

THE DEVELOPMENTAL RELATIONSHIP BETWEEN
NEUROPSYCHOLOGICAL AND ACHIEVEMENT VARIABLES:
A CLUSTER ANALYTIC STUDY

BY

CHARLES A. SCHAUER

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Charles A. Schauer

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Current discussions of specific reading disabilities increasingly mention the heterogeneity of this population and the need for ways to delineate meaningful subgroups. This study attempted to respond to this need by developing a multivariate classification system based on neuropsychological subskills which was then related to achievement measures. A unique characteristic of this study is its longitudinal approach. Furthermore, the classification system is based on the performance of children from all skill levels in order to verify that specific deficits are unique to single categories of achievers.

Data were collected from 211 boys first during their kindergarten year of school. They were then re-evaluated twice on the same measures at subsequent 3-year periods; the entire study spanned 6 years. The basic test measures at each probe included the Developmental Test of Visual-Motor Integration. The Recognition-Discrimination Test, the Embedded Figures Test, Peabody Picture Vocabulary Test raw score, WPPSI/WISC Similarities, the Verbal Fluency Test, and the Dichotic Listening Test (total recall). From an independent factor analysis of the Satz Predictive Battery these measure were found to be factor-pure and strong contributors to particular factors. They are also untroubled by floor and ceiling effects. Consequently, they were combined into spatial-perceptual and conceptual-linguistic factor scores at each of the three probes. These neuropsychological factor scores were then submitted to a cluster analytic procedure which resulted in 12 distinctive patterns of performance. Internal and external validity were verified through a series of statistical procedures.

Results confirmed a direct relationship between neuropsychological subgroups and achievement. Subgroups with the best neuropsychological performance were also the best achievers, just as those most deficient neuropsychologically were also the lowest achievers. Examining the

impact of each factor type, however, revealed much more complex relationships. One subgroup with a specific perceptual deficit had very low achievement. Another subgroup deficient only in verbal skills had low reading and spelling scores and average arithmetic skills. At the opposite end of the continuum, subgroups with relative strengths in either perceptual or verbal skills had very superior achievement scores. For all levels of skills, however, the impact on achievement is greatest when neuropsychological skills are equivalent.

Clear developmental changes were evident in three subgroups. For two subgroups the changes were regressive. The third subgroup showed consistent improvement in neuropsychological subskills. For these subgroups, the eventual level of performance, rather than the developmental patterns, seemed most clearly related to achievement competency.

A trend was apparent for a relationship between perceptual skills and arithmetic achievement. From other analyses, it was determined that the subgroups which were lowest on neuropsychological skills were also rated as having lower socioeconomic backgrounds and as having more frequent positive neurological findings. In addition, the mothers of these children were also the poorest readers.

No significant relationship was found between fathers' reading scores and the subgroups.

The results of this study underscore the benefits from examining children within the context of a carefully generated classification system. Evidence contrary to unitary deficit models was discussed, as were implications for future research.

CHAPTER I
INTRODUCTION

Overview

Consider the following two quotes:

More than fifteen thousand articles on the teaching of reading have appeared in professional journals in the last forty years; failure in reading is the largest single cause of school failure during the grade school years. With so much attention devoted to the teaching of reading, it seems anomalous that the problem of the nonreader remains with us. (Smith & Carrigan, 1959, p.1)

Despite over 30 years of research on specific reading and writing disabilities in children with normal intelligence, the results are contrary as indicators of either causes of the disabilities or remedial programs that can help persons to overcome them. (Valtin, 1979, p. 204)

Taken at face value, these statements present a dim view of the previous 60-year accomplishments in the areas of reading and, more specifically, reading disabilities, despite highly competent professionals having spent innumerable hours, manpower, and enormous sums of money in clinics, tutorial, and research programs. Admittedly, the prevailing opinion is not one of complete futility, but any

optimism (Benton, 1978) comes at the expense of restricting expectations to progress of a less wholistic nature. The fact remains that we do not have specific and effective remediation methods for failing readers. Nor do we have a satisfactory understanding of how reading disability relates to the overall process of reading.

It is legitimate to ask whether research should continue for reasons other than a "thirst for knowledge." From a practical point of view, making such a decision must include considerations of prevalence and consequences of reading failure. Due largely to differences in diagnostic criterion and age categories being studied, estimates of the number of children whose reading skills are significantly below expectation for their chronological and mental age have varied from 10 to 30 percent of the population (Applebee, 1971; Kline, 1972; Benton, 1975; Gibson & Levin, 1975; Rutter, Tizard, Yule, Graham, & Whitmore, 1976). Awareness of the impact on this staggering number of children is heightened by an understanding that theirs is more than a simple inability to process written symbols. Quite often other areas of academic achievement are also deficient, so that there is a high frequency of referral to child clinics (Meerloo, 1962; Mendelson, Johnson, & Stewart, 1971) if not complete school dropout (Silberman, 1964). Additional followup studies demonstrate a relationship between learning

disabilities and severe behavioral or emotional disorders (Robins, 1966; Rutter et al., 1976; Watt & Lubensky, 1976) and adult criminal behavior. Wright (1974) went so far as to postulate a theory in which reading failure is the single most significant factor in those forms of delinquency described as being antisocially aggressive. The hope remains that such significant distress and loss of human productivity could be lessened if adequate remediation techniques were available; to that end research continues.

In examining the reasons for the limited progress in this area, it might prove advantageous to briefly look at the lines of research in reading; as elaborated by Gibson and Levin (1975), there are essentially two. For approximately the first quarter of the twentieth century, experimental and educational psychologists attempted to understand the process of reading, raising many of the basic problems still confronting us today. Around 1920 the focus of research changed dramatically by attempting to compare the value of one method of teaching reading to another. What resulted was a mass of confusion with advocates of each curriculum attacking the other. It only took 40 years -- until about 1960 -- for us to realize that this was fruitless and that the concern should be with the process of reading rather than the outcome of a method. With the "swing of the pendulum" back to this

earlier trend, the integration of information from perceptual learning and cognitive and linguistic development would seem to increase our chances of understanding what has gone wrong for those children who do not develop adequate reading skills.

In what could be described as a subtrend of reading research, the literature has fairly mushroomed on those children who fail to learn to read effectively despite adequate intellectual, physical, and social motivational development. The terminology for this group includes such words as dyslexia, specific reading retardation, specific learning disability, unexpected reading failure, and specific developmental dyslexia, to choose just a few. Recent reviews (Satz, 1977; Rutter, 1978; Eisenberg, 1978; Valtin, 1979) have examined the issues involved in the various definitions. What is of importance to this discussion is that all definitions have proven inadequate. Fundamental disputes about the nature of the reading problems have resulted in circular and vague definitions, definitions by exclusion, and a looseness in the use of terms. Ross (1976, p. 11) stated the problem like this:

Stripped of those clauses which specified what a learning disability is not, this definition is

circular, for it states, in absence, that a learning disability is an inability to learn. It is a reflection on the rudimentary state of knowledge in this field that every definition in current use has its focus on what the condition is not, leaving what it is unspecified and thus ambiguous. Furthermore, when defined in this manner "learning disability" is a heterogeneous category; progress in this field demands further refinement of the definition and an identification of subcategories.

The interest of professionals from education to medicine is a mixed blessing as the role of variables of interest to a single professional discipline is emphasized and restricted conceptual models are constructed (Applebee, 1971). As a direct consequence of definitional inconsistencies, different criteria are used in sample selection, uncertainty exists as to what, if any, comparison group should be used (Valtin, 1979), and inferences across studies become tenuous. The result has been further chaos.

Recently there has been discussion of whether or not concepts such as developmental dyslexia are even valid. A recent study by Taylor, Satz, and Friel (1979) cuts to the heart of this issue. Carefully satisfying definitional requirements, comparisons were made between dyslexic and nondyslexic disabled readers, and both of these with normal readers. Results indicate that the two categories of poor readers could not be distinguished along any of several dimensions, including severity and outcome of reading disturbance, frequency of reversal

errors, parental reading and spelling competencies, math skills, neuro-behavioral performance, or personality traits. The only significant differentiation was between the total group of disabled readers and the group of normal readers, thereby challenging the dissociation of dyslexics from other forms of reading problems. The authors attribute a large portion of the current confusion in the area to use of such presumed concepts as dyslexia.

What is needed is the willingness among researchers to retreat from historical trends so they can develop an objective framework in which to classify and differentiate the numerous types of learning deficiency. The focus, however, should remain on matters of first-order relevance (i.e., an objective and descriptive classification of learning disorders) which can later be investigated on an explanatory level (i.e., second-order relevance). A major obstacle during the initial phase is the tendency to confound classification with etiology in which the "causal" event is loosely inferred from the minor signs (often behavior) or is based on observable inner events which may or may not exist (Satz, 1977). A descriptive classification schema would have the significant advantage of avoiding the use of hypothetical constructs. It would also operationally specify those variables which must be present to define the disorder. Such achievement-oriented behaviors are measurable and allow one to specify the type

of special handicaps (e.g. reading, writing, arithmetic, perception, speech, etc.) under consideration.

By searching for naturally occurring subtypes of learning disorders, one has more or less, rejected the unitary deficit hypothesis. Such a position identifies a single type of reading difficulty having a single radical cause (Wiener & Cromer, 1967; Applebee, 1971). Examples include Smith and Carrigan's (1959) synaptic transmission theory of reading disability, Delacato's (1959) theory of central neurological organization, Cruickshank's (1972) perceptual deficit hypothesis, and Vellutino's (1978) verbal mediation hypothesis. Examinations of the empirical and theoretical bases for such positions have proven them untenable, adding further impetus to the search for subtypes of learning disabilities (Benton, 1978; Doehring, 1978; Fletcher & Satz, 1979).

Because reading is a highly complex activity which utilizes a great number of skills (Maliphant et al., 1974; Gibson & Levin, 1975) and exhibits a strong relationship to other academic subjects (Rutter, 1978), the researcher is free to choose the level at which he will differentiate the syndromes (Boder, 1973; Rutter, 1978). One approach is to examine the actual pattern of reading deficit in isolation or as it relates to other academic skills. Although quite difficult, attempts have been made to classify retarded

spellers (Sweeney & Rourke, 1978), spelling and reading errors (Ingram et al., 1970; Naidoo, 1972; Nelson & Warrington, 1976), or reading, spelling, and math performance (Rourke, 1978). The second approach is to focus on those skills which have been shown to be important in a child's academic development and which are felt to be related to reading acquisition. Examples would be differentiation based on some type of cognitive or motor skills, disabilities in oral language, perceptual capacity, or short-term memory. Such a search for patterns of performance (and not just deficits) which may be associated with particular levels of reading proficiency is not meant to provide etiological statements, but rather is a quantitative attempt to describe patterns of skills at a more microcosmic level since any one of several clusters of deficiencies can limit the development of reading skills (Mattis, French, & Rapin, 1975).

Once the assumption of heterogeneity of learning disabilities has been adopted and the dimension of differentiation specified, the researcher must decide on the technique for determining the "correct" number of subgroups and for assigning individual children to the cluster types. For the purposes of this paper, an important distinction is whether the classification schema is derived through the use of high speed computers and multivariate statistical procedures or via visual

inspection of the data. Studies using the latter technique will be reviewed first and more briefly because of their weaker methodology.

