared to those involving line orientations ($p < .05$), letters ($p < .05$), and words ($p < .05$). Figure 11 illustrates the covariations between the d' scores and the attentional differences in the VEP components as a function of problem type. The relationship between behavioral and electrophysiological response discrimination seems quite evident.

Attentional differences in the VEP as measured by the $DAEO_zNP$ were also influenced by the effects of replication, F (3, 72) = 5.269, $p < .003$. As evidenced in Figure 12, evoked responses in replication One showed significantly greater attentional difference than in replications Two ($p < .05$), Three ($p < .05$) or Four ($p < .01$). In addition, a significant problem by replication effect prevailed, F (9, 216) = 3.33, $p < .001$. An analysis of simple main effects, which is summarized in Tables 8 and 9, indicated that there was a significant difference across replications for the problems involving colors, F (3, 72) = 11.08, $p < .01$, with replications One and Four providing significantly greater attentional differences than replications Two ($p < .01$) and Three ($p < .01$). This interaction effect also was attributable to the simple main effects of problem type within a given replication. Replications One and Four both showed significant problem effects with problems involving colors again providing greater attentional differences.

Dependent Variable Interrelationships

A correlation matrix consisting of the 10 dependent measures and the two covariate indices (RTC and subject's age) was calculated in an attempt to understand more fully the covariations among these variables within the milieu of the various independent variable manipulations. These correlation coefficients along with their associated probability statements are tabulated in Table 10. A principle component factor analysis with varimax rotations was conducted on these data to delineate the clustering patterns of the 12 measures. Five significant orthogonal factors were extracted from this analysis, which are summarized in Table 11 in terms of factor loadings on each of the 12 variables.

Factor One and Two appear to reflect primarily the psychophysical parameters. The MRT and d' scores, which are significantly interrelated ($\underline{r}$ = .402), were predominantly weighted by Factor One. Factor Two reflected the psychophysical parameters with particular emphasis placed on the MRT scores and the two covariate indices of age and RTC. The clustering of these three variables can be attributed to the significant correlations of age with both MRT ($\underline{r}$ = -.300) and RTC ($\underline{r}$ = -.570) scores, which indicate that younger children have longer reaction times and were also given more time to respond.

Factor Three is most indicative of the CNV and integrated attentional difference responses. While the high correlations between the CNV measures ($\underline{r}$ O_ZCNV-C_ZCNV = .659) and between the attentional measures ($\underline{r}$ DAEO$_Z$-DAEC$_Z$ = .570) could be expected, the significant relationships between the CNV and attentional measures is unexpected ($\underline{r}$ DAEO$_Z$-O_ZCNV = .457;

$\underline{r}$ DAEO$_Z$-C$_Z$CNV = .442; $\underline{R}$ DAEC$_Z$-O$_Z$CNV = .261; $\underline{R}$ DAEC$_Z$-C$_Z$CNV = .419). These relationships suggest that CNV amplitude reflects the ability to attend: larger CNV amplitudes are associated with greater selective attentional states.

Factor Four is most indicative of the VEP latency measures. These two measures which were significantly correlated ($\underline{r}$ O$_Z$LAT-C$_Z$LAT = .765) appeared to be unrelated to any of the other physiological or psychophysical indices. Factor Five can be considered the attentional vector. The peak-to-trough attentional measures were highly weighted on this factor, with weighting on the integrated attentional measures being marginally evident.

Therefore, the 12 variables brought under analysis can be reduced to five independent dimensions, comprised of two psychophysical and three electrophysiological factors. In terms of the independent variable manipulations of this investigation, Factors One, Three, and Four are most responsive to the effects of problem type; Factors One, Two, Three, and Five are most responsive to the replication effects; and Factors Three, Four, and Five were discriminative of subject groups. This partitioning of the variables and their associated treatment effects is related to the significant independent variable effects elucidated by the initial multivariate analysis of variance. The generation of five independent factors from 12 variables indicates the importance of employing an experimental approach where multiple dependent measures are assessed.

Table 12 is presented to summarize the numerous significant independent variable effects associated with each dependent measure. Significant between-group differences were observed on the VEP indicants of selective attention and component latencies. A significant group by problem interaction effect prevailed in the psychophysical d' scores. The effects of problem type were manifested in the CNV measures, in the one peak-to-trough VEP amplitude measure ($DAEO_zNP$) and in the d' scores. Replication effects were prevalent in the d' and MRT scores and also in the occiput CNV and $DAEO_zNP$ measures. Problem by replication interaction effects were observed in both the d' and $DAEO_zNP$ measures.

CHAPTER IV

DISCUSSION

In an attempt to characterize the perceptual and neurophysiological parameters which would differentially typify children with reading disabilities, psychophysical and neurophysiological indices generated within a selective attention visual discrimination task were examined. Other than the VLD group's comparatively greater difficulty with word discriminations, results of this investigation indicated no substantial differentiation of the reading disability subjects from the normal controls based on the behavioral psychophysical measures. However, the VEP measures of selective attention and speed of sensory processing reflected considerable differences between the clinical and normal groups. In addition, VEP attention effects were sensitive to differences in reading disabilities. The results indicate selective attention effects manifested in the VEP provide, in conjunction with the selective attention paradigm of this experiment, a particularly useful means of assessing the interrelationship between the perceptual and neurophysiological capacities of learning disability children.

Psychophysical Data

Unquestionably, in the usual classroom situation the LD child exhibits comparatively inferior performance on the joint perceptual and cognitive skills which are required to read proficiently. Although the visual discrimination tasks employed in this investigation required proficiency on many of these same perceptual skills, this disparity in performance between the reading disability and normal subjects did not prevail except where most expected. The VLD subjects, in contrast to the NC and ALD subjects, had significantly greater difficulty with the word discrimination problems in comparison to the other types of problems; no other statistically significant difference in psychophysically measured performance between the subjects occurred. Several explanations may be offered for the psychophysical measures' general insensitivity to individual subject differences in reading proficiency.

One explanation for this lack of differentiation is the possibility that performance on the investigated visual discrimination tasks, with exception of the word problems, does not reflect the prerequisite skills for which the LD child is lacking. Rozin, Poritsky, and Sotsky (1971) contend that reading problems are related to the child's ability to interpret cognitively a string of symbols rather than the ability to decode or recognize individual symbols. Blank and Bridger (1967) concur with this interpretation stating that the problem with the retarded reader is not the perceptual requirements of the task but rather the structuring of conceptual tasks involved with applying labels to abstract concepts. While these notions of the problem being related to higher order cognitive processes are feasible, there has been substantial data to suggest that a problem also exists at the lower perceptual processing level (Ayres, 1964; Frostig, Lefever, & Whittlesey, 1961; Gibson, 1969; Wold, 1969).

The perceptual task itself, rather than the level of cognitive processing, required in the present investigation may be the reason for the lack of group differences. This is substantiated to some extent by the findings of Williams and Ackerman (1971). In a study involving first-grade normal children it was observed that children could learn to discriminate and respond to very similar letters that are reversals of one another (b vs. d) more easily if the letters were presented successively rather than simultaneously. Katz and Wicklund (1972) who also used successive presentations to assess the scanning rate for letters of the alphabet found no significant difference in the task performance between good and poor readers. However, Spring and Hopkins (1972), used a discrimination task which involved the simultaneous presentation of pairs of letters and which required subjects to indicate whether or not letters were identical with a reaction time response. They found a significant between-subject difference in reaction times related to reading proficiency. It may be possible that in the case of very similar stimuli, successive presentations tend to reduce the confusion associated with such a discrimination. Additionally, analysis of the perceptual tasks involved in the typical reading situation suggests that presenting stimuli in a tachistoscopic, successive manner may be somwehat contrived. Perceptual skills entailed in reading are more related to discriminating letters embedded in words and words embedded in sentences, wherein the complexity and multitude of the stimuli would tend to amplify the difficulty of the individual discriminations. Since the present investigation employed successive rather than simultaneous presentations, where confusions might be kept at a minimum for the LD child, the absence of a relationship between reading proficiency and psychophysical performance is tenable.

The exceptionally high level of motivation across all subjects partaking in this investigation provides an additional explanation for there being minimal between-group differences in behavioral performance. By setting the response criteria and thus the rate of reinforcement in accordance with the individual child's capabilities, all children perceived their own performance as successful. Since all subjects were run on an individual basis, there were no failures. Goyen and Lyle (1971) also found no difference in performance between retarded and normal readers on a visual-associate learning task where incentives were imposed. Likewise, Toffler (1972) was able to increase the performance of children diagnosed as learning disabled and hyperactive on workbook assignment related tasks by means of behavior modification procedures.

In studies where differences in performance between disabled and normal readers have prevailed, one must query as to the differences in motivational levels of these children. If the LD child who has already a history of failures, frustrations and conditioned emotional responses associated with stimuli related to reading, shows inferior performance on a perceptual task employing many of these same stimuli, concluding that this child is perceptually handicapped may be very presumptuous in light of the child's past history of reinforcement. While the role of reinforcement in perceptual tasks is a major unresolved issue (Wohlwill, 1966), it,nevertheless, must be considered when one is attempting to designate individual differences in perceptual ability based on behavioral measures. If motivation levels are disparate, performance levels are surely to be differentially affected. In the area of learning disabilities, proper incentives and the attendent levels of motivated behavior have pervading implications not only to research involving performance measures, but more importantly, to the development of more effective remedial procedures.

Contingent Negative Variation

Regardless of what psychological parameters are implicated by the CNV response -- level of expectancy (Low et al., 1966; Walter et al., 1964), motivation (Irwin et al., 1966; Rebert, 1972), attention (Cohen & Walter, 1966; Pincton & Low, 1971; Tecce, 1971, 1972), or arousal (Tecce, 1971, 1972) -- the three groups of subjects did not differ significantly on any of these constructs based on the measures of CNV magnitude. This is contrary to the results of Fenelon (1968) who observed the disappearance of CNV activity in reading disabled children when the imperative stimulus consisted of reading-related materials such as words and trigrams. Just the opposite situation prevailed in the present investigation, wherein all subjects, including the reading disabled, gave significantly larger CNV responses to problems involving words compared to the color, line orientation, and letter problems. This discrepancy in results may be attributable to differences in motivational levels of the reading disability children between the two studies. Fenelon suggested that due to the negative connotations associated with the word and trigram stimuli, the reading disability child rejected these problems and thus showed reduced CNV activity. In the present study where high motivation levels were maintained across all problem types, CNV activity prevailed regardless of the nature of the stimuli. Other than the word problems possibly providing a more challenging and interesting task, no other explanation for the higher levels of CNV associated with the word problems is readily apparent.