Nonstatistical Classification Systems

An important study historically is that by Monroe (1932) because of the attempt to decrease the complexity and variability of reading disability cases by identifying subgroups on the basis of the nature and method of their being referred. One group was referred exclusively because of deficient reading. The second group had a variety of behavior and environmental problems, in addition to the poor reading, and were often referred by social agencies or the juvenile court. The final group was composed of children with borderline or deficient intelligence. In order to be able to make comparisons between groups, Monroe developed a reading index by comparing each child's composite reading grade with his average chronological, mental, and arithmetic grade. The three groups of reading deficiency cases were found to have highly similar distributions of scores and eventually had to be placed together in a single distribution. Since subgroups based on type of referral did not prove useful, Monroe examined the frequency of ten patterns of errors (reversals, addition or omission of sounds, substitution, repetition, etc.) for the combined reading deficiency group in comparison to

controls. From this, she discussed the various defects which could give rise to reading disability, the pattern of errors resulting, and the remediation methods recommended for children with each type of error pattern.

In a series of articles based on the Isle of Wight Studies of an entire population (Rutter & Yule, 1975; Rutter et al., 1976; Yule & Rutter, 1976), a broad classification system is first described, depending on whether the child fails to ever acquire reading skills or if he somehow loses the skill after it seemingly was well-established. Little is known of this latter group because its relative infrequency discourages extensive research. Those children who never learned to read were further subdivided into specific reading retardation (disabled independent of IQ) and general reading backwardness (low achievement in relation to age regardless of IQ). Multiple regression techniques were used to assign children to the categories, but the distinction rests on the congruence between the child's age, intelligence, and reading attainment. Even though this classification system is reported to be valid and as having educational implications, it effectively does little more than establish criteria for identifying a child as being deficient in reading.

Critchley (1964) and Rabinovitch (1968) advocate a common classification system based on proposed etiology. Children are categorized as having secondary reading retardation when the reading disability is associated with an encephalopathic event and primary reading retardation when there is a family history of learning disability without clear evidence of brain damage. The group of children with secondary reading retardation is shown to have a better prognosis. The distinction is essentially the basis for diagnosing specific developmental dyslexia and, as such, is subject to the difficulties of definition by excluding other possible pathologies.

From an examination of the literature, Bannatyne (1971) developed a hierarchical classification of the causes and types of all language and reading disabilities. The first breakdown creates the major groupings of dyslexia, aphasia, autism, emotional disturbance, low intelligence, and "Others." The dyslexics are then further divided into these causal groups: (1) primary emotional communicative causes related principally to maternal pathology; (2) minimal neurological dysfunction characterized by perceptual or cognitive deficits; (3) social, cultural, or educational deprivation; and (4) genetic dyslexia. The categories are not mutually exclusive, with characteristics being classified instead of children.

Another theoretical classification of the different types of poor readers might be carried out by differentiating individual reading performances (Vernon, 1977). The first group would be those children who cannot read at all. In addition to a measure of general linguistic development, these children would be studied to evaluate whether they can analyze or memorize word structures visually or auditorily. The second group, who can read only a few simple words and appear incapable of comprehending phonic teaching, should be studied for difficulties in assigning visual and symbolic material, especially in relation to hemispheric functioning and integration. Next, those children who can read simple regular words but do not understand how to manipulate irregular grapheme-phoneme correspondences would be tested for deficiencies in conceptual reasoning. And finally, for those readers who can read single words but cannot group words syntactically into phrases, Vernon recommends investigation of conceptual deficiencies and visual sampling ability. As should be evident, no direct assessment has been made of the validity for either the basis of the classification or the varying methods for studying the groups.

Interested in the developmental persistence of neurological signs, Silver and Hagin (1960, 1964) examined 24 dyslexics with a battery of neurological and psycho-

logical tests on two occasions with an interval of 10 to 12 years. When originally tested, the children ranged from 8 years, 6 months to 14 year of age, with intelligence quotients from 81 to 123. All of the children had been referred primarily for behavior disorder. In the first study, three groups of specific reading disability were identified: (1) a developmental group; (2) an organic group with evidence of structural organic defect; and (3) a very small group showing no perceptual deficits or signs. At follow-up, 15 of this sample were deemed to be adequate readers, and they tended to come from the "developmental" group and to be less severely retarded as children. The "organic" group showed less improvement than the others, and their specific perceptual deficits and lack of clear cerebral dominance tended to persist. No explanation was given as to the derivation of the three groups.

Zigmond (1978) was also concerned with the course of reading disability, but from an educator's point of view. She suggested that there is a sizeable number of "problem readers" who will achieve competency in reading if only teaching is improved. This means that there will remain a small minority of learners for whom attempts at achieving reading competence will be unsuccessful. Zigmond would only define this latter group as "dyslexic." Challenging researchers to sort these two groups on medical,

psychological, and educational characteristics, she concluded that individualized instruction seems to be the most promising remedial approach.

Other discussions of reading disability subgroups have used performance on single, objective tests to determine subgroup membership. For Kinsbourne and Warrington (1963), the differentiation was between Group 1, in which the score on the nonverbal section of the WISC (or WAIS) exceeded that of the verbal section by at least 20 points, and Group 2, in which the converse was true. There were six patients in Group 1 and seven in Group 2. Their ages ranged from 8 to 14 years, with the exception being a 31 year-old patient in Group 1. Additional evaluations indicated that Group 1 patients were characterized by delays in the acquisition of speech and in clinically apparent difficulties in verbal comprehension and expression, symptoms analogous to aphasia in adults. Group 2 children demonstrated poor performance on tests of finger order and differentiation, significant retardation in right-left orientation and mechanical arithmetic, as well as constructional difficulty; this grouping of symptoms is comparable to the Gerstmann syndrome in adults. The authors concluded that among backward readers and writers there exist two groups with developmental defects reminiscent of adult acquired

cerebral syndromes and called them the "language retardation" (Group 1) and the "Gerstmann" (Group 2) groups.

Smith (1970) also used intellectual abilities to delineate between subgroups of educationally handicapped children. Having tested 300 Anglo, male school children with severe reading retardation despite at least average Verbal or Performance Intelligence, Smith ascertained patterns of specific abilities and weaknesses for each individual by regrouping WISC subtest scores into categories suggested by previous studies. Three patterns of intellectual functioning were delineated in this group of children, with no similar patterns emerging from 74 control subjects. Pattern I individuals had strength in Spatial Ability and Spatial Organization, earned lower scores in Symbol Manipulation than in Spatial Organization, and were deficient in Sequencing Ability. Pattern II had deficits in Spatial Organization and/or Perceptual Organization and frequently had deficits in Visual-Motor Coordination. Pattern III had characteristics of both Patterns I and II. The proportion of Pattern I individuals tended to increase as the age of the children increased. In Pattern II individuals, the opposite tendency was apparent: 40 percent of the group at age 6, but only 8.7 percent by age 11. The incidence of Pattern III increased until age 13, then decreased rapidly. Similarities were drawn between Pattern I and Bannatyne's

(1971) genetic dyslexia and Boder's (1973) dysphonetic dyslexia. The variety of deficits in spatial ability for Pattern II is also comparable to that in Bannatyne's minor neurological dysfunction dyslexia.

The preceding notion of performance deficits changing with age (Smith, 1970) is compatible with recent formulations advanced by Satz and associates (Satz & Sparrow, 1970; Satz, Rardin, & Ross, 1971; Satz & Van Nostrand, 1973). This latter position postulates a differential relation between cognitive variables based on age. Briefly, at earlier ages learning disabled children are hypothesized to be delayed in visual-perceptual skills and at later ages, during failing reading, more delayed in cognitive-linguistic skills. Although the theory highlights the importance of both types of skills at all ages, it posits two subgroups of learning disabled children, with the primary deficit being perceptual for a younger group and linguistic for the older group. Support for this theory has been variable (Fennell, 1978; Fletcher, 1978), with concurrent measures being more favorable than longitudinal evaluations. The main problem is that there may not be a complete transition from the first to the second subgroup, creating the likelihood of at least a third subgroup deficient in both areas. Nevertheless, theories such as this reinforce the position that age-dependent concepts either have relevance in the

context of subgroups or must be considered in delineating those subgroups. The necessity of including developmental or longitudinal parameters has been reiterated (Money, 1962; Rice & Mattsson, 1966; Satz & Sparrow, 1970, Sontag, 1971) but remains largely ignored (Doehring, 1978; Satz, 1978).

A series of studies by Rourke and associates (Rourke & Finlayson, 1978; Rourke & Strang, 1978) examined patterns of academic performance in relation to neuropsychological variables. Forty-five 9- to 14-year old children with learning disabilities whose WISC Full Scale IQs fell within the range of 86 to 114 were divided into three groups. Group 1 was composed of children who were uniformly deficient in reading, spelling, and arithmetic; children in Group 2 were relatively adept at arithmetic as compared to reading and spelling; Group 3 was composed of children whose reading and spelling performances were average or above, but whose arithmetic was relatively deficient. Before discussing results, it should be noted that the composition of each group is obscured by overlapping criteria. For example, there is no statistically significant difference in arithmetic performance between Groups 2 and 3, despite the level being described as "adept" for Group 2 and "deficient" for Group 3. The authors skirt this issue by arguing for patterns of performance instead of levels of performance.

Combining the results from both studies, the performances of the children in the three groups were compared on a total of 27 dependent neuropsychological measures. The performances of Groups 1 and 2 were superior to that of Group 3 on measures of visual-perceptual, visual-spatial, some psychomotor, and tactile-perceptual skills. There were no statistically significant differences between the groups on "motor" measures. Group 3 performed at a superior level to that of Groups 1 and 2 on measures of verbal and auditory-perceptual abilities. These studies highlighted the number of adaptive deficiencies which should render children such as in Group 3 the focus of more serious concern, especially because their pattern of deficits is analogous to that seen in the Gerstmann syndrome (Kinsbourne & Warrington, 1963). Furthermore, the conclusion was made that subjects in Group 3 performed very much as would be expected were they to have a relatively dysfunctional right cerebral hemisphere, and subjects in Groups 1 and 2 performed in a fashion similar to that expected were they to have a relatively dysfunctional left cerebral hemisphere.

From their work in a learning disability clinic, Cole and Kraft (1964) observed patients falling into groups with differing neuropsychological defects. In a sample

of 36 children without behavior disorders or mental retardation, five groups emerged based on various combinations of these characteristics: dyslexia, abnormal speech on examination and/or history of retarded speech development, and visuo-spatial constructional abnormality. The five groups were defined as (1) dyslexia with general language defect, (2) dyslexia with visuo-spatial defect, (3) dyslexia without general language or visuo-spatial defect but with abnormalities of synthesis, (4) dyslexia with mixed defects, and (5) specific learning disability without dyslexia. One problem with this classification system is the small size of some groups (as low as 4 for Group 2) presenting serious questions of reliability. Nevertheless, beyond the definitional criteria, intergroup variations exist for the ratio of males to females, IQ distribution, handedness, and right-left disorientation. Basic properties of all groups include family history of learning disability, sinistrality or ambilaterality, and incidence of abnormal neurological signs. Cole and Kraft concluded that the similarities are great enough to define the global syndrome of limited cerebral dysfunction of childhood, a heredo-familial abnormality of cerebral organization.

Currently, one of the most popular approaches is the differentiation made by Mattis, French, and Rapin (1975)

and Denckla (1972, 1977). After an initial attempt to find a difference between brain-damaged and non-brain damaged dyslexics failed, Mattis et al. (1975) determined in a post-hoc observation that 90 percent of the 82 dyslexic (combined brain-damaged and non-brain-damaged) children could be isolated into three independent dyslexic syndromes. The children were aged 8 to 18 years, had a Verbal or Performance IQ exceeding 80, and were being evaluated at a neurological clinic for a learning or behavior disorder. Denckla's (1972) subjects were also seen in a neurology clinic, but no additional descriptive data are provided. Of her last 190 private patients, about 30 percent were seen as having an easily recognizable dramatic cluster of signs. No explanation was given as to the derivation of the clusters.

Although not modeled after the work of Cole and Kraft (1964), the basic dyslexic syndromes of Denckla (1972) and Mattis et al. (1975) are remarkably similar. These syndromes include: (1) a language disorder syndrome with defects in both the understanding and expression of oral language; (2) a dyscoordination syndrome with defects in speech articulation and design copying and normal understanding of oral language; and (3) a visuospatial-perceptual disorder syndrome with defective visuo-perceptive and visuoconstructive capacity and intact oral language abilities. To this basic classification system

can be added the dysphonemic sequencing disorder syndrome characterized by phonemic substitutions and missequencings despite normal naming, comprehension, and articulation. This syndrome was described by Denckla (1977) and has been found in a cross-validation study of Mattis' work (Erenberg, Mattis, & French, 1976). There is also a verbal memorization disorder syndrome (Denckla, 1977) with noteworthy impairment in sentence repetition and verbal paired-associates learning in older children, and which may be a milder and continuing form of the language disorder syndrome of younger dyslexics.

A second frequently discussed classification system is that described by Johnson and Myklebust (1967), Boder (1970, 1971, 1973), and Tallal (1976). If the overall differentiation between general and specific dyslexia is overlooked, the criteria for the distinction used by Ingram et al. (1970) is also consistent with this system. Ingram et al. (1970) did a retrospective study of 82 "highly pre-selected patients" who meet the common definition of dyslexia. Boder (1973) had 107 children between 8 and 16 years of age in her sample. From an analysis of how the child reads and spells rather than at what grade level, 100 of the 107 children exhibited one of the three reading-spelling patterns. Dysphonetic or auditory dyslexia reflects a primary deficit in symbol-sound (grapheme-phoneme) integration resulting in an

inability to develop phonetic word analysis-synthesis skills. Dyseidetic or visual dyslexia is marked by an inability to perceive letters and whole words as configurations, or visual gestalts. Finally, there is a mixed dyslexia group with both deficits. Indirect evidence supporting the validity of the dysphonetic and dyseidetic clinical subgroups has appeared from electrophysiological recordings of event-related potentials (Fried, Tanquay, Boder, Doubleday, & Greensite, 1979), but, in large part, use of such dependent measures could not differentiate between dyslexic subgroups. Children with audiophonological errors are more frequently encountered than those with visuospatial errors. In general, too, the outlook for improvement in reading level appears to be better for the child with audiophonological difficulties. None of the three patterns have been found among normal readers.

The last two classification systems are good examples of the differing approaches, one based on the analysis of reading performance per se (Boder, 1973) and the other on the occurrence of concomitant disabilities (Mattis et al., 1975). It is possible that systematic relationships exist, for example, between Boder's visuospatial type of defective reading and the visuospatial-perceptual disorder syndrome of Mattis, or between Boder's audiophonological type and Denckla's dysphonemic sequencing disorder

syndrome. Investigative work for such similarities could jointly consider the two approaches to classification by analyzing reading performance and concomitant disabilities (Benton, 1978) but this overlooks basic and pernicious methodological limitations. In every classification study reviewed up to this point, the rationale for the particular subcategories comes exclusively from the developer's theoretical system. Such a priori grounding inherently imposes biases sympathetic to the particular theoretical position, etiological inferences, or investigator's goals (Myklebust, 1968; Blom & Jones, 1970). Too often, then, the classifications are treated as fact rather than an hypothesis to be tested, subjecting the categories to serious questions of validity. Furthermore, the method of assigning children to categories has been based solely on visual inspection of quite complex data sets. At a time when rigorous and systematic statistical procedures are available, such a practice is an unnecessary source of error variance and demonstrates poor experimental design.

Statistical Classification Systems

In 1959, Smith and Carrigan published a study far ahead of its time, as indicated by the early use of advanced statistical techniques and the extent to which their fellow researchers ignored their work. Thirty-two

retarded readers in the third through sixth grades were given a battery of tests providing 18 scores on measures from digit span to flicker fusion. Using a cluster analysis technique, five subgroups were derived for additional study. Group 1 was low in both cognitive-associational skills and in perceptual-metabolic skills. Group 2 was evenly balanced with neither high nor low skills except for cognitive-perceptual skills, which were low. Group 3 did not present a clear pattern and Groups 4 and 5 appeared to be superior to the other groups. Using a variety of measures including height, weight, blood pressure, bone age hemoglobin, protein-bound iodine, etc., an attempt was made to see if the physical characteristics of the five subgroups conformed to theoretical expectations. The results were largely negative. Next, a complex analysis was presented of the profiles of the five subgroups in terms of the effects of varying amounts of the two chemical substances acetylcholine and cholinesterase. The authors concluded that both the absolute amount of the chemical present and the relative balance of the two chemicals is important. Another part of the study found subgroup differences along an anxiety dimension.

The study has a number of serious defects, including a small sample size, lack of replication, lack of normal controls, and use of fairly unreliable instruments. Furthermore, the authors failed to describe the "cluster

analysis" technique, so one can only guess how it may have been carried out at a time when the use of computers was limited. Yet it is still interesting that a series of subgroups did emerge from the analysis, subgroups which showed a number of significant differences on a series of measures unrelated to those by which they were originally separated.

Naidoo (1972) also used a cluster analysis to examine the possibility of subtypes within a clinic sample of 94 dyslexic boys, aged 8 to 13 years. She compared the boys on a variety of data from the psychological and neurological examinations, perinatal and developmental histories, and family history information on reading, spelling, speech difficulties, and left-handedness. Five groups were identified using a single linkage cluster analysis, the groups consisting of 27, 5, 3, 3, and 2 boys. Naidoo concluded that these were not clear clusters, but instead the abilities appeared to exist along a continuum. Nevertheless, she proposed four groups, but almost one-third of the children could not be included in any of these. Although one large group could be characterized by linguistic problems, and another smaller group by visual perception and memory problems, the considerable variability within all groups made a simple classification of all poor readers impossible.

These negative results, however, must be re-evaluated with our current knowledge of cluster analysis. Since the time of this study, it has been pointed out that use of the single linkage method gives rise to a property called chaining, which refers to the tendency of the method to join together relatively distinct clusters if a small number of intermediate points are present between the clusters (Everitt, 1974; Blashfield, 1976). It appears, therefore, that Naidoo mistakenly used a method which looks for optimally connected clusters or outliers (children who are not very similar to other children in the data set) when she actually wanted one which would discover homogeneous, compact clusters.

Another multivariate statistical classification procedure which has been used within the multiple-syndrome paradigm of reading disabilities is the Q-technique of factor analysis. In such a procedure, the factor is defined by the children who have high loadings on that particular factor. It is an "inverted" method which groups together children who show similar patterns of test scores.

The first researchers to use the Q-technique on children with reading problems were Doehring and Hoshko (1977). They used two groups from somewhat different populations. The first group had purer reading problems

and consisted of 34 children (31 boys) ranging in age from 8 years, 8 months to 17 years, 4 months, in IQ from 71 to 125, and in word reading level from grade 0.2 to 9.2 (as measured by the Slosson Oral Reading Test). The second group had a mixture of problems, with learning disorders, language disorders, and mental retardation; for no children was the primary diagnosis reading disability. This group consisted of 31 children (21 boys) ranging in age from 8 years, 2 months to 12 years, 5 months, in IQ from 79 to 105, and in word reading level from grade 0.6 to 5.9. The results from 31 tests of reading-related skills were submitted to a Q-technique factor analysis. For both groups of children, three subgroups resulted. Overall, eight children could not be classified, and three had high loadings on more than one factor.

Subgroup 1R (the R indicating membership in the group with reading problems) was characterized by good performance on all of the visual matching and on three of the seven auditory-visual matching tests, and poor performance on the oral reading tests involving words and syllables. In general, Performance IQs were higher than Verbal IQs. The subgroup 2R profile revealed good performance on visual scanning tests involving numbers and letters, very poor performance on auditory-visual letter matching, and relatively poor performance on two other auditory-visual tests and on the four oral reading tests involving words.

The children seemed unable to associate printed and spoken letters rapidly. In contrast, the children of subgroup 3R were characterized by very good visual and auditory-visual matching of single letters, and differed from subgroup 1R in terms of the poor visual and very poor oral word, sentence, and syllable reading skills. Using independent criterion, most of the children in subgroup 1R were classified as distractible and all but one were in regular classes; most of the children in subgroup 2R were also in regular classes; and most of the children in subgroup 3R were in special classes, had repeated a grade, and had some kind of family reading problem.

Subgroups for the children with mixed problems showed remarkable similarity to those with reading problems. The profile of subgroup 1M was very similar to the profile of subgroup 2R but without as marked a deficit in auditory-visual matching. The profile of subgroup 2M was similar in almost all respects to subgroup 3R, with the only marked discrepancies occurring on the auditory-visual matching tasks. Subgroup 3M, however, was completely different; both visual and auditory-visual letter matching skills were low, two of eight visual scanning tests were very high, and oral reading of words and syllables was relatively good. This profile might reflect a certain type of visual perception deficit. When the results of all children were analyzed together,

subgroup 1R retained its separate identity, subgroup 2R and subgroup 1M formed a second subgroup, subgroup 3R and half of subgroup 2M formed a third subgroup, and subgroup 3M disappeared. Doehring and Hoshko valiantly attempted to relate their statistically derived subgroups to those of other investigators, but this proved difficult due to the complexity of their data.

Petrauskas and Rourke (1979) also sought to classify subgroups of retarded readers using a Q-technique factor analysis. For this purpose, 133 poor readers and 27 normal readers between the ages of 84 and 107 months were selected. All children were right-handed with WISC Full Scale IQ scores between 80 and 120 and had been screened for evidence of sensory deficits, primary emotional disturbance, and linguistic and cultural deprivation. The total sample was randomly subdivided into two equal subsamples. A total of 44 measures were originally collected on each child, although this number was reduced by a "rational grouping procedure" so as to better reflect six skill areas. An analysis of the data from 20 neuropsychological tests resulted in six factors (or subtypes) from each of the two subsamples examined separately and combined. Only four of the subtypes were reliable enough for further consideration. Additionally, just 119 of the 160 subjects exhibited adequate loading on a single factor.

The test performance of subtype 1 is characterized by the following: relatively well developed visual-spatial and eye-hand coordination skills; average or near-average performances on measures of tactile-kinesthetic abilities, abstract reasoning, and nonverbal concept formation; near average performances on word definitions; mildly impaired word blending, immediate memory for digits, and store of general information; moderately to severely impaired verbal fluency and sentence memory. Subtype 2 is characterized by: average or near-average kinesthetic, psychomotor, visual-spatial constructional and word-definition abilities, and nonverbal problem-solving and abstract reasoning skills within a context that provides immediate positive and negative feedback; borderline to moderately impaired immediate memory for digits and other "sequencing" skills, store of general information, sound blending, verbal fluency, and concept formation when substantial verbal coding is required and/or when no positive and negative feedback is provided; and moderately to severely impaired finger recognition, immediate visual-spatial memory, and memory for sentences. The test performances of subtype 3 is summarized by the following: average or near-average finger recognition (left hand), kinesthetic, visuo-spatial constructional, vocabulary and sound-blending abilities, and nonverbal concept formation within a context of immediate positive and negative feedback; borderline to mildly impaired finger recognition

(right hand), immediate memory for digits, eye-hand coordination under speeded conditions, store of general information, and nonverbal abstraction and the shifting of set without the benefit of positive and negative feedback; mildly to moderately impaired verbal fluency, sentence memory, and immediate visual-spatial memory; and moderately to severely impaired concept formation which involves substantial verbal coding. The performance of subtype 4 was largely average due to the fact that it was the normal readers who loaded on this factor. Considering this subtype, it seems likely that there are different types of normal readers since all normal readers did not have the same constellation of abilities.