In the present investigation an interesting relationship between CNV amplitude and behavioral response strategies prevailed which deserves some consideration in light of previous research findings. Besides the existence of a positive correlation between reaction time and CNV magnitude, CNV activity tended to covary with changes in overall response strategies across replications. As subjects tended to respond more impulsively with shorter reaction times and reduced accuracy in the later replications, the magnitude of their CNV also declined. Waszak and Obrist (1969) observed shorter reaction times associated with larger magnitude CNV within individual subject's data; Loveless (1973) found increased CNV amplitude and decreased reaction times when the S_1-S_2 interval was incremented, and Rebert (1972) observed only a tenuous relation between reaction time and CNV. While the relationship between the behavioral measures and CNV are equivocal and may be dependent on the specific characteristics of the particular CNV paradigm employed, the results of this and other investigations do suggest that CNV activity is reflecting more than just a motor response. The fact that the CNV is related to response sensitivity in terms of accuracy and speed lends some credence to the notion that the CNV response may be indicative of psychological and cognitive parameters.

Selective Attention

Sensitivity of the VEP to the effects of selective attention was clearly demonstrated across all children in this investigation. The peak-to-trough amplitude measures of the $\overline{N}200$ and $\overline{P}300$ components of the VEP were significantly amplified when the subject was requested to selectively respond to the eliciting S_{2rel}. These findings corroborate previous research (Donchin & Cohen, 1967; Eason et al., 1969; Harter & Salmon, 1972) which has found the differential responsiveness of the VEP as a function of selective attention in adults.

The VEP measures of selective attention indicated that the VLD group selectively attended more than the NC and ALD groups. These VEP measures suggest that some difference prevailed between the three groups which was not manifested in their overt behavioral performance. While the behavioral indices showed little difference between the groups, with the exception of the VLD subjects doing poorly on word discriminations, the VEP measures of selective attention suggest that the VLD group may have been compensating for their deficiencies by increased attentional states.

These findings also may be indicative of differences in motivation between the three groups. Previous research indicates that the magnitude of the attentional effects manifested in the VEP are related to differential states of arousal (Eason et al., 1969), or activation and preparation (Karlin, 1970; Naatanen, 1970). While an attempt was made to match the three groups in terms of motivational levels by the imposed behavioral contingencies, the VLD subjects may have been expending more effort than the other subjects to attain the same rate of reinforcement on the behavioral tasks. Additionally, CNV responses, which are indicative of levels of motivation (Irwin et al., 1966; Rebert, 1972; Waszak & Obrist, 1969) tended to be larger for the VLD group than the other two groups, although the differences did not reach statistical significance. It thus appears conceivable that the VLD subjects were working more intensely at the visual discrimination tasks than the other subjects which, in turn, may be related to the degree of their perceptual deficiency.

Of greater importance is the fact that the interpretation of these results is contrary to the findings of other investigators (Anderson et al., 1973; Dykman et al., 1970; Luria, 1961, 1966a, 1966b) which indicate attentional deficits in learning disability children. In the present investigation the ability to behaviorally discriminate words was the only indication of attentional deficits in the LD child. In fact, the LD child tended to show more discriminative attentional states as reflected in the VEP than the normal child. The VLD group indicated greater selective attention, as indicated by VEPs, and indicated inferior performance on only the word discrimination problems as indicated by d'. The data suggest, therefore, that the increased attention of the VLD group reflected a compensation for a deficit (a) located beyond the level of processing indicated by the VEPs, recorded from O_Z and C_Z, and involved in the discrimination of colors, line orientations, and letters, as measured behaviorally, but (b) located before the level of processing the discrimination of words, as indicated behaviorally. In light of the findings of this and other studies on attention, one must conclude that deficiencies in LD children may not be attributed to attentional processes but rather to motivational or other deficits.

The magnitude of the selective attention difference in the VEP recorded from the occiput was sensitive to the difficulty of the visual discrimination problem as indicated by the behavioral response accuracy measures. Problems involving color discriminations resulted in the greatest selective attention effects on the VEP components as well as the most discriminative behavioral responses in terms of d' scores. Similar effects were observed in the study of Harter and Salmon (1972) which found selective attention effects on the VEP to be greatest when colors were discriminated and when the behavioral performance was most proficient. Also, VEP selective attention effects were related to replications, with greatest response differentiation both in terms of VEP differences and response accuracy scores occurring on the first replication. The covariation between behavioral performance and VEP attentional changes as a function of the independent variable manipulations of the investigation are quite consistent. The relationship between behavioral and electrophysiological levels of response differentiation emphasizes the importance for interpretation of collecting concomitant psychophysical and electrophysiological data.

While the changes in the VEP components as a function of selective attention prevailed at both the vertex and the occiput, the vertex recordings were not as responsive to the other parametric manipulations of the investigation. The magnitude of the selective attention effects on the VEPs from the vertex were not sensitive to the imposed problem and replication effects. The differential sensitivity of the vertex and occiput recordings may be related to the findings of Lehtonen (1973) which suggest that the $\overline{N}200$ and $\overline{P}300$ components from the two electrode locations represent separate physiological processes. Further data are required under the present independent variable manipulations before such a conclusion can be put forth.

While there was a significant separation of groups based on the effects of attention in the VEPs, the importance of finding selective attention processes manifested in the VEP of children classified into various clinical populations is a noteworthy observation in and of itself. Since the components of the VEP, when recorded under the appropriate behavioral conditions, are sensitive to attentional variables in an experimentally naive subject population of children with clinical disorders, the potential for assessing the neurophysiological information processing capacities of clinical populations becomes very apparent. By being able to identify selective attention properties by a specific VEP component, one is able to investigate further cognitive processes in various clinical situations. Also, interpretation of differences between clinical populations in terms of behavioral performance and neurophysiological responsiveness as reflected in the VEP becomes more compelling. Advantages of a selective attention paradigm when investigating differences between clinical populations cannot be overemphasized. Not only is one able to control the motivational and attentional levels of all subjects while acquiring the data, but one is also afforded with the interrelationships between the behavioral and physiological indices required for the meaningful interpretation of the data. Moreover, many clinical disorders are related to attentional processes which makes such a task particularly relevant.

VEP Latency

The latency measures of the $\overline{P}300$ VEP component significantly differentiated the three groups of subjects. Given that the $\overline{P}300$ component is involved with selective attention processes in the visual discrimination task, it may be concluded that the rate of this sensory processing is significantly slower for the reading disability subjects compared to the normals in the present study. These findings are concordant with the electrophysiological observations of Shields (1973) who found LD children in comparison to normals had longer latency VEP components.

These differences in latencies suggest that one source of the LD child's problem may be the inability to process sensory information rapidly. Rapid sequential processing obviously is required of a proficient reader. This contention has been substantiated in a visual masking study by Stanley and Hall (1973) which found reading disabled children required longer interstimulus intervals before being able to temporally distinguish two sequential stimuli. Likewise, Guthrie and Goldberg (1972), after reviewing the literature, have intimated sequential processing of visual information as a problem in the LD child.

While a significant difference between clinical groups prevailed for the VEP latency measures, these differences were not reflected in the behavioral reaction times of the subjects. Additionally, since the actual difference in processing time between groups was relatively small when compared to the total processing time (12.9 msec: 300 msec = 4.3%), this latency measure difference may be more symptomatic of the problem than the actual problem itself. The longer VEP latencies in the LD child may be indicative of a maturational lag in the visual nervous system. Numerous investigations (Crutzfeld & Kuhnt, 1967; Ellingston, 1960; Harter & Suitt, 1970; Weinmann, Crutzfeld, & Heyde, 1965) have shown differences in the latencies of VEP components related to age and maturational development. Similarly, Hunter, Johnson, and Keefe (1972) concluded that reading disability children have physiologically less mature nervous systems on the bases of a battery of psychophysiological responses in LD children recorded under orienting and habituating stimulation conditions. This finding in conjunction with the results of the present study suggest that the neurophysiological immaturity may be quite diffuse in effect. However, if the comparatively longer latencies found in the VLD child are restricted to the visual system, while other sensory pathways operate at standard processing rates, the reading disability may be related to a dysynchrony in the multiple modes of sensory input.

Sensory Interactions

The question of there being a sensory specific deficit (auditory vs. visual) in the reading disability child can be viewed in light of the present data which yielded significant between-group differences. The VLD group tended to be expending more effort into the visual discrimination tasks, as indicated by the VEP measures of selective attention, than either the NC or ALD groups. Since the measures of selective attention in the NC and ALD groups were not significantly different, the differences in selective attention tend to support the notion of a sensory specific deficit.

The VEP latency measures, on the other hand, do not provide such a clear cut separation of the three groups. VEP recordings from the occiput, which tend to be more indicative of primary visual processing than recordings from the vertex, indicated that while the VLD subjects had significantly longer VEP latencies than the NC subjects, the ALD group's latencies were at intermediate levels, not significantly different from either the NC or the VLD group. However, the VEPs recorded from the vertex, which may be more indicative than the occiput of higher order sensory processing and where a number of sensory modalities interact, significantly differentiated the NC group from both the ALD and the VLD groups. The ALD and VLD groups were not significantly different. The extent to which a distinction between the VEPs from the vertex and occiput in terms of primary and secondary sensory processing is valid is directly related to whether or not the VEP latency measures indicate a sensory specific deficit.

While the notion of modality specific deficits is far from definite based on the present study's findings, the VEP measures of selective attention and component latencies are amenable to such an interpretation. The separation of reading disability children according to modality specific perceptual capacities by the Slingerland Screening Test is concordant with the VEP measures which indicated between-subject differences. An investigation similar to the present, except for employing auditory rather than visual stimuli, would address this question of sensory specific deficits directly.

Conclusions

A summary of the dependent measures assessed in the present investigation as they reflect differences between the three groups of subjects is presented in Figure 13. While behavioral performance (d' and MRT) on the visual discrimination tasks of this study did not differentiate the subjects according to their diagnosed reading disabilities, several of the VEP measures indicated differences among the children. Latency measures of the VEP components suggest that the LD child has a predisposition for processing sensory information at a slower rate of speed than the normal child, which may be indicative of an immature nervous system. Measures of selective attention, as evidenced in the VEP, indicate that the LD child required a more intense effort than the normal child to complete the visual discrimination tasks at the same level of proficiency. Reasons for the LD child not showing greater differences in behavioral performance in light of the neurophysiological differences manifested in the VEP may be attributed to the nature of the prescribed perceptual task or to the unusually high levels of motivation.