Interpreting the above results is, to say the least, laborious. While it is advantageous to have unbiased computerized statistical programs available to demarcate and assign individuals to clusters, the experiment must be so designed that our understanding has increased afterwards. While hoping to accomplish this, Doebling and Hoshko (1977) and Petrauskas and Rourke (1979) made this unlikely by using, respectively, 31 and 20 test scores, far too many to determine adequately meaningful patterns consistent with particular theoretical positions.

The final study to be reviewed here was recently completed by Darby (1978). Working with a relatively

unselected sample of 236 boys in the fifth grade, from within a single county and reflecting all levels of achievement, nine general academic subgroups were identified by submitting the boys' WRAT reading, spelling, and arithmetic scores to a cluster analytic procedure. These initial subgroups were then compared on a variety of intellectual, neuropsychological, socioeconomic status, and neurological variables. As expected, there was a general trend for the low-achievement subgroups to perform more poorly on all variables. The two lowest subgroups had an extremely high proportion of boys rated "affected" on neurological examination. However, the mean IQ for all achievement subgroups exceeded 90. One notable finding was the absence of a purely reading disabled subgroup, even though there was one deficient only in arithmetic.

By virtue of their markedly deficient achievement scores, the lowest two subgroups were identified as a learning disabled population (N=89). A second cluster analysis using two language and two perceptual-motor variables generated four unique subtypes of learning disabilities. The subtypes consisted of: (1) children who showed neither language nor perceptual-motor deficits; (2) children with deficits in both areas; (3) children with generally average scores except in verbal fluency where their performance was significantly impaired; and (4)

children with substantial deficits only on perceptual-motor variables. These differences were present despite no significant differences between subtypes on achievement, socioeconomic status, neurological ratings, or personality variables. This investigation supported the use of cluster analytic techniques in the identification of meaningful subtypes of low-achieving children.

Summary and Rationale

An attempt has been made in this paper to address some of the critical issues in the area of reading disability. Central to the discussion have been criticisms of definitions, subject populations, methodologies, and statistical procedures. The difficulties in definitions have largely stemmed from their being vague, circular, and exclusionary, often identifying reading disabled children by what characteristics were not present. Consequently, there is little consistency from study to study as to the children that should be investigated. Highly variable subject populations have been used, sometimes with a very narrow age range and other times, too large an age range. For example, one study included subjects from 8 to 31 years of age. In only a few studies have developmental parameters been included, an essential consideration for a population that changes as rapidly as children. In the midst of this

quagmire, samples have been further restricted on the basis of intelligence or type of presenting complaint (academic, behavioral, psychological, medical, or some combination of these). It is little wonder that the concept of specific reading disability is increasingly criticized as being of inconsequential utility (Taylor, Satz, & Friel, 1979).

More recently the trend is away from treating reading disability as a homogeneous entity and towards viewing it as a set of diverse syndromes. During the search for individual patterns of deficits, new problems have emerged. Much too often, delineations of subgroups have been totally theoretical and without supporting data, treating the existence of subgroups as fact instead of something to be tested. Several of the preceding studies included too few subjects, especially in the search for subgroups; one in particular had glaring reliability problems when a subgroup with two members was identified. Completely overlooked have been subgroups of normal readers, describing how they relate to subgroups of children with deficient reading skills (Doehring, 1978; Knights, 1978). Without concomitant evaluations of normal readers and contrasts of their subgroup strengths and weaknesses, one can never be sure that particular deficits are idiosyncratic to reading failure. Methodologically the studies have been plagued by retrospective designs,

the use of unspecified or small numbers of clustering variables, and reliance upon visual inspection of complex data arrays in separating the subgroups.

The final criticism centers around the use of inadequate or inappropriate statistics. In some cases, statistical procedures caused the results of the analyses to be more complicated and uninterpretable than the original data. An additional unacceptable condition, but one which appears in the literature, is the delineation of subgroups which either overlap one another or do not classify all the children being studied. While offering hope, the concern with subgroups of reading disability has provided limited clarifications.

The current research attempts to circumvent these problems in a search for naturally occurring subgroups within a data set. The Darby (1978) study was a good first attempt in the rigorous application of cluster analysis to the area of reading disability, but it was limited by the use of only four neuropsychological variables in the clustering process and to comparisons at a single age level. This experiment, while also developing a classification system based on neuropsychological variables, departs in several significant ways from what has previously been done. First, developmental considerations are built into the classification

system from the beginning by including variables from 3 probes spanning a 6-year period. Second, a broader range of subskills will be tapped by using performance on 7 neuropsychological variables at each of the 3 probes. And third, the classification system will be based on children from all reading levels.

Subsequent to the derivation of the classification system from neuropsychological variables, its external validity will be primarily assessed through subgroup comparisons of achievement scores. Such an approach will make it possible to examine the development of neuropsychological skills and their relationship to reading. From between- and within-subgroup comparisons, it will be possible to gain a better understanding of the complete reading process: what patterns across time result in superior reading skills, as well as what types of interference come from differing patterns of deficient subskills.

Choosing the appropriate statistical procedure for classifying the children is extremely critical. In a project such as this, the choice is essentially between cluster analysis and Q-technique factor analysis. Methodological constraints of these procedures will be discussed in the next chapter. For now it is sufficient to say that cluster analysis is more powerful (Sokal &

Sneath, 1963; Sneath & Sokal, 1973; Everitt, 1974; Blashfield & Aldenderfer, 1978) and will, therefore, be used in this study.

To summarize the objectives of this project, these questions will be answered:

- (1) Will definable clusters (subgroups) emerge on the basis of factor-pure neuropsychological variables?
- (2) Are the clusters related to external achievement criteria such as reading, spelling, and arithmetic; and, if so, does this relationship vary by factor type (perceptual vs. verbal) and/or by age?
- (3) Are the clusters related to external nonachievement measures such as intelligence, parental reading level, neurological status, and socioeconomic status?

CHAPTER II

METHOD

Subjects

The subjects for the present investigation are a subsample of those children who participated in the longitudinal study of Satz and associates (1973, 1976, 1978). In 1970, the entire population of white males beginning kindergarten in Alachua County, Florida, were given an extensive battery of cognitive, perceptual, and motor tests. A cross-validation sample of white males entering kindergarten in 1971 also joined the project (total N of 678). After the Kindergarten examinations (Probe 1), all children were subsequently tested at roughly 3-year intervals, at the end of the second grade (Probe 2) and the end of the fifth grade (Probe 3) on identical measures to those at the first probe, in addition to appropriate standardized achievement measures. The present investigation is conducted within the context of this large on-going project.

Based on their achievement performance at Probe 2, 80 boys were identified as disabled readers (reading scores more than one standard deviation below the mean). Primary

and alternate control subjects were also identified at that time, the criterion being one-to-one matching on age and at least average proficiency in reading. This procedure provided identical subjects based on sex, age, race, geographical location, and source of referral. These subjects were checked for completeness of neuropsychological data at Probe 1 and re-evaluated at Probe 3 if they still resided in Alachua County. Such a follow-back, follow-up design made the data from 211 boys available for this study. The mean age of these children at Probe 1 was 65.6 months ($SD = 4.37$), at Probe 2 was 93.2 months ($SD = 4.08$), and Probe 3 was 130.0 months ($SD = 3.9$).

The original rationale for including only white children was to increase the cultural and educational homogeneity of the sample. Consequently, error variance attributable to differences along these dimensions was automatically reduced. The additional restriction of testing only males made it more likely that the problems of poor readers would be present, since the male-to-female ratio is approximately 4 to 1 (Rutter, 1978).

Procedure

Test Measures

A factor analysis of the original neuropsychological test variables (Fletcher & Satz, 1979) identified those

measures which load most highly on the various factors. The 7 test measures not restricted by floor or ceiling effects were used in the search for naturally occurring subgroups. Included were the following tests: (1) the Recognition-Discrimination Test (RD), total correct at time limit (Small, 1968); (2) the Embedded Figures Test (EF), total correct at time limit; (3) the Developmental Test of Visual Motor Integration (VMI), age- equivalent in months (Beery & Buktenica, 1967); (4) the WPPSI or WISC Similarities subtest (SIM), scaled score (Wechsler, 1949; 1967); (5) the Peabody Picture Vocabulary Test (PPVT), raw score (Dunn, 1965); (6) a Verbal Fluency Test (VF), total score (Spren & Benton, 1965); and (7) a Dichotic Listening Test (DL), total words recalled. Raw scores were used for PPVT because this eliminates the age-correction which is built into the test. More detailed description of each test measure is available in an earlier publication (Satz & Friel, 1973). Inclusion of more variables than were in the Darby (1978) study stems from a deliberate attempt to represent more completely the children's subskills which may be related to academic achievement.

Classification systems based on statistical procedures such as cluster analysis have the distinct advantage of deriving the cluster arrays in a systematic and impartial manner. Nevertheless, human judgment is introduced in the choice of clustering variables and

method, as well as in determining when an optimal number of clusters has been obtained. Even though the highly structured nature of the Florida longitudinal data renders these choices less critical, this paper gave special consideration to the questions of external validity, meaningfulness, and utility of the cluster solutions.

The primary validity of derived subgroups was examined using separate measures, particularly the Wide Range Achievement Test (WRAT) which was administered at Probe 3 (Jastak & Jastak, 1965). The WRAT has subtest scores in reading, spelling, and arithmetic, and has gained acceptance as an economical and reasonably accurate estimate of a child's level of school achievement (Rourke & Finlayson, 1978). These variables were in the form of a discrepancy score, derived by comparing the child's chronological age with the age-equivalent score obtained on each subtest. Additional comparisons were made using data on intelligence, parental reading level, neurological ratings, and socioeconomic status (SES).

Statistical Analyses

Difficulties inherent to the Q-technique factor analysis make it unsatisfactory for imposing order on a large data set. These problems are discussed more completely in Fleiss and Zubin (1969) and Everitt (1974), but can be briefly reviewed: (1) The Q-technique's use of

the correlation coefficient as a measure of similarity between individuals can be questioned; (2) If the data are not linear, the procedure is an idle exercise; (3) Classification is most difficult when an individual has high factor loading on more than one factor; and (4) Given a set of p variables on each individual, the number of subgroups can never be more than $p-1$, one less than the number of variables.

These difficulties are not present in cluster analysis, which, in fact, has several advantages. First, once a classification system has been developed, it can be subjected to a relocation procedure, a test for optimal solution. Next, cluster analysis prevents a child from being placed into more than one subgroup. Third, cluster analysis is able to classify every subject in the sample, even if a cluster with a single member should exist. And finally, it is possible to use a procedure such as factor analysis to reduce the number of variables before using the cluster method. Flexibility like this permits a complex data base with a reduction to fewer variables for easier interpretation. The previously described studies by Doehring and Hoshko (1977) and Petrauskas and Rourke (1979) illustrate the need for this option. It was, however, unavailable because their analyses used the Q-technique, which is itself a factor analysis.

Factor analysis of the original neuropsychological battery (Morris & Satz, 1978) identified two factors at Probes 1 and 2 and three factors at Probe 3. Factor I (sensorimotor-perceptual) remained stable across probes and included these tests: Recognition Discrimination Test, Embedded Figures Test, and Developmental Test of Visual Motor Integration. At Probes 1 and 2, Factor II (general conceptual-linguistic) tasks included: The WPPSI or WISC Similarities subtest, the Peabody Picture Vocabulary Test, Verbal Fluency Test, and Dichotic Listening Test. This general conceptual-linguistic factor split at Probe 3 into a receptive conceptual-linguistic factor (consisting of WISC Similarities subtest and the Peabody Picture Vocabulary Test) and an expressive conceptual-linguistic factor (consisting of the Verbal Fluency Test and Dichotic Listening Test).