If the lack of between-subject differentiation in behavioral performance is attributable to the nature of the perceptual task, several alternative tasks could be suggested. Since several investigators (Brod & Hamilton, 1973; Wold, 1969) have implicated binocular interactions as a possible problem in the reading disability syndrome, psychophysical and electrophysiological indicants of binocular rivalry and summation might prove to be very discriminative. Parametric investigations employing sequential information processing tasks which would provide psychophysical and electrophysiological indicants of temporal processing and visual masking may also be fruitful in light of the observed differences in VEP latencies. Regardless of the actual perceptual tasks employed to ascertain the differences between children with various levels of reading proficiency, such future endeavors will require a multivariate, behavioral-electrophysiological approach due to the multifaceted, subtle nature of the reading disability problem.

If the lack of differentiation in behavioral performance between children with various levels of reading proficiency on a reading-related perceptual task is attributable to motivational variables, this has pervading implications for remedial and educational procedures. The fact that a reading disability child cannot compete with children of the same age in reading-related tasks in the typical classroom situation, yet shows minimal differences in performance in the laboratory where he is performing similar tasks on an individual basis under highly motivating conditions, suggests that this child's problem may be compounded by his present educational environment. While the reading disability child may have a predisposition to have difficulty with reading, this problem may be amplified in the usual classroom environment where performance, on a comparative basis, is low, frustration is high, and reinforcement is low. It appears imperative that procedures be established wherein performance and learning is individually paced under a contingency management system, so that the child, regardless of his level of proficiency, will be optimally motivated to succeed.

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Appendix of Tables and Figures

Table 1

Experimental Design

Order / Subjects	1	2	3	4	5	6	7	8
	(Replication 1)				(Replication 2)			
	8	7	6	5	4	3	2	1
	(Replication 4)				(Replication 3)			
S_1 & S_2	Red	Vert.	b	was	saw	d	Horiz.	Green
S_3 & S_4	Vert.	Red	was	b	d	saw	Green	Horiz.
S_5 & S_6	b	was	Red	Vert.	Horiz.	Green	saw	d
S_7 & S_8 & S_9	was	b	Vert.	Red	Green	Horiz.	d	saw

Table 2

Summary of Visual Screening Results

SUBJECTS	BINOCULAR ACUITY	RIGHT-EYE ACUITY	LEFT-EYE ACUITY	LATERAL PHORIA	VERTICAL PHORIA	COLOR BLINDNESS	VER SPHERICAL ERROR
NC-1	20:20	20;20	20:20	NO	NO	NO	0
NC-2	20:25	20:25	20;20	NO	NO	NO	-1
NC-3	20:25	20:20	20:29	NO	NO	NO	-1
NC-4	20:20	20:20	20:20	Esophoric	NO	NO	0
NC-5	20:20	20:20	20:20	NO	NO	NO	0
NC-6	20:20	20:20	20:22	NO	NO	NO	0
NC-7	20:18	20:20	20:20	NO	NO	NO	0
NC-8	20:20	20:29	20:20	NO	NO	NO	0
NC-9	20:20	20:20	20:20	NO	NO	NO	0
VLD-1	20:29	20:29	20;25	Esophoric	NO	NO	-1
VLD-2	20:20	20:20	20:20	NO	NO	NO	0
VLD-3	20:29	20:25	20;25	Exophoric	NO	NO	-½
VLD-4	20:20	20:20	20:20	NO	NO	NO	0
VLD-5	20:18	20:20	20:20	NO	NO	NO	0
VLD-6	20:20	20:20	20:20	NO	NO	NO	0
VLD-7	20:20	20:20	20:20	NO	NO	NO	0
VLD-8	20:20	20:20	20:20	NO	NO	NO	0
VLD-9	20;20	20:20	20:20	NO	NO	NO	0
ALD-1	20;20	20:20	20:20	NO	NO	NO	0
ALD-2	20:20	20:20	20:20	NO	NO	NO	0
ALD-3	20;29	20:25	20:29	NO	NO	NO	-1
ALD-4	20:20	20;20	20:20	NO	NO	NO	0
ALD-5	20:29	20:25	20:29	NO	NO	NO	-1
ALD-6	20:20	20:20	20:20	NO	NO	NO	0
ALD-7	20:20	20:20	20:20	NO	NO	NO	0
ALD-8	20;29	20;29	20:29	NO	NO	NO	-2
ALD-9	20;20	20;20	20:20	NO	NO	NO	0

Table 3

Summary of Multivariate Analysis of Variance

Source of Variance	Log. Gen. Variance	df	Approx. F	Prob.
Group	135.441	24, 26	2.587	.01
S (G)	148.616			
Problem	135.447	36, 181	22.150	.01
G x P	132.737	72, 338	1.189	
S x P (G)	137.339			
Replication	133.282	36, 181	3.991	.01
G x R	133.190	72, 338	1.630	.01
S x R (G)	138.595			
P x R	132.716	108, 1505	1.201	
G x P x R	132.247	216, 2086	1.154	
S x P x R (G)	132.114			

Dependent Variables:

- d'
- MRT
- RTC
- $CNVO_z$
- $CNVC_z$
- $DAEO_z$
- $DAEC_z$
- $DAEO_zNP$
- $DAEC_zNP$
- O_zLAT
- AGE

Table 4

Simple Main Effects of Problem Type Within Replications for Psychophysical Response Accuracy (d')

	PROBLEMS				Simple Main Effects
	color	lines	letters	words	
Rep. One					
Mean	2.009	1.816	1.052	1.205	p = .01
Var.	1.079	1.373	.578	.942	
color	-----	N.S.	p = .01	p = .01	
lines		------	p = .01	p = .01	
letters			------	N.S.	
words				------	
Rep. Two					
Mean	1.366	.932	.508	.569	p = .01
Var.	.785	.509	.457	.359	
color	------	p = .05	p = .01	p = .01	
lines		-------	N.S.	p = .05	
letters			-------	N.S.	
words				-------	
Rep. Three					
Mean	1.179	.745	.547	.487	p = .01
Var.	.763	.809	.479	.237	
color	-------	p =. 05	p = .01	p = .01	
lines		-------	N.S.	N.S.	
letters			-------	N.S.	
words				-------	
Rep. Four					
Mean	1.063	.996	.578	.800	p = .05
Var.	.920	1.097	.414	.706	
color	-------	N.S.	N.S.	p = .05	
lines		-------	N.S.	N.S.	
letters			-------	N.S.	
words				-------	

Table 5

Simple Main Effects of Replication Within Problem Type for

Psychophysical Response Accuracy (d')

	REPLICATIONS				Simple Main Effects
	One	Two	Three	Four	
Colors					
Mean	2.009	1.366	1.179	1.063	p = .01
Var.	1.079	.785	.763	.920	
Rep. One	-------	p = .01	p = .01	p = .01	
Rep. Two		-------	N.S.	N.S.	
Rep. Three			-------	N.S.	
Rep. Four				-------	
Lines					
Mean	1.816	.932	.745	.996	p = .01
Var.	1.373	.509	.809	1.097	
Rep. One	-------	p = .01	p = .01	p = .05	
Rep. Two		-------	N.S.	N.S.	
Rep. Three	----		-------	N.S.	
Rep. Four				-------	
Letters					
Mean	1.052	.508	.574	.578	N.S.
Var.	.578	.457	.479	.414	
Rep. One	-------	N.S.	N.S.	N.S.	
Rep. Two		-------	N.S.	N.S.	
Rep. Three			-------	N.S.	
Rep. Four				------	
Words					
Mean	1.205	.569	.487	.800	p = .05
Var.	.942	.359	.237	.706	
Rep. One	-------	p = .05	p = .05	N.S.	
Rep. Two		-------	N.S.	N.S.	
Rep. Three			-------	N.S.	
Rep. Four				-------	

Table 6

Simple Main Effects of Problem Type Within Groups for

Psychophysical Response Accuracy (d')

	PROBLEMS				Simple Main Effects
	color	lines	letters	words	
Normal Gp.					
Mean	1.587	1.117	.567	.980	p = .001
Var.	.794	.880	.292	.582	
color	-------	p = .01	p = .001	p = .01	
lines		-------	p = .01	N.S.	
letters			-------	N.S.	
words				-------	
VLD Gp.					
Mean	1.537	1,407	.778	.776	p = .001
Var.	.800	1.180	.414	.843	
color	-------	N.S.	p = .01	p = .01	
lines		-------	p = .01	p = .01	
letters			-------	N.S.	
words				-------	
ALD Gp.					
Mean	1.089	.843	.689	.539	p = .01
Var.	1.317	1.128	.861	.393	
colors	-------	N.S.	p = .05	p = .01	
lines		-------	N.S.	N.S.	
letters			-------	N.S.	
words				-------	

Table 7

Main Effect of Problem Type on CNV Responses

	PROBLEMS			
	color	lines	letters	words
CNV-Oz				
Mean*	458.8	495.8	460.5	533.9
S.D.*	267.0	235.3	207.3	226.4
color	------	N.S.	N.S.	p = .01
lines		-------	N.S.	p = .05
letters			-------	p = .01
words				-------
CNV-Cz				
Mean*	374.2	361.0	360.7	411.3
S.D.*	248.1	143.2	166.2	154.1
color	-------	N.S.	N.S.	p = .05
lines		-------	N.S.	p = .05
letters			-------	p = .05
words				-------

* CNV measures in units of microvolts·msec
(See text)

Table 8

Simple Main Effects of Problem Type Within Replications for

VEP Attentional Differences ($DAEO_2NP$)

	PROBLEMS				Simple Main Effects
	color	lines	letters	words	
Rep. One					
Mean*	4.433	1.332	1.309	1.737	p = .01
S.D.*	4.204	5.987	2.770	3.546	
color	-------	p = .01	p = .01	p = .01	
lines		-------	N.S.	N.S.	
letters			-------	N.S.	
words				-------	
Rep. Two					
Mean*	.647	.674	1.633	1.478	N.S.
S.D.*	2.832	4.741	2.892	2.960	
color	-------	N.S.	N.S.	N.S.	
lines		-------	N.S.	N.S.	
letters			-------	N.S.	
words				-------	
Rep. Three					
Mean*	.311	.091	.907	1.193	N.S.
S.D.*	2.815	4.942	4.141	5.195	
color	-------	N.S.	N.S.	N.S.	
lines		-------	N.S.	N.S.	
letters			-------	N.S.	
words				-------	
Rep. Four					
Mean*	2.826	1.478	.215	-.221	p = .01
S.D.*	3.789	2.841	4.302	4.666	
color	-------	N.S.	p = .01	p = .01	
lines		-------	N.S.	N.S.	
letters			-------	N.S.	
words				-------	

* VEP measures in units of microvolts (see Text)

Table 9

Simple Main Effects of Replication Within Problem Type for

VEP Attentional Differences ($DAEO_zNP$)

	REPLICATIONS				Simple Main Effects
	One	Two	Three	Four	
Colors					
Mean*	4.433	.647	.311	2.826	p = .01
S.D.*	4.204	2.832	2.815	3.789	
Rep. One	-------	p = .01	p = .01	N.S.	
Rep. Two		-------	N.S.	p = .01	
Rep. Three			-------	p = .01	
Rep. Four				-------	
Lines					
Mean*	1.332	.674	.091	1.478	N.S.
S.D.*	5.987	4.741	4.942	2.841	
Rep. One	-------	N.S.	N.S.	N.S.	
Rep. Two		-------	N.S.	N.S.	
Rep. Three			-------	N.S.	
Rep. Four				-------	
Letters					
Mean*	1.309	1.633	.907	.215	N.S.
S.D.*	2.770	2.829	4.141	4.302	
Rep. One	-------	N.S.	N.S.	N.S.	
Rep. Two		-------	N.S.	N.S.	
Rep. Three			-------	N.S.	
Rep. Four				-------	
Words					
Mean*	1.737	1.478	1.193	-.221	N.S.
S.D.*	3.546	2.960	5.195	4.666	
Rep. One	-------	N.S.	N.S.	N.S.	
Rep. Two		-------	N.S.	N.S.	
Rep. Three			-------	N.S.	
Rep. Four				-------	

* VEP measures in units of microvolts (see Text)

Table 10

Intercorrelation Matrix for 12 Variables with Associated Probabilities

VARIABLES	MRT	d'	RTC	CNVOz	CNVCz	DAEOz	DAECz	OzLAT	CzLAT	DAE OzNP	DAE CzNP	AGE
MRT	1.000											
	.000											
d'	.402	1.000										
	.000	.000										
RTC	.551	.084	1.000									
	.000	.076	.000									
CNVOz	.223	.134	.170	1.000								
	.000	.006	.001	.000								
CNVCz	.174	.100	.274	.659	1.000							
	.001	.036	.000	.000	.000							
DAEOz	.221	.112	.207	.457	.442	1.000						
	.000	.019	.000	.000	.000	.000						
DAECz	.106	.067	.173	.261	.419	.570	1.000					
	.026	.167	.001	.000	.000	.000	.000					
OzLAT	.035	.025	.128	.045	.081	.059	.060	1.000				
	.481	.608	.008	.349	.090	.216	.210	.000				
CzLAT	.197	.018	.276	.026	.129	.169	.107	.765	1.000			
	.000	.790	.000	.596	.007	.001	.024	.000	.000			
DAEOzNP	.045	.106	.054	-.040	.028	.074	.012	-.006	.012	1.000		
	.348	.026	.261	.416	.574	.119	.802	.895	.788	.000		
DAECzNP	.067	.080	.183	.049	.157	.104	.146	.061	.116	.140	1.000	
	.162	.092	.000	.308	.001	.029	.003	.201	.015	.004	.000	
AGE	-.300	.034	-.570	-.217	-.246	-.186	-.065	-.016	-.180	-.059	-.087	1.000
	.000	.490	.000	.000	.000	.000	.172	.744	.000	.215	.068	.000

Table 11

Varimax Rotated Factor Matrix

Variables	Factor One	Factor Two	Factor Three	Factor Four	Factor Five
MRT	.75608	.48515	.11561	.06796	-.01185
d'	.91189	-.10863	.08418	-.00110	.09164
RTC	.19232	.83411	.13798	.15494	.11176
CNVOz	.12323	.15948	.75627	-.05381	-.18341
CNVCz	.02293	.20585	.79699	.03217	.00650
DAEOz	.08913	.06817	.77983	.07728	.11609
DAECz	-.00918	-.05299	.72713	.07981	.18040
OzLAT	.00588	-.02452	.03947	.94026	-.00864
CzLAT	.03943	.18242	.07032	.92055	.04837
DAEOzNP	.10116	.00127	-.03873	-.05572	.76159
DAECzNP	-.02627	.11319	.13738	.08852	.69995
AGE	.07103	-.86576	-.12897	-.00482	-.03645

Table 12

Summary of Significant Univariate Effects

Dependent Measures	MRT	d'	RTC	CNVOz	CNVCz	DAEOz	DAECz	DAEOzNP	DAECzNP	OzLAT	CzLAT
Group (G)	N.S.	N.S.	N.S.	N.S.	N.S.	$p < .018$[1]	$p < .002$[2]	$p < .048$[3]	N.S.	$p < .045$[4]	$p < .004$[5]
Problem (P)	N.S.	$p < .001$[6]	N.S.	$p < .001$[7]	$p < .034$[8]	N.S.	N.S.	$p < .017$[9]	N.S.	N.S.	N.S.
Replica. (R)	$p < .001$[10]	$p < .001$[11]	N.S.	$p < .002$[12]	N.S.	N.S.	N.S.	$p < .003$[13]	N.S.	N.S.	N.S.
G x P	N.S.	$p < .044$[14]	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
G x R	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
P x R	N.S.	$p < .042$[15]	N.S.	N.S.	N.S.	N.S.	N.S.	$p < .001$[16]	N.S.	N.S.	N.S.
G x P x R	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

NOTE:

1. VLD > ALD, NC
2. VLD > ALD, NC
3. VLD > ALD, NC
4. VLD > NC (VLD-$\overset{>}{ns}$-ALD; ALD-$\overset{>}{ns}$-NC)
5. VLD, ALD > NC
6. color > line orient. > letters, words
7. words > colors, line orient., letters
8. words > colors, line orient., letters
9. color > line orient, letters, words
10. Rep One < Rep Two < Rep Three, Rep Four
11. Rep One < Rep Two, Rep Three, Rep Four
12. Rep One > Rep Two, Rep Three, Rep Four
13. Rep One > Rep Two, Rep Three, Rep Four
14. (See Table 6)
15. (See Tables 4 and 5)
16. (See Tables 8 and 9)

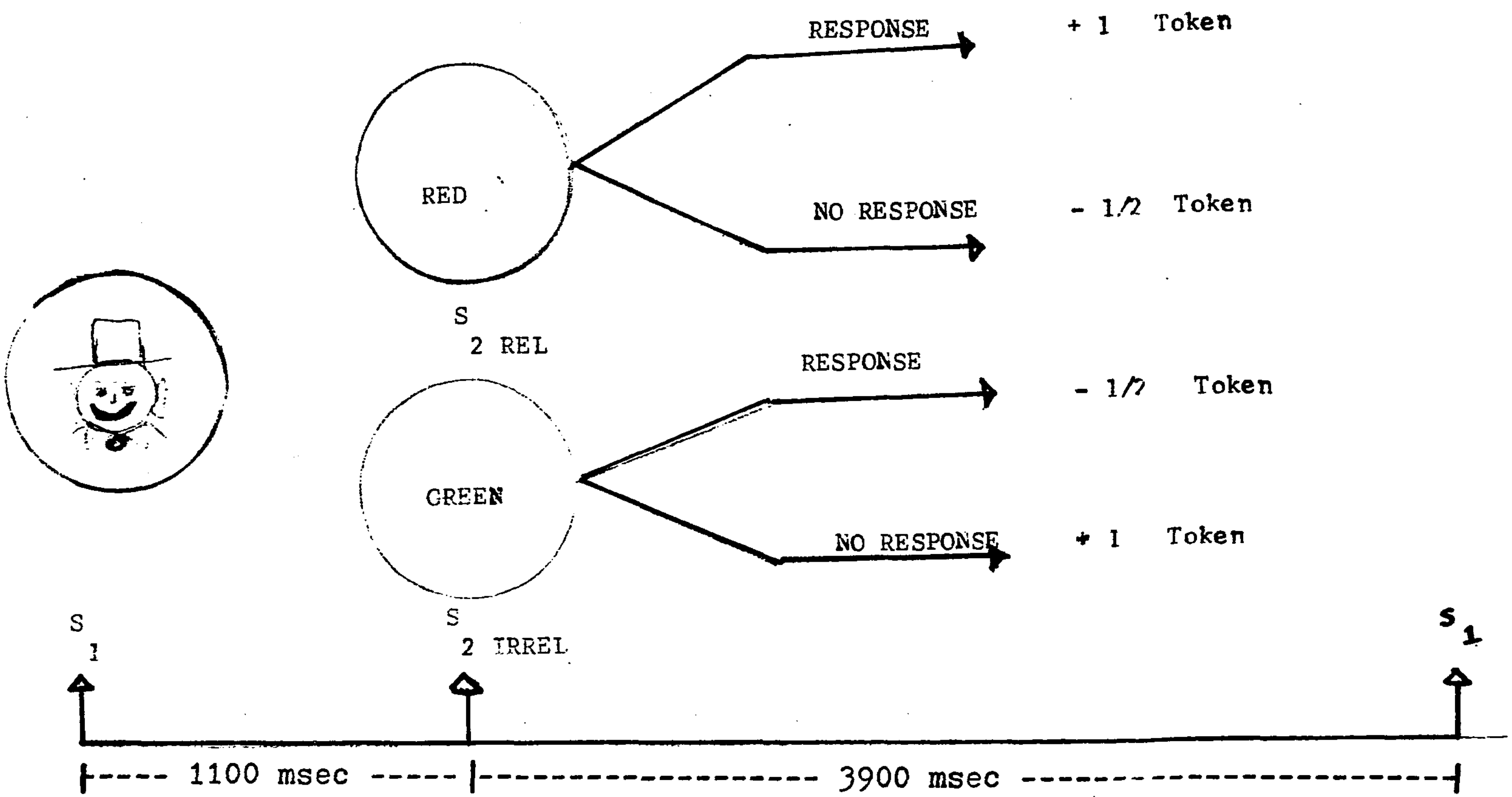
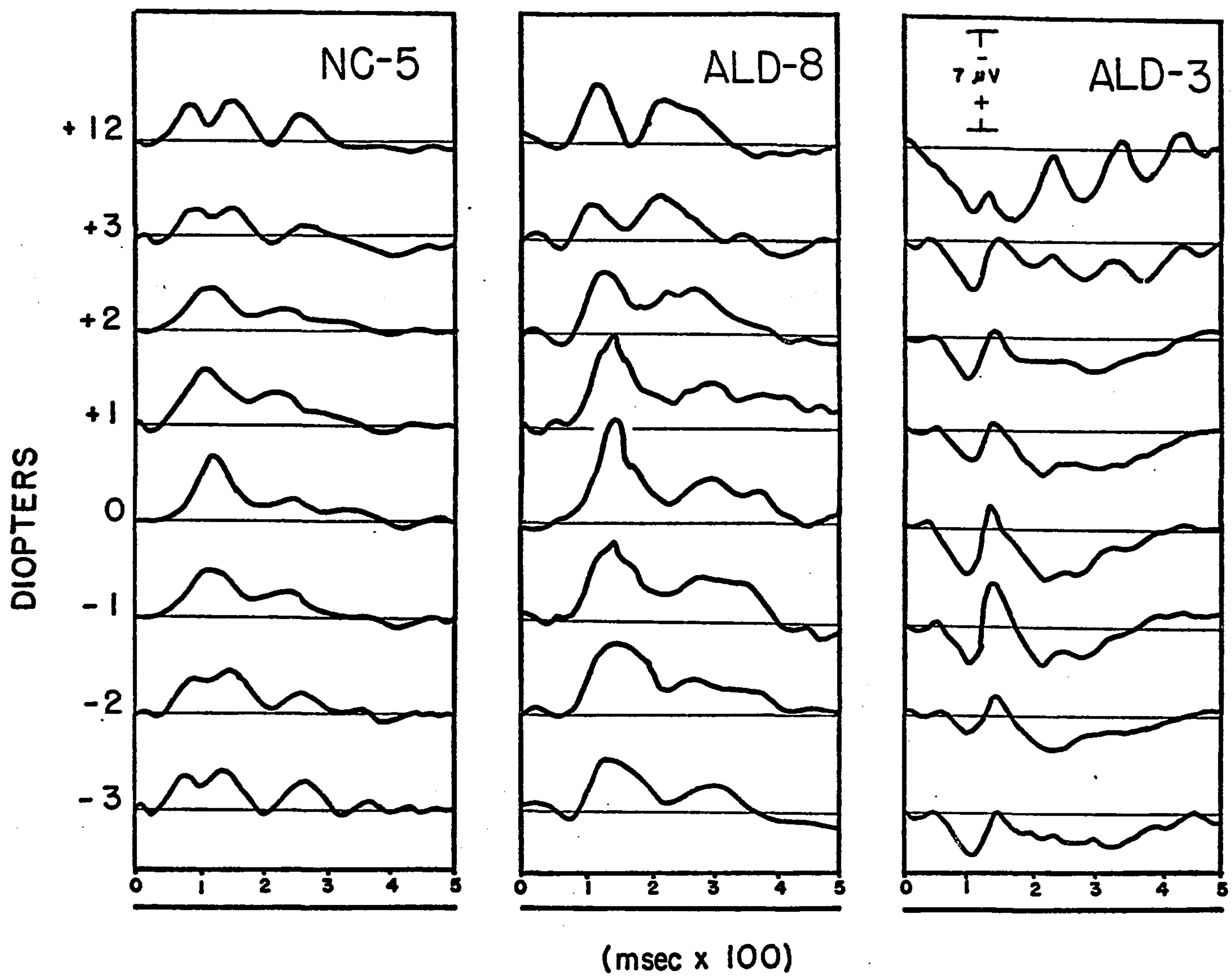