The search for discrete, naturally occurring subgroups of neuropsychological skills were accomplished through a cluster analytic procedure employing a CLUSTAN 1C Program (Wishart, 1975). Rather than submitting 21 variables for each subject to the clustering procedure (RD, EF, VMI, SIM, PPVT, VF, and DL at each of three probes) and creating severe interpretation problems as was discussed earlier, the data was transformed to seven factor scores:

- Probe 1: (1) Sensorimotor-perceptual (P1) consisting of RD, EF, and VMI;
 (2) General conceptual-linguistic (V1) consisting of SIM, PPVT, VF, and DL;
- Probe 2: (3) Sensorimotor-perceptual (P2) consisting of RD, EF, and VMI;
 (4) General conceptual-linguistic (V2) consisting of SIM, PPVT, VF, and DL;
- Probe 3: (5) Sensorimotor-perceptual (P3) consisting of RD, EF, and VMI;
 (6) Receptive conceptual-linguistic (V3-Rec) consisting of SIM and PPVT;
 (7) Expressive conceptual-linguistic (V3-Expr) consisting of VF and DL.

With the neuropsychological subskills in this form, a hierarchical agglomerative average-linkage method employing a squared euclidean distance similarity coefficient was used to search for subgroups. This particular combination of similarity measure and fusion technique has proven most effective in deriving classification systems from other subsets of the Florida longitudinal data (Darby, 1978; Satz, Morris & Darby, 1979). A constraint of cluster analysis is its lack of a generally accepted test statistic for determining when the number of clusters accurately reflects the underlying structure of the data. In its absence, the process of combining data points was traced through the means of the clustering variables and the magnitude of the similarity coefficient at each stage. A solution was sought which did not fuse markedly dissimilar subgroups (or individuals), retained subgroups with unique and interesting profiles, and avoided early regression towards the overall sample mean. It was

essential to maintain the configural nature of the data and not have purely scalar clusters in which the subskills fell into a ranking from proficiency to deficiency.

The validity of these subgroups was then evaluated by multivariate and univariate analyses of the clustering and validity variables. These analyses were conducted using the General Linear Models Procedure of the Statistical Analysis Systems (SAS) program (Barr, Goodnight, Sall, & Helwig, 1976). Individual means were compared using post hoc Duncan's Multi-Range Tests (Winer, 1971). Because of the nature of the data, chi-square tests for independence were utilized for the teacher's rating of socioeconomic status and the neurological ratings.

CHAPTER III

RESULTS

The organization of the Results section will follow the objectives of this project as stated at the end of Chapter I.

Cluster Analytic Solution

(1) Will definable clusters (subgroups) emerge on the basis of factor-pure neuropsychological variables?

Using guidelines identified in the previous chapter, it was determined that a 12-cluster solution yielded the most distinctive pattern of subgroups. Continuation of the clustering process beyond this point would have fused subgroups which are statistically different on two of the seven clustering variables. Subjecting the initial array to an evaluation of optimal cluster membership improved the subgroup clarity by placing various children in more similar clusters, thus increasing within-subgroup homogeneity without a complete reorganization. Further confirmation of the 12-cluster solution came from submitting the data to additional hierarchical procedures.

Cluster membership using different procedures was similar, the primary difference being in the degree to which subgroups were separated from each other. Table 1 presents the final 12-cluster solution with the means for each clustering variable. As additional validation, examination of the subgroup means suggests that the solution makes sense heuristically given what is known about the data and the external criteria. This will be elaborated upon in subsequent sections. More extensive descriptive statistics can be found in the Appendix.

The upper half of Figure 1 presents a visual representation of each subgroup. The achievement data in the lower half of the figure will be used for later contrasts. Before describing the clusters, attention should be given to characteristics of the figure since an understanding of it is critical to the current discussion. The horizontal line represents the overall sample mean for all tests, which is 0.00 since factor scores were used as clustering variables. Units along the ordinate correspond to positive and negative deviations from that mean. Perceptual factor scores appear first as three solid lines within each cluster, followed by the four verbal factors as dotted lines. And finally, within each factor sequence (perceptual or verbal), the data are presented sequentially, i.e. Probe 1, Probe 2, and then Probe 3.

Table 1
Mean Factor Scores By Neuropsychological Subgroups

<u>Cluster</u>	<u>N</u>	<u>P1*</u>	<u>P2*</u>	<u>P3*</u>	<u>V1*</u>	<u>V2*</u>	<u>V3-Rec*</u>	<u>V3-Expr*</u>
1	29	0.26 CD	0.15 D	0.16 C	0.20 D	0.17 CD	0.67 C	-0.28 D
2	21	-0.03 E	-0.38 E	-0.48 D	0.30 CD	-0.17 E	-0.67 F	-0.61 E
3	22	-0.73 F	-0.41 E	-0.55 D	-0.63 E	-0.51 F	-0.53 F	-0.31 D
4	20	-0.07 E	0.31 CD	0.34 C	-0.65 E	-0.49 F	-0.50 F	-0.65 E
5	19	0.05 DE	0.64 B	0.71 B	-0.45 E	-0.12 E	-0.17 E	0.48 C
6	19	0.94 AB	1.11 A	1.13 A	0.54 C	0.37 BC	0.62 C	0.62 BC
7	10	1.14 A	0.52 BC	0.82 AB	1.03 B	1.15 A	1.91 A	1.66 A
8	9	-1.03 F	-1.47 F	-1.55 F	-0.46 E	-0.83 FG	-1.13 G	-1.04 F
9	12	-0.64 F	-1.07 E	-0.77 DE	-1.50 F	-1.01 G	-1.26 G	-1.12 F
10	9	0.59 BC	0.47 BCD	0.13 C	1.58 A	1.02 A	1.28 B	0.65 BC
11	16	-0.68 F	-1.17 F	-0.88 E	0.08 D	-0.04 DE	-0.19 E	-0.03 D
12	25	0.11 DE	0.31 CD	0.19 C	0.34 CD	0.56 B	0.21 D	0.85 B

* Means followed by the same letter are not significantly different within variables (Duncan's Multi-Range Test, Alpha level = 0.05).

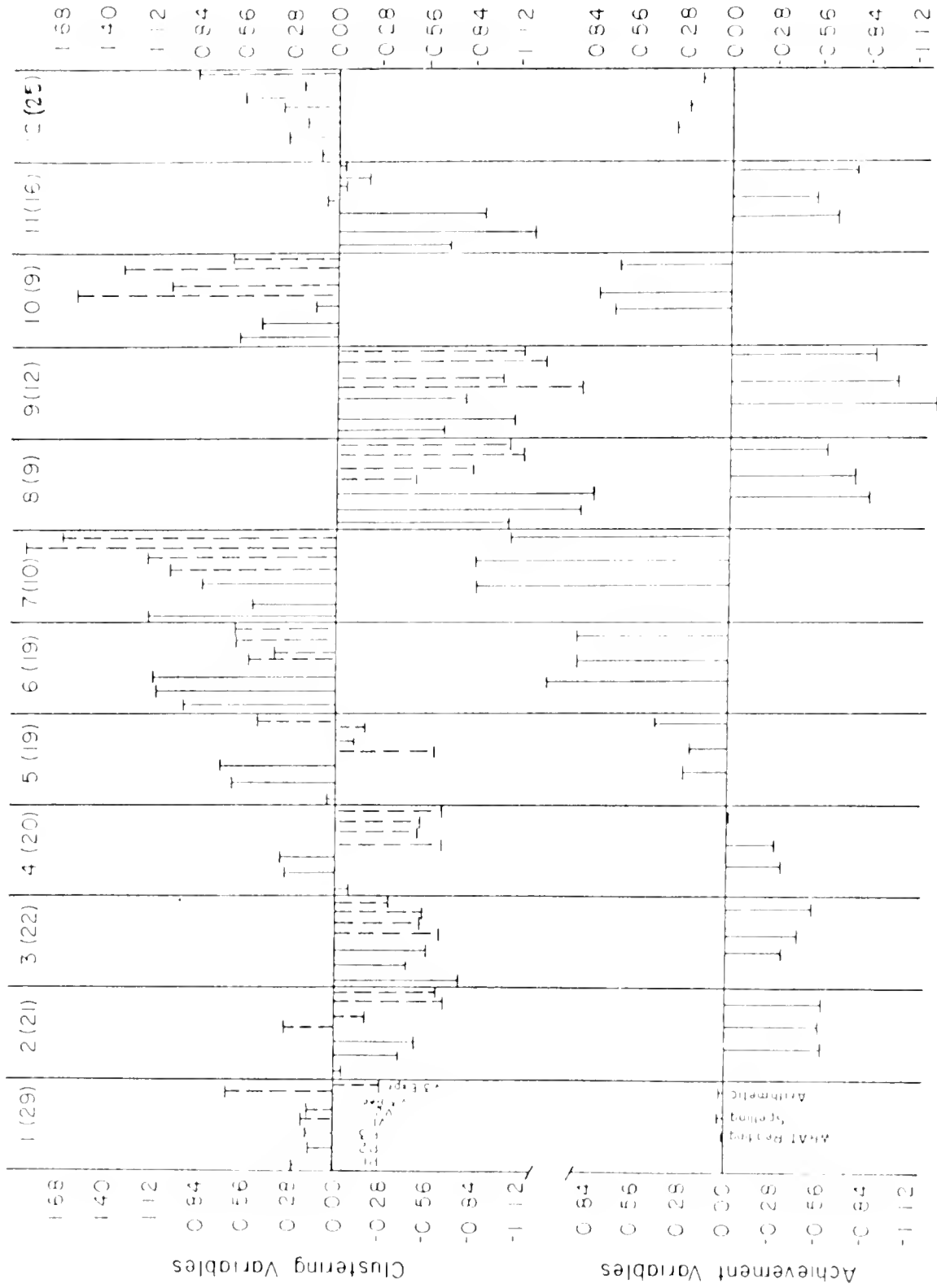


Figure 1 Subgroup Factor Scores for Clustering Variables and Standard Scores for Achievement Variables

From an examination of Figure 1 it can be seen that there are two general approaches for depicting subgroup patterns. The first approach involves comparing the clustering variables, as a whole, to the overall mean. For example, there are some clusters with above-average performance (6, 7, 10, and 12), others with consistently deficient performance (3, 8, and 9), and a third group with scores both above and below the mean (1, 2, 4, 5, and 11). The second and more precise approach is to describe the relative elevation for factor-type and year-probe. The latter approach will be used for individual descriptions of each cluster.

Subgroup 1 is distinguished by generally above-average performance on all variables. Both factor types (perceptual and verbal) are fairly equivalent across probes. The only deviation from this very consistent performance is a split between receptive and expressive language skills at Probe 3. If a single language measure had been used, the clear superiority of receptive language skills would have been masked. Subgroup 2, in contrast, is characterized by generally below average performance which becomes lower with time. Perceptual skills began just below average while verbal skills started at an above-average level. Both factor types, however, were deficient by Probe 3. The pattern for subgroup 3 has both

perceptual and verbal factors below average across probes. The fourth cluster is characterized by a split as a function of factor type. Verbal factors are consistently well below average while the perceptual factor began just below average and improved to its more adequate level within the first three years of the study.

Subgroup 5, like subgroup 4 but at a slightly higher level, improved on perceptual skills early with no further relative gains. Its verbal skills, on the other hand, began at a very deficient level and became better year by year. Subgroup 6 demonstrates above average skills, especially in the perceptual area; no age effect is apparent. Similarly, subgroup 7 is very superior on all measures. Because of improvements through the years, verbal skills are much higher than perceptual ones by Probe 3. Perceptual skills varied with time, but showed no specific trend. Subgroup 8's pattern is very similar to that of subgroup 2, but at a lower level. Subgroup 8 performed very poorly in both perceptual and verbal areas, and then regressed during each re-examination. Subgroup 9 is like the preceding cluster in terms of overall deficient performance for both factors; there are, however, no age differences.

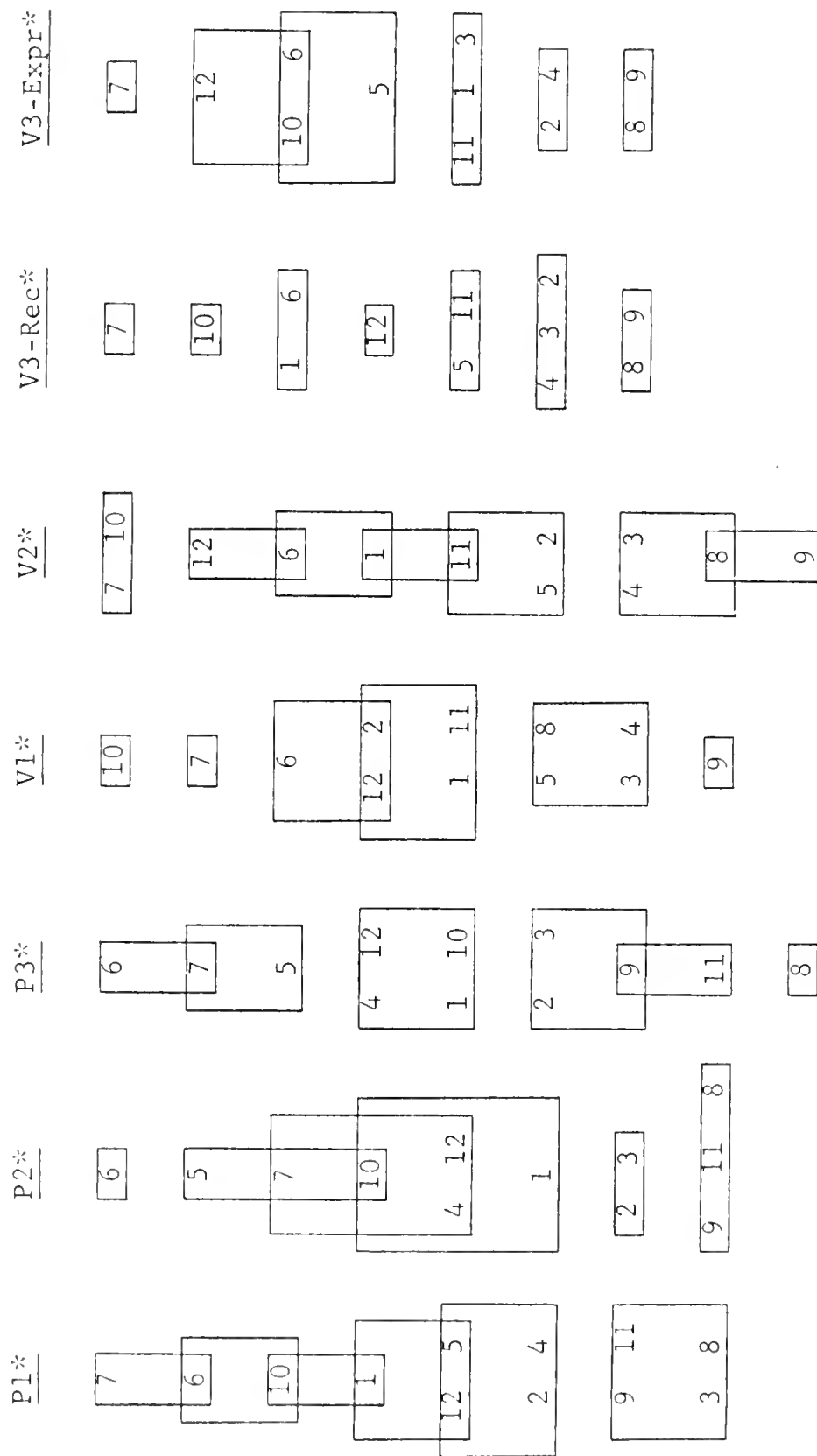
Like subgroups 6 and 7, subgroup 10 is distinguished by above-average performance at all probes for both

factors. While verbal skills are at a high and variable level, perceptual skills deteriorated over time to a level just above average. In contrast to subgroup 4, subgroup 11 demonstrates a specific perceptual deficit: perceptual skills are consistently very low while verbal skills are better and just below average. Subgroup 12 performed at an above-average level on all variables. There is a suggestion that verbal skills are slightly higher than perceptual, although this is obscured by the random variation across probes.

The number of subjects in each subgroup is presented in Table 1 and in the parentheses adjacent to the cluster numbers in Figure 1. The overall sample size is apparently large enough to allow an adequate number of children in each cluster, the range extending from 9 to 29. The smallest subgroups are those with either the best or worst overall performance, and the largest subgroup is the one with the most average performance; this pattern is just as is expected in a normal distribution. It is very important to note that the cluster analytic procedure was able to classify every child in the sample. This is in marked contrast to other classification techniques which generally account for only 40 to 70 percent of their subjects.

It was next necessary to determine the extent to which subgroups differed from one another. A multivariate analysis of variance (MANOVA) on the seven clustering variables revealed an overall significant effect for subgroup (Hotelling-Lawley Trace = 15.89, F approximation (77,1339) = 39.48, $p < 0.0001$. This finding justified the application of univariate analyses for each variable, which yielded significant effects for subgroups on factors P1, $F(11,199) = 31.38$, $p < 0.0001$, on P2, $F(11,199) = 49.51$, $p < 0.0001$, on P3, $F(11,199) = 42.65$, $p < 0.0001$, on V1, $F(11,199) = 49.53$, $p < 0.0001$, on V2, $F(11,199) = 31.71$, $p < 0.0001$, on V3-Rec, $F(11,199) = 52.91$, $p < 0.0001$, and on V3-Expr, $F(11,199) = 41.20$, $p < 0.0001$. Results of significance tests (Duncan's procedure, $p < 0.05$) for differences between subgroup means on each clustering variable are presented in Table 1.

Central to considerations of internal validation is the extent of inter-subgroup heterogeneity on each clustering variable. Figure 2 presents a visual comparison of the subgroup means. An examination of this figure reveals robust differences between subgroups despite similarities between adjacent means. Furthermore, comparisons between factors indicate that relative subgroup rankings are very different, thereby emphasizing the importance of each clustering variable in descriptions of the subgroup



* Subgroups within the same box do not differ significantly.

Figure 2. Configuration of Neuropsychological Subgroup Means for Clustering Variables

patterns. From the preceding discussion of subgroup patterns and supporting statistics, it is apparent that the clusters are definable and internally valid.

Primary External Validation

(2) Are the clusters related to external achievement criteria such as reading, spelling, and arithmetic, and, if so, does this relationship vary by factor type (perceptual vs. verbal) and/or by age?

Achievement scores are available for all children on the Iota Word recognition Test at Probe 2 and Reading, Spelling, and Arithmetic subtests of the Wide Range Achievement Test at Probe 3. In addition, Gates-McGinitie Vocabulary and Comprehension scores were collected for 154 of the children at Probe 2. All achievement scores are highly correlated, but this is especially true of language measures (Table 2). In light of this and so as not to be repetitive, subgroup comparisons will only be presented for the WRAT scores. This measure was selected because of its sampling from more diverse academic areas and because its scores should be more stable, having been obtained at an older age.

Mean scores for the WRAT subtests are reported by subgroup in Table 3. An examination of the subtest means

Table 2

Correlations Between Achievement Measures

	Iota Word Recognition	Gates McGinitie Vocabulary	McGinitie Comprehension	Reading	WRAT Spelling
Gates McGinitie Vocabulary	0.89	---	---	---	---
Gates McGinitie Comprehension	0.81	0.86	---	---	---
WRAT Reading	0.84	0.85	0.76	---	---
WRAT Spelling	0.83	0.79	0.71	0.87	---
WRAT Arithmetic	0.64	0.62	0.62	0.66	0.66

Table 3

Mean WRAT Scores (Probe 3) by Neuropsychological Subgroups

Cluster	Reading*		Spelling*		Arithmetic*	
	Mean	SD	Mean	SD	Mean	SD
1	1.83 DE	21.32	- 9.76 CDE	17.55	-10.55 CD	9.94
2	-13.57 F	14.99	-23.14 FG	10.88	-17.71 DE	7.73
3	- 7.18 EF	20.80	-19.64 EFG	12.09	-16.95 DE	5.60
4	- 6.95 EF	16.77	-16.95 DEF	18.28	-10.95 CD	9.28
5	8.68 CD	16.67	- 5.42 BCD	13.98	- 5.63 BC	12.82
6	30.37 AB	17.36	9.89 A	19.57	0.05 AB	8.78
7	41.70 A	31.94	23.50 A	38.28	4.70 A	17.02
8	-20.56 FG	12.94	-27.11 FG	11.26	-17.78 DE	6.82
9	-30.50 G	9.97	-32.83 G	6.94	-21.17 E	7.40
10	19.89 BC	32.04	7.44 AB	31.15	- 2.78 ABC	15.59
11	-15.19 FG	17.12	-21.44 EFG	12.60	-19.63 E	8.79
12	10.48 CD	22.32	- 4.56 BC	18.20	- 8.76 C	8.41
Total	1.31	26.30	-10.65	22.23	-10.91	11.88

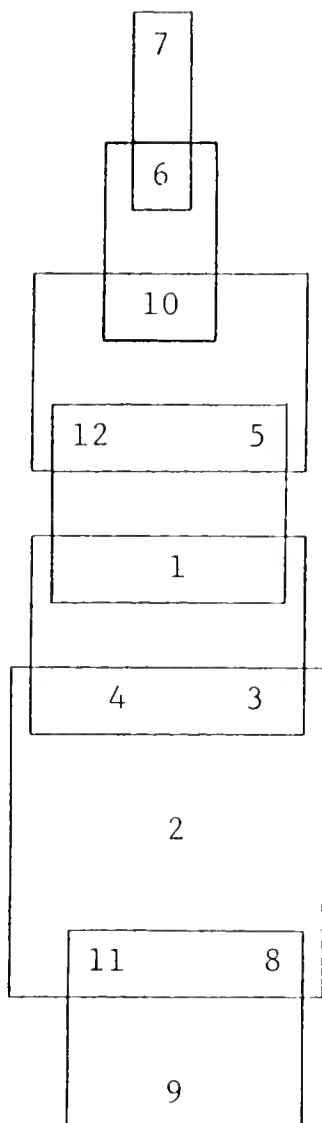
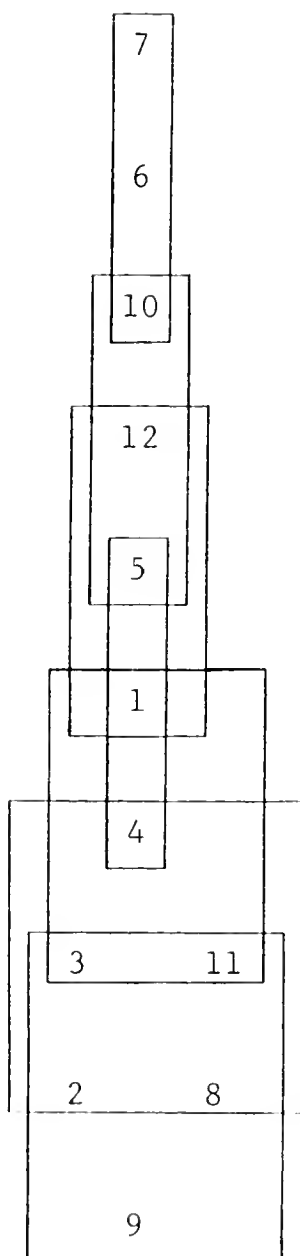
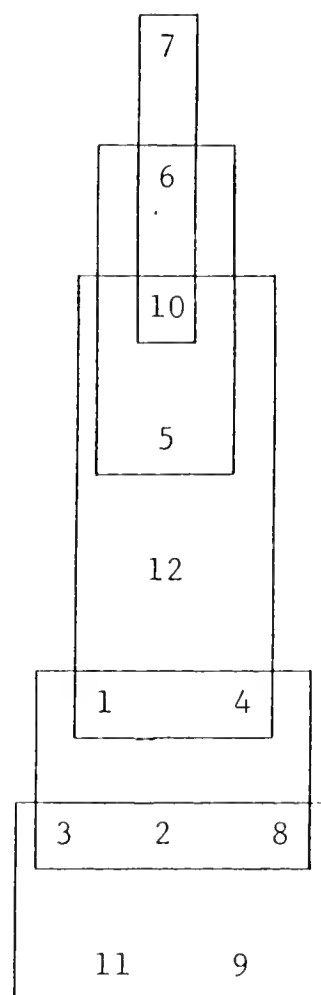
* Means followed by the same letter are not significantly different within variables (Duncan's Multi-Range Test, Alpha level = 0.05).

for the total sample reveals overall age-expected performance in reading. However, in spelling and arithmetic the sample means are approximately 11 months below that expected from the children's chronological age.