Figure 1. Schematic representation of an experimental trial.

Figure 2. Averaged evoked cortical potentials from subjects NC-5, ALD-8, and ALD-3 as a function of induced refractive error. Spherical lenses of +12, +3, +2, +1, 0, -1, -2, and -3 diopters were employed while 100 responses to a transient checkerboard patterned stimulus were accumulated in a counterbalanced order for each evoked potential.


NC-5
ALD-8
ALD-3
7 μV
+
+12
+3
+2
+1
0
-1
-2
-3
DIOPTERS
0 1 2 3 4 5
0 1 2 3 4 5
0 1 2 3 4 5
(msec x 100)

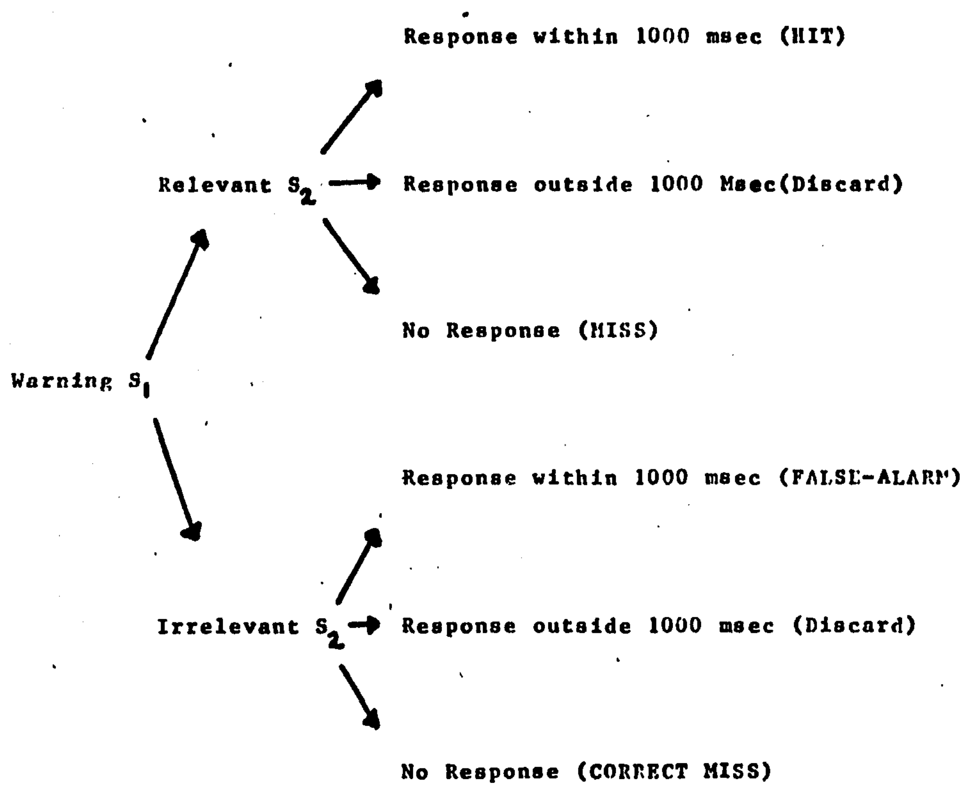


Figure 3. Classification of response outcomes used for the determination of the psychophysical indices.

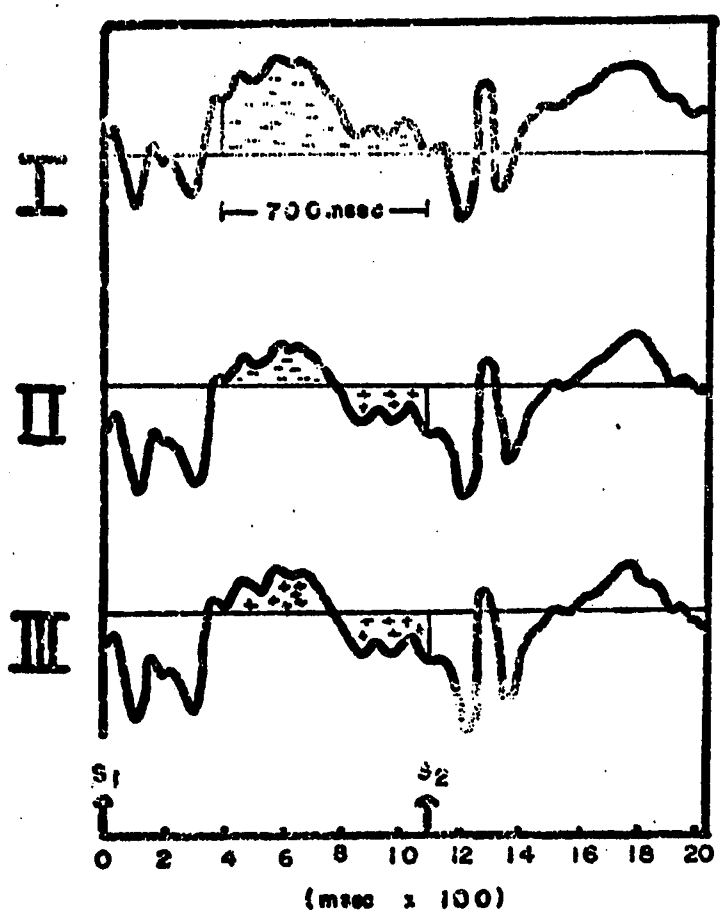


Figure 4. Determination of the integrated CNV measure for the evoked cortical response recorded from the occiput of subject NC-5. Phase I entails determination of the arithmetic integrated voltage of the 700 msec interval prior to S_2. Phase II requires setting a baseline voltage level so that the averaged arithmetic integrated voltage of the 700 msec epoch is equal to zero. Phase III yields the CNV measure which is equal to the absolute integrated voltage of the 700 msec interval expressed in units of microvolts·msec.