In determining whether the clusters are related to external achievement criteria, a MANOVA on the WRAT subtests yielded an overall significant effect for subgroup (Hotelling-Lawley Trace = 1.05, F approximation (33,587) = 6.23, $p < 0.0001$) justifying the application of univariate statistics. Individual analyses reveal significant effects for subgroups on reading, $F(11,199) = 15.49$, $p < 0.0001$, on spelling, $F(11,199) = 11.41$, $p < 0.0001$, and on arithmetic, $F(11,199) = 10.14$, $p < 0.0001$. Means for each variable, with additional results from Duncan's procedures ($p < 0.05$), appear in Table 3 and Figure 3.

From an examination of Figure 3, it is apparent that the classification system developed from neuropsychological factor scores also separates subgroups on academic achievement variables. Even though adjacent subgroups are not statistically significant, there is a clear delineation for clusters which are several steps removed. A comparison of Figures 2 and 3 suggests that the relative ranking of subgroups on achievement measures is most similar to that present with perceptual clustering variables (P1, P2, and P3). To illustrate this point,

Wide Range Achievement Test

Reading*Spelling*Arithmetic*

* Subgroups within the same box do not differ significantly

Figure 3. Configuration of Neuropsychological Subgroup Means for WRAT Scores at Probe 3

subgroups 6 and 7 are ranked highest, 1, 4, and 12 are generally intermediate, and 8, 9, and 11 are ranked lowest for both perceptual and achievement variables; an altogether different pattern is present with the verbal measures.

Figure 1 will be used to examine more closely the relationship between achievement and neuropsychological variables. For uniform comparisons, the achievement data are presented in the form of standard scores which vary above and below the various subtest means of 0.00. The overall pattern is that high neuropsychological skills (both perceptual and verbal) are related to high achievement (e.g., subgroup 7), average neuropsychological skills to average achievement, (e.g., subgroup 1), and low neuropsychological skills to low achievement (e.g., subgroup 9). However, a more complex relationship is apparent with comparisons of various combinations of clusters. Take, for example, subgroup 4 characterized by low verbal and higher perceptual skills and subgroup 11 with its low perceptual and higher verbal skills. Both of these clusters have low (and statistically equivalent) reading and spelling scores. Only in arithmetic did subgroup 4 attain average scores. Subgroups 6 and 10 present a comparable pattern with higher relative performance in one of the neuropsychological areas. Subgroup 6 has higher perceptual than verbal skills while

subgroup 10 has higher verbal than perceptual skills. Nevertheless, their corresponding academic proficiencies are statistically equal. These comparisons suggest that equivalent academic achievement can result from different combinations of neuropsychological subskills. As additional confirmation of this point, these comparisons should be made: subgroups 1 and 5, subgroups 5 and 10, and subgroups 5 and 12. Each comparison is characterized by statistically equivalent achievement but with different combinations of neuropsychological subskills.

Influence of Factor Types

The purpose of this section is to examine the differential contribution of factor types on achievement. Comparisons between individual subgroups will be used in an attempt to partition out the effect of language and nonlanguage measures on achievement competency. Stated another way, what is the relationship between academic achievement and neuropsychological factor type?

The impact of perceptual subskills is evident in those combinations of subgroups with different perceptual, equivalent verbal, and unequal achievement scores. Individual comparisons of subgroups 6 and 12 and subgroups 5 and 11 best illustrate this point. Significant differences between these pairings for all achievement

scores are present when similar differences occur only in perceptual areas. The effect is comparable for subgroups 1 and 11 and subgroups 3 and 4 except that the differences are most apparent on arithmetic tasks. While not causative, the relationship between perceptual skills and academic achievement (especially arithmetic) is apparent.

A similar comparison of verbal subskills and achievement was made using these comparisons: subgroups 1 and 10, subgroups 5 and 7, subgroups 4 and 10, and subgroups 4 and 12. Such comparisons are characterized by equivalent perceptual skills and unequal verbal and achievement scores, thereby highlighting the relationship between these latter two variables. Although the achievement scores are not significantly different, the same trend is apparent in subgroups 1 and 4, subgroups 1 and 12, and subgroups 6 and 7.

By comparing subgroup 11 with both 8 and 9, it appears that very low perceptual skills counteract any expected improvement related to better verbal subskills. Subgroup 11 has perceptual skills equally low to those of subgroups 8 and 9. However, subgroup 11's average verbal skills were not sufficient for more adequate achievement scores.

In conclusion, it appears that high perceptual skills can lead to high achievement and that low perceptual

skills can lead to low achievement. An equivalent direct relationship exists between verbal skills and achievement. Furthermore, one factor type may moderate extreme levels of the other factor type, but the extent to which they interact depends on characteristics of each particular subgroup.

Influence of Age

Subgroup 2 is unique in that its perceptual and verbal scores decrease consistently over time and by Probe 3 are no better than those of subgroup 3. Concurrently, these clusters have equivalent achievement scores. It appears, therefore, that subgroup 2's early proficiency in both perceptual and verbal areas was inadequate to prevent the eventual poorer achievement. A similar trend of decreasing subskill performance is apparent for subgroup 8 while subgroup 5 reveals an increasing pattern of improvement in neuropsychological subskills over time. In each of these subgroups there are clearly developmental changes. But rather than these patterns of developmental changes being related to achievement, the relationship is stronger between achievement and the eventual level of neuropsychological subskills. In concrete terms, this means that for subgroup 2 the impact on achievement of decreasing perceptual and verbal skills is less important than the eventual low level of functioning on the factors.

Secondary External Validation

(3) Are the clusters related to external nonachievement criteria such as IQ, parental reading level, neurological status, and socioeconomic status?

Intelligence

An analysis of variance of Peabody Picture Vocabulary Test intelligence scores yielded a significant effect for subgroup, $F(11,199) = 25.11$, $p < 0.0001$. The results of individual comparisons of subgroup means (Duncan's procedure, $p < 0.05$) are presented in Table 4 and Figure 4. The total sample mean (104) closely approximates the standardization sample mean. As might be expected, subgroup 7 has the highest level of neuropsychological skills in addition to the highest IQ (139), while subgroup 9 is lowest on both variables (IQ = 82). For some clusters, however, there is an interaction between IQ and neuropsychological performance. Subgroups 3 and 8 have average IQs of 96 and 91, respectively, in combination with very low neuropsychological skills. In contrast, subgroup 6's performance on neuropsychological and achievement measures was extremely good compared to its IQ of 114.

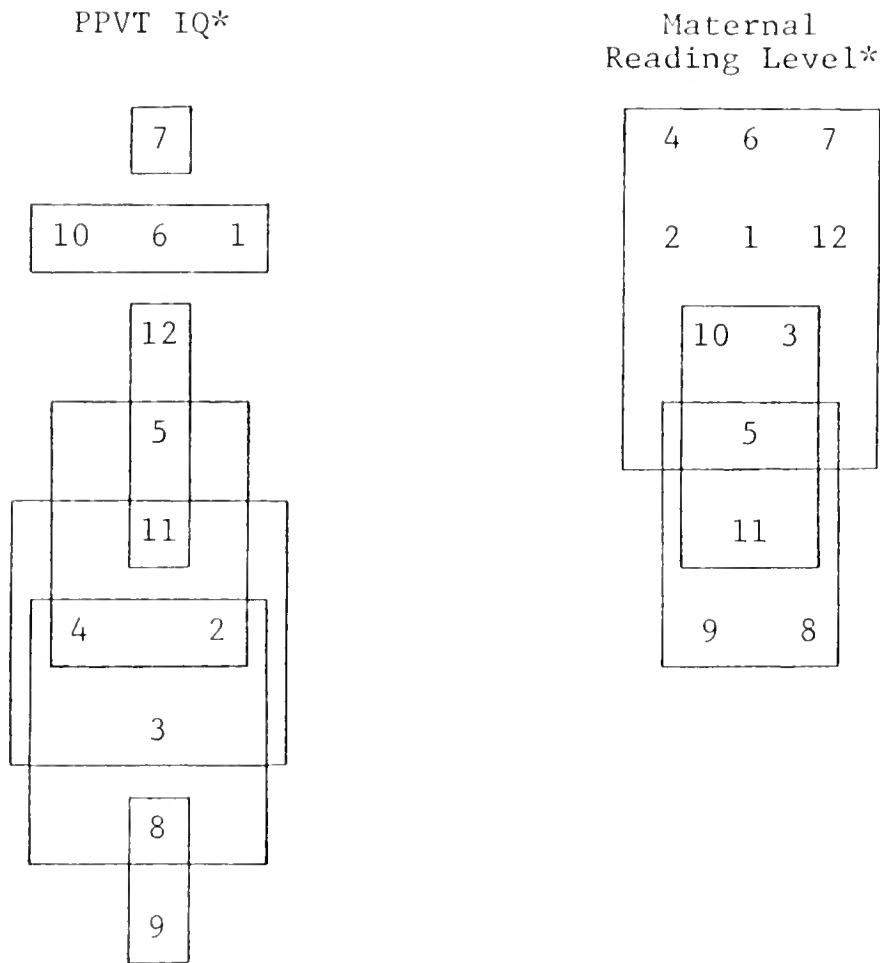
A pattern similar to the achievement data is evident in the IQ scores: in a ranking of the subgroups, adjacent

Table 4

Mean PPVT IQ Scores, Maternal and Paternal Reading
Levels by Neuropsychological Subgroups

<u>Cluster</u>	<u>PPVT IQ*</u>		<u>Maternal Reading Level*</u>		<u>Paternal Reading Level</u>	
	<u>Mean</u>	<u>SD</u>	<u>Mean</u>	<u>SD</u>	<u>Mean</u>	<u>SD</u>
1	113.66 B	10.61	12.38 A	0.64	12.43	0.65
2	96.57 DEF	12.07	12.41 A	0.82	12.30	0.89
3	95.50 EF	10.04	11.81 AB	0.72	13.32	0.85
4	97.80 DEF	11.24	13.25 A	0.83	10.87	0.94
5	103.16 CD	9.89	10.81 ABC	0.95	11.28	1.01
6	113.79 B	7.98	13.13 A	0.79	14.66	0.90
7	138.90 A	11.99	13.13 A	1.09	13.05	1.11
8	90.89 FG	9.94	8.71 C	1.12	12.14	1.26
9	81.75 G	11.76	8.92 C	0.96	10.43	1.29
10	121.22 B	13.28	12.56 AB	1.26	15.48	1.33
11	100.63 CDE	11.97	9.76 BC	0.83	11.68	0.96
12	106.20 C	7.72	12.36 A	0.75	12.22	0.74
Total	104.49	15.85				

* Means followed by the same letter are not significantly different within variables.