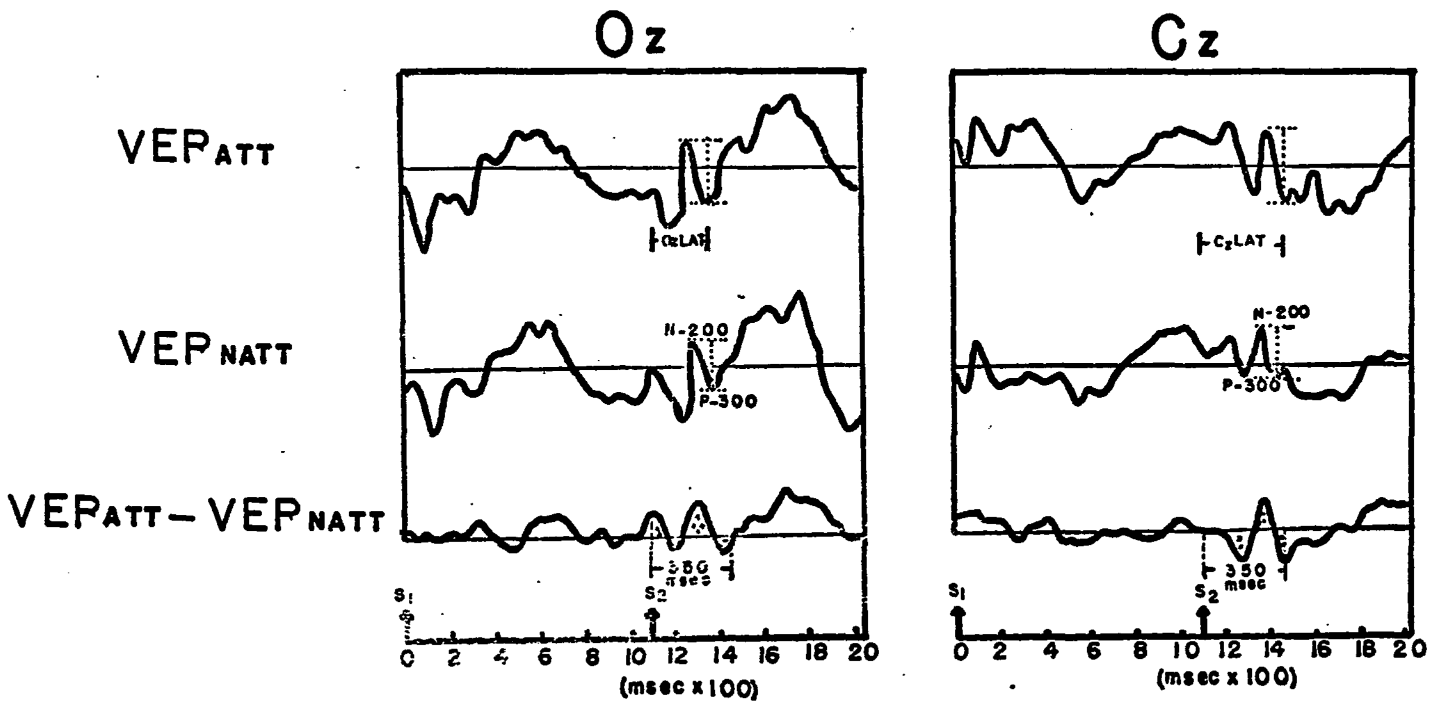


Figure 5. Determination of the VEP attentional measures from the evoked responses obtained from a given problem for subject NC-5. To determine the peak-to-trough attentional measures ($DAEO_zNP$ and $DAEC_zNP$): (1) measure the peak-to-trough amplitude of the $\overline{N}$-200 and $\overline{P}$-300 VEP components for both the attended and nonattended stimuli; (2) compute the differences in amplitude attributable to selective attention by subtracting the amplitude of VEP_{natt} from the amplitude of VEP_{att}. To determine the integrated attentional measures ($DAEO_z$ and $DAEC_z$): (1) set the baseline voltage level established in the CNV measure determination; (2) subtract VEP_{natt} from VEP_{att}; (3) from this difference response determine the absolute integrated voltage of the 350 msec epoch following the presentation of S_2.

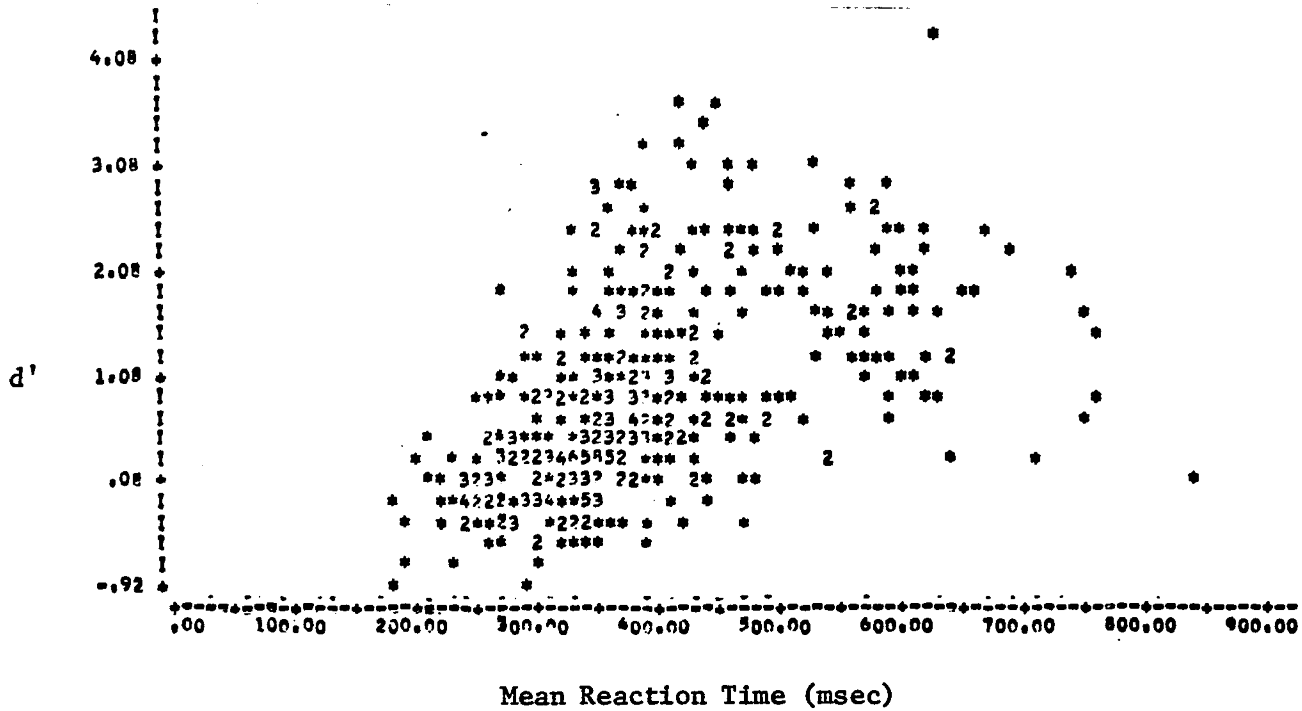


Figure 6. Psychophysical response accuracy (d') as a function of mean reaction time (MRT). Plot contains the data from 27 subjects' 16 separate problems. Numbers within the graph indicate multiple points on a given d'-MRT coordinate.

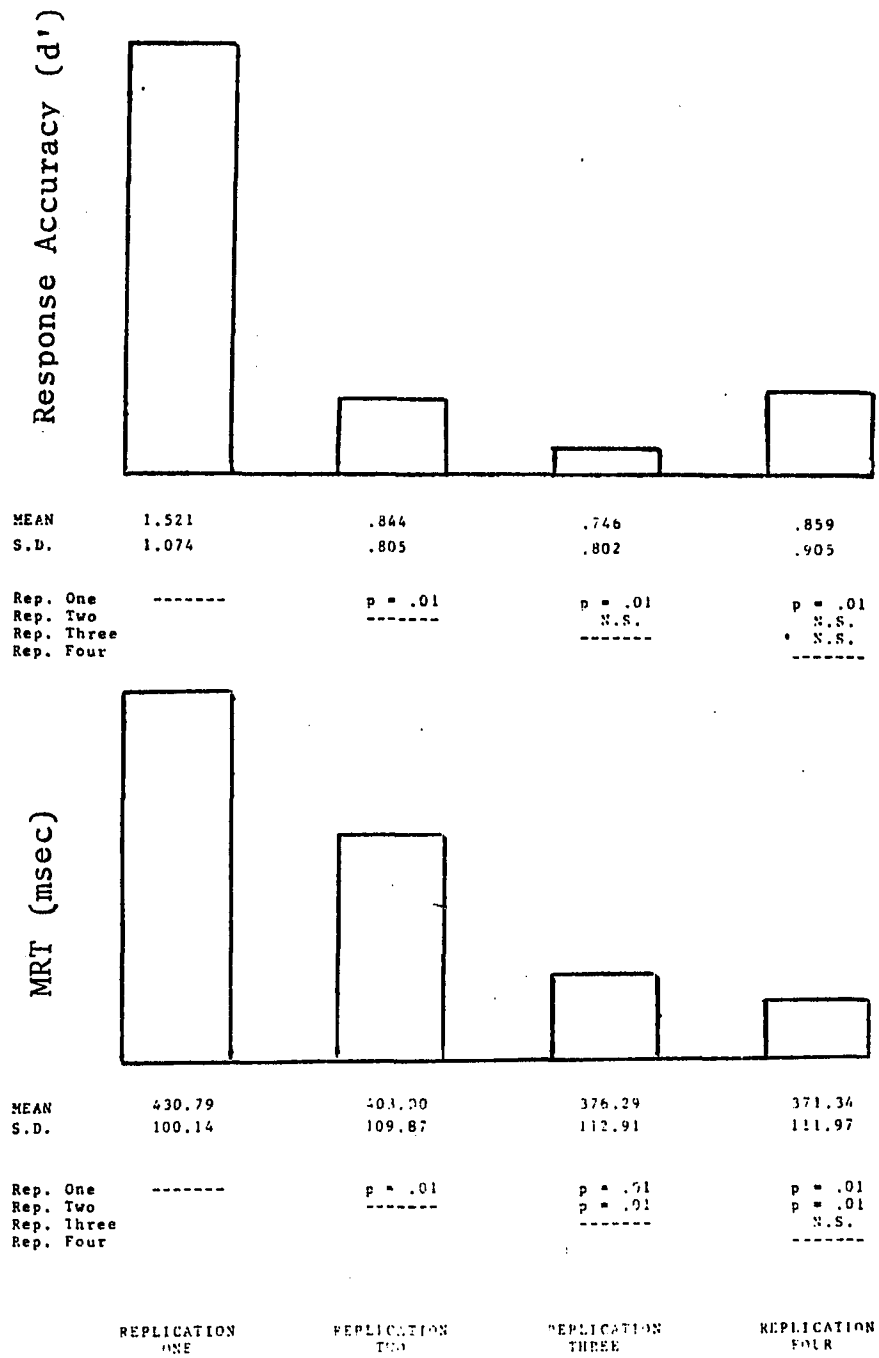


Figure 7. The effects of replication on response accuracy (d') and speed (MRT). Values for each dependent variable are averaged across all subjects and problem types. The results of Newman-Keuls post-hoc tests are also included.

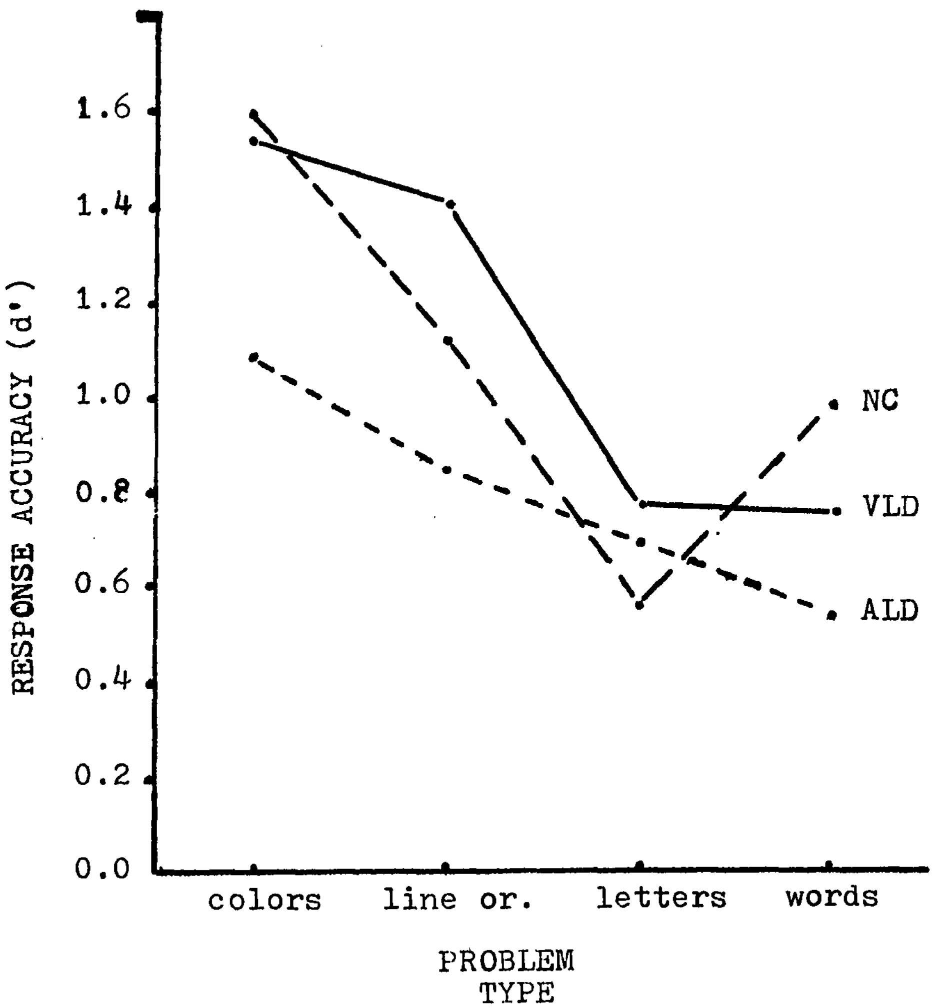


Figure 8. Psychophysical response accuracy (d') as a function of problem type for each of the three groups: NC, ALD, and VLD.

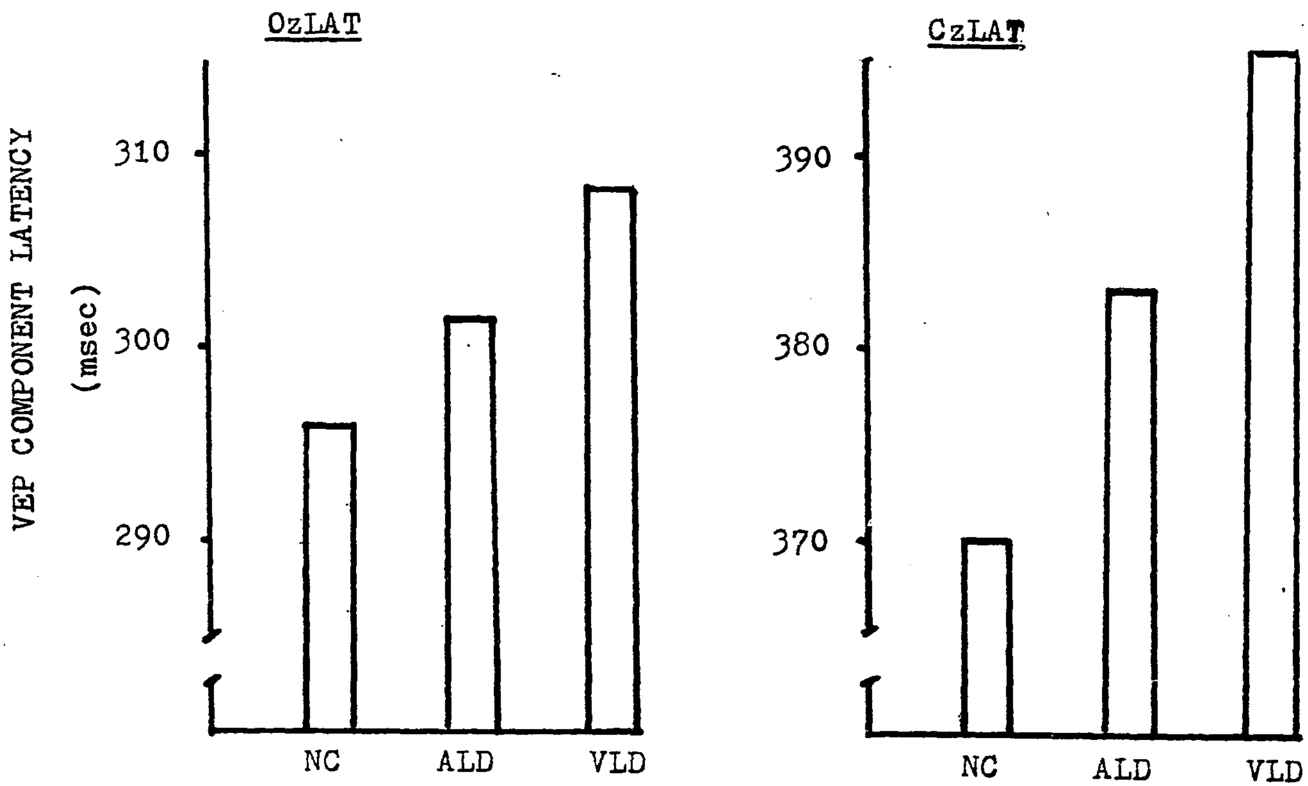


Figure 9. Mean latencies of the $\overline{P}300$ components recorded from the occiput (O_ZLAT) and vertex (C_ZLAT) for each of the three reading disability groups (NC, ALD, and VLD).

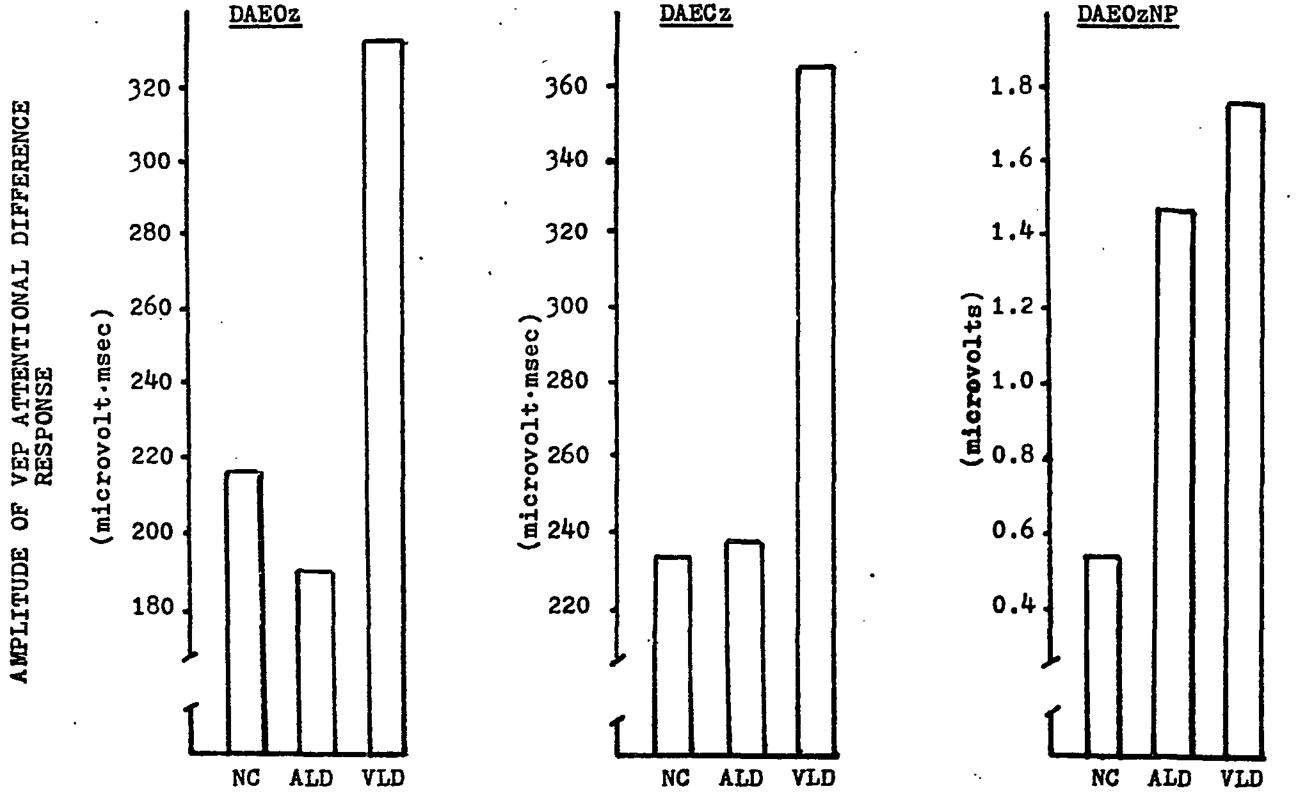


Figure 10. Group means for three of the VEP measures of selective attention which significantly differentiated the three reading disability groups (NC, ALD, and VLD). Definition of the VEP measures recorded from both the occiput ($DAEO_Z$ and $DAEO_ZNP$) and the vertex ($DAEC_Z$) may be found in the text.

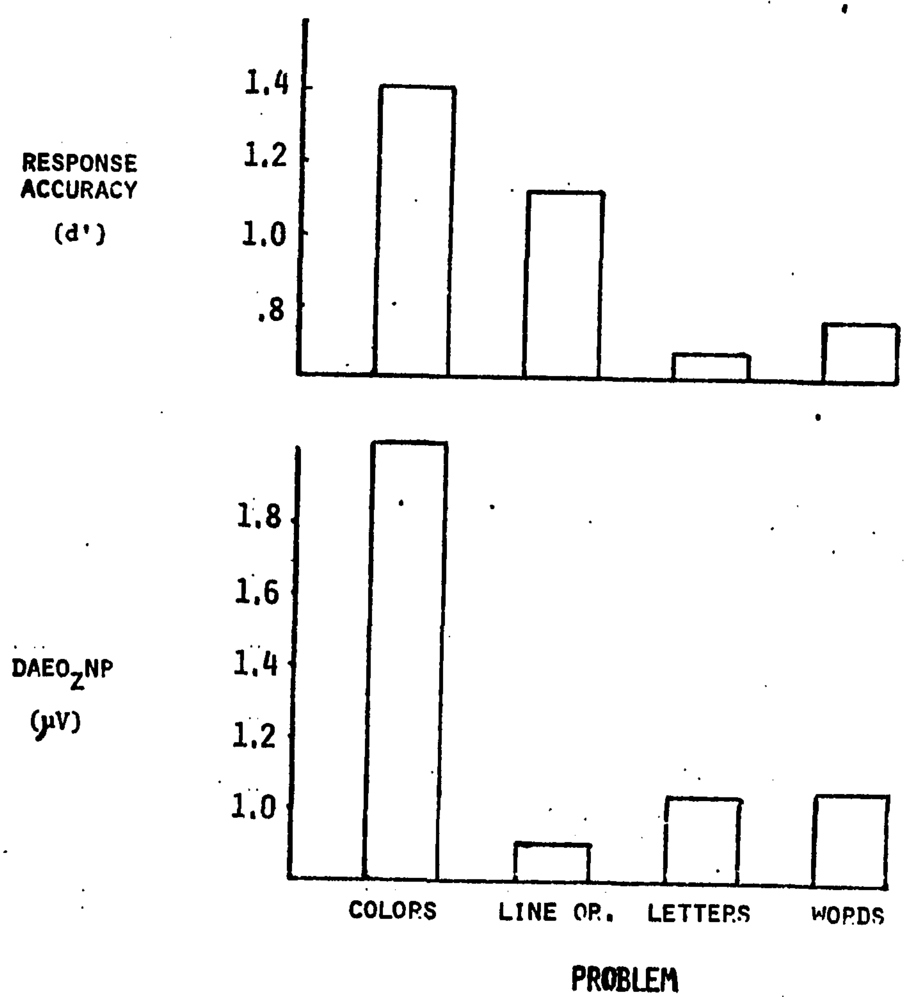


Figure 11. The effects of problem type on behavioral (d') and electrophysiological ($DAEO_ZNP$) response differentiation -- in terms of selective attention. $DAEO_ZNP$ is the difference in the peak-to-trough amplitude measures of the VEP recorded from the occiput as a function of selective attention, while d' represents psychophysical response sensitivity. Graphed values are averaged across all subjects and replications.

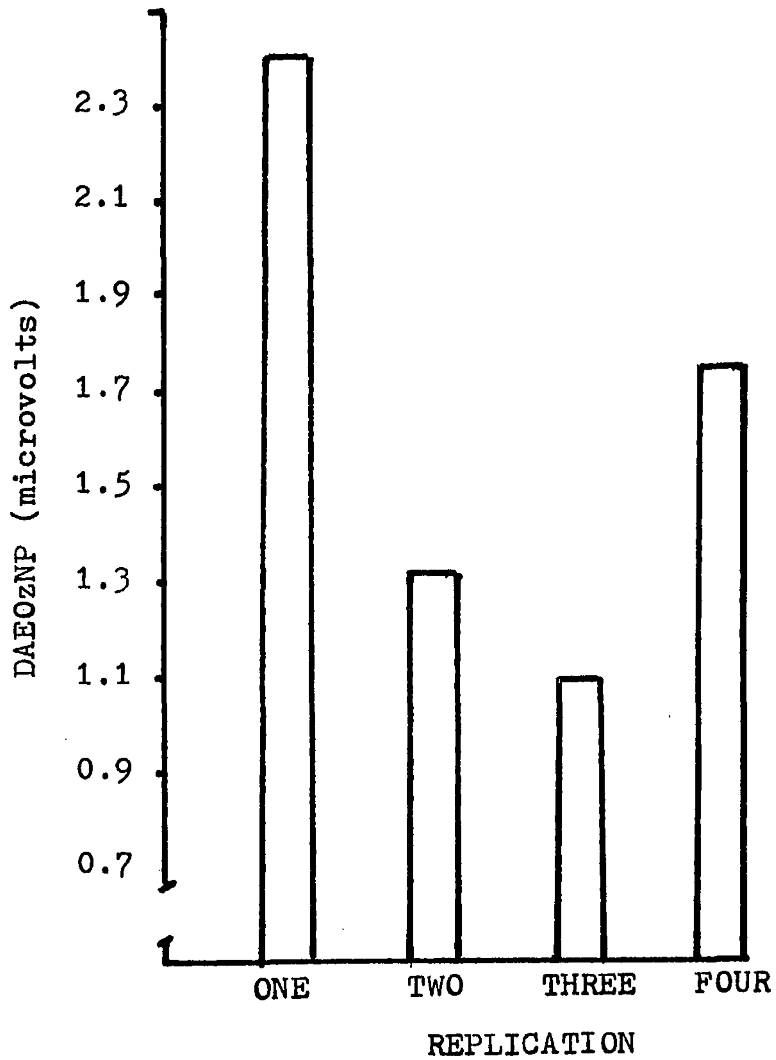
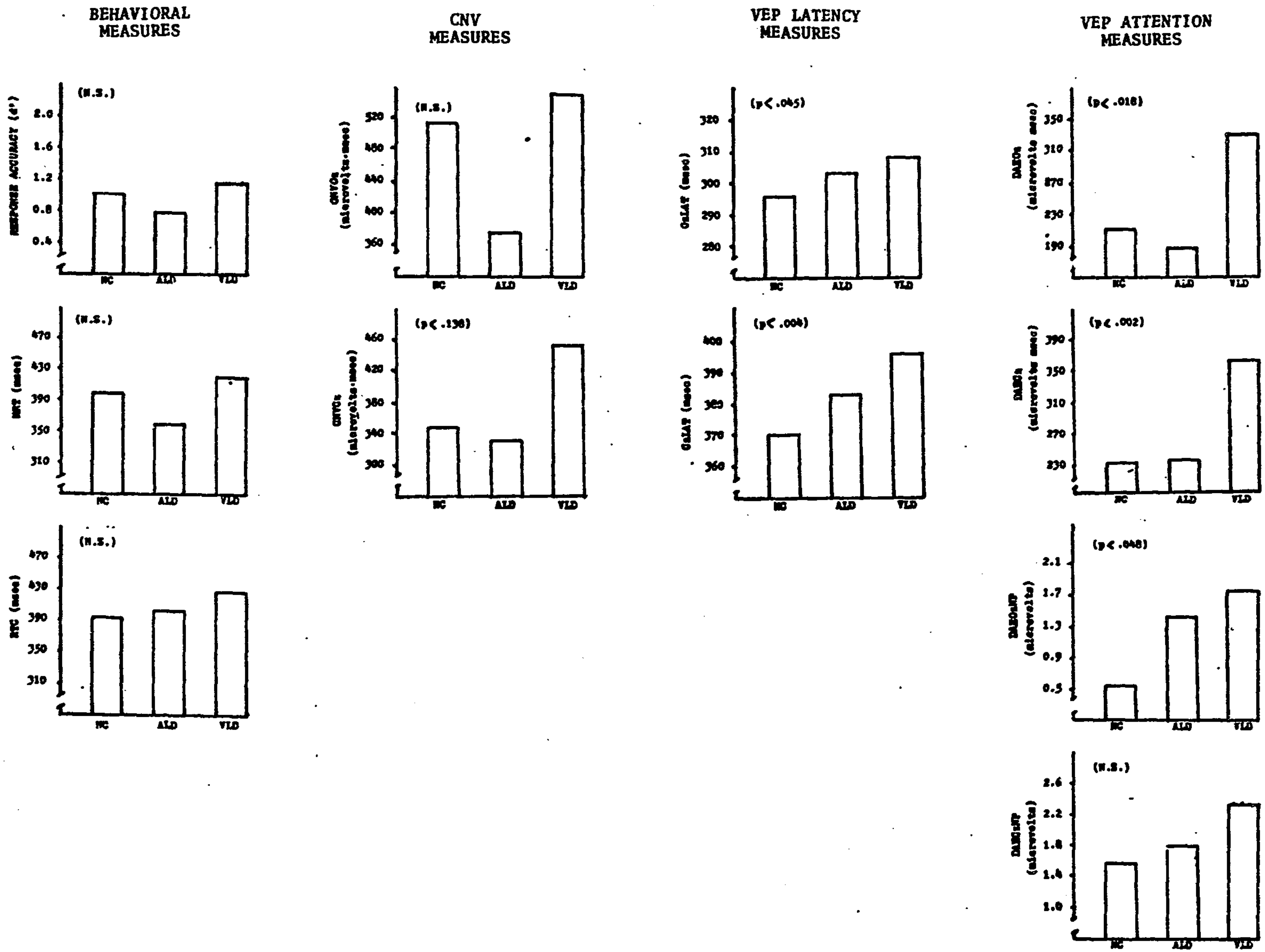


Figure 12. The effects of replication on the occipital VEP measure of selective attention: $DAEO_zNP$.

Figure 13. Summary of the group differences for each of the 11 dependent measures. Graphed values represent the group means of each variable. In the upper left hand corner of each graph is found the level of significance for which each measure differentiates the three groups (NC, ALD, and VLD). N.S. refers to not significantly different.


BEHAVIORAL MEASURES
CNV MEASURES
VEP LATENCY MEASURES
VEP ATTENTION MEASURES
(N.S.)
(N.S.)
(p< .045)
(p< .018)
(N.S.)
(p< .138)
(p< .004)
(p< .002)
(N.S.)
(p< .048)
(N.S.)
NC
ALD
VLD