* Subgroups within the same box do not differ significantly

Figure 4. Configuration of Neuropsychological Subgroup Means for IQ Scores (Probe 3) and Maternal Reading Level

means tend not to be significantly different. Comparisons of Figure 4 with Figure 2 suggest similar relative rankings on the IQ scores and clustering variables. The relationship is strongest with V3-Rec, a finding consistent with the opinion that the PPVT measures receptive language abilities. Relative IQ rankings are also markedly similar to those of achievement measures (Figure 3) except for subgroups 1 and 11, whose rankings on all achievement measures are below that of their IQ scores.

Parental Reading Levels

Reading grade equivalents were obtained on 141 mothers and 102 fathers of the children used in this study. Because of differences on these measures, the levels of parental socioeconomic status and education level were taken into consideration through covariate analyses of the data.

The effect of mothers' education level was significant, $F(1,127) = 72.63$, $p < 0.001$, as was the effect of SES, $F(1,127) = 11.52$, $p < 0.0001$. An analysis of covariance of the mothers' reading grade equivalents yielded a significant subgroup effect, $F(11,127) = 2.72$, $p < 0.003$. Subgroup means for maternal reading levels (corrected for covariates) appear in Table 4. The results of pairwise comparisons (Least Squares Means, $p, 0.05$)

between subgroups appear in Figure 4. Although not nearly as clear as other contrasts, there are significant differences between clusters. After adjustments for the covariates, the mothers of children in subgroup 4 exhibited the highest reading skills (grade equivalent = 13.25). Neuropsychologically, the children of subgroup 4 are characterized by a specific verbal deficit. The mothers of subgroups 6 and 7 are also good readers (grade equivalents of 13.13) while the mothers of subgroups 8, 9, and 11 are the worst readers (8.71, 8.92, and 9.76, respectively). It should be noted that the children in subgroups 6 and 7 demonstrate consistently high neuropsychological skills while these measures are very low for subgroups 8 and 9. Subgroup 11 has a specific perceptual deficit.

While there was a significant covariate effect for the fathers' education level $F(1,88) = 84.11$, $p < 0.001$, the effect for SES was nonsignificant, $F(1,88) = 0.29$, $p < 0.59$. The analysis of covariance of the fathers' reading grade equivalents failed to yield a significant subgroup effect, $F(11,88) = 1.76$, $p < 0.071$. The subgroup means for paternal reading level also appear in Table 4.

Neurological Examination

During the fourth year of the longitudinal study, 143 of the children in this study received a neurological exam consisting of the following: 1) a general examination

assessing cranial nerves, motor responses, sensation, reflexes, and cerebellar functioning; 2) special exam to evaluate fine and gross motor functioning, right-left discrimination and eye tracking; and 3) an evaluation of gross body anomalies or stigmata of head, eyes, ears, mouth and feet. Neurologists from the University of Florida conducted each examination without concurrent data on the child and made an assignment to one of three categories (affected, borderline-equivocal, or normal) on the basis of overall clinical judgment and component numerical scores.

The data on neurological ratings for each subgroup are presented in Table 5. Overall, a high proportion (46 percent) of the children were rated as being "affected" neurologically. Furthermore, the absence of data on 68 children results in some subgroups being under-represented, such as subgroup 10 with 5 members. Because of these observations, the neurological data must be viewed with some caution. However, a significant relationship between the distribution of neurological status by subgroup was confirmed using the chi-square test for independence, $\chi^2 = 52.75$, $p < 0.0002$. From an inspection of cell frequencies in Table 5, it is evident that subgroups with the most deficient performance on neuropsychological clustering variables (subgroups 8 and 9) also have the highest frequency of positive neurological

Table 5

Neurological Ratings By Neuropsychological Subgroups

<u>Subgroup</u>	<u>N</u>	<u>Missing Value</u>	<u>Normal % of</u>		<u>Equivocal % of</u>		<u>Affected % of</u>	
			<u>Freq</u>	<u>Subgroup</u>	<u>Freq</u>	<u>Subgroup</u>	<u>Freq</u>	<u>Subgroup</u>
1	29	10	8	42	3	16	8	42
2	21	9	3	25	3	25	6	50
3	22	6	2	13	5	31	9	56
4	20	8	4	33	2	17	6	50
5	19	9	2	20	3	30	5	50
6	19	5	10	71	1	7	3	21
7	10	2	6	75	2	25	0	0
8	9	1	0	0	0	0	8	100
9	12	0	1	8	1	8	10	83
10	9	4	2	40	3	60	0	0
11	16	4	1	8	3	25	8	67
12	25	10	8	53	4	27	3	20
Sample	211	68	47	33	30	21	66	46

findings (100 and 83 percent). Conversely the highest performing subgroups (numbers 6, 7, 10, and 12) have fewer children so rated (3, 0, 0, and 3 percent, respectively).

Socioeconomic Status

The measures of SES were obtained at Probe 3 on a scale of (1) low or (2) average or above. The teachers rated each child based on enrollment in the free lunch program. From this gross differentiation of cultural background only 16 percent of the children were designated as having low SES. Based on the frequency distribution in Table 6, the relationship between subgroups and this variable was determined to be significant, $\chi^2 = 61.69$, $p < 0.0001$. More particularly, those subgroups with the lowest neuropsychological performance consistently had a greater representation of low SES ratings (subgroups 8 and 9). Such ratings were infrequent, if at all present, for clusters with average and above scores on all clustering variables (e.g., subgroups 6 and 7).

Table 6

Socioeconomic Status By Neuropsychological Subgroups

<u>Subgroup</u>	<u>N</u>	<u>Missing Value</u>	<u>Low</u>		<u>Average or Above</u>	
			<u>Freq</u>	<u>% of Subgroup</u>	<u>Freq</u>	<u>% of Subgroup</u>
1	29	0	0	0	29	100
2	21	1	4	20	16	80
3	22	0	8	36	14	64
4	20	0	2	10	18	90
5	19	0	1	5	18	95
6	19	0	1	5	18	95
7	10	0	0	0	10	100
8	9	0	5	56	4	44
9	12	0	9	75	3	25
10	9	0	1	11	8	89
11	16	0	1	6	15	94
12	25	0	2	8	23	92
Sample	211	1	34	16	176	84

CHAPTER IV

DISCUSSION

The results of this project demonstrated the utility of a cluster analytic approach to longitudinal neuropsychological data. Previous applications of cluster methods to longitudinal data have been infrequent (Rice & Mattsson, 1966), and cluster analysis has never been used in a longitudinal study of learning disabilities. The study was strengthened, in part, by its use of an unselected group of failing achievers who were then matched with twice as many same-aged children selected only on the basis of their being at least average achievers. The children were not included because of clinic referral and were homogeneous with regard to sex, race, educational experience, and geographic location. And finally, the study was unique in its inclusion of repeated measures on the same children over a six-year period, multiple measurements of neuropsychological functioning, extensive neurological data, and family history variables.

Internal Validation

The first and major question addressed by this project was: Would definable subgroups emerge from longitudinal neuropsychological data? The issues of whether the subgroups are definable and, similarly, meaningful are extremely important because cluster analysis cannot take these factors into consideration. In fact, without proper safeguards, cluster analysis will identify subgroups from data in which there is no underlying structure. Cluster analysis begins with every subject as an independent cluster and then proceeds to combine those which are most similar. If left unchecked, cluster analysis will eventually organize all subjects into a single large cluster. Of critical importance, then, is determining when to stop the clustering process. When such characteristics are acknowledged and appropriate safeguards taken, cluster analysis becomes a precise and powerful statistical procedure.

Data analyses were used to confirm the internal validity of the subgroups. Individual subgroups were adequately compact (homogeneous) and statistically different from other subgroups. Descriptions of some subgroups proved easy because they were either high (subgroup 7), intermediate (1 and 12), or low (3 and 9) on all clustering variables. For the majority of the subgroups, however, the pattern of neuropsychological

development was more complex. It became necessary to consider the relative elevation of factor types in addition to the overall level of the subskills. For example, some subgroups demonstrated exclusively high perceptual (subgroup 6) or verbal (10) performance competency, while for others one of the performance factors was low. Subgroup 4 was low only in verbal skills and subgroup 11 was low in perceptual skills. For still other subgroups it was necessary to consider changes with time; two subgroups (2 and 8) consistently regressed on both factor-types during the 6 years of the study while subgroup 5 showed the pattern of improving subskills. The results, then, confirmed that the subgroups were definable and meaningful. Furthermore, descriptions of a child's neuropsychological functioning must optimally contain statements of the overall level of the skills, relative elevations of factor-types, and whether any developmental changes exist.

Primary External Validation

The study's second question involved whether the neuropsychological clusters were related to achievement variables. This was of particular concern because the issue of external validity is virtually never addressed in subgroup research regardless of the method of subtype division. As was stated in the first chapter of this paper, too many researchers have been satisfied to simply

describe the categories of poor readers which they believe to exist based on clinical experience. When no data are presented to justify the derivation of the categories, it is not surprising that verification of subgroups' meaningfulness is also lacking.

The results showed a robust relationship between neuropsychological competency and reading achievement, just as was expected (Darby, 1978; Rourke & Finlayson, 1978; Satz et al., 1978). For some clusters it was a simple direct relationship of high neuropsychological performance to high achievement (subgroup 7), intermediate to intermediate (subgroup 1), or low to low (subgroups 3 and 9). For other subgroups, however, the relationship between achievement and factor type had to be considered. The unique design of this investigation with its separation of variables into perceptual and verbal factor scores made it possible to study the relationship in more detail.

Comparisons between individual subgroups, as was elaborated in the previous chapter, helped clarify the influences of individual neuropsychological factors upon achievement. Independent of the method of examination, the importance of language skills in academic achievement, and especially reading, is certain. There are clearly subgroups (4, 10, and 12) for which verbal skills are most

closely related to reading level. While this relationship is well recognized for the learning disabled (Cole & Kraft, 1964; Denckla, 1972; Benton, 1975; Yule & Rutter, 1976; Darby, 1978), similar conclusions can now be extended to average and superior readers. This latter point should not be minimized.

For other subgroups, however, the relationship between perceptual performance skills and reading seemed greater. Subgroup 11 is a case in point because it is characterized by average verbal skills and a specific perceptual deficit. Academically, this subgroup is deficient and at a level consistent with its perceptual skills. Apparently, then, verbal strengths in this cluster group were insufficient to compensate for their academic achievement failure. The comparison between subgroups 6 and 10 also illustrated this point. Subgroup 6 is characterized by higher perceptual than verbal skills; the reverse is true for subgroup 10. Furthermore, their respective IQs are 114 and 121. If language skills are the crucial factor, subgroup 10 should have a clear advantage. Yet it is subgroup 6 which is slightly, though nonsignificantly, better academically. The present results provide additional evidence against the exclusive role of language measures in the development of reading competence (cf., Vellutino et al., 1975; Vellutino, 1977).

For example, it was shown that delays in perceptual scores were associated with reading failure and that elevations in this factor type were associated with reading success. Intact verbal skills, in the presence of deficient perceptual performance did not protect children in these subgroups from reading failure. These findings are compatible with other clinical subtype studies which have employed less precise multivariate methods (Cole & Kraft, 1964; Denckla, 1972; Boder, 1973; Mattis et al., 1975). However, in most of these approaches, the perceptual deficit subtype group has either been small (Denckla, 1972; Mattis et al., 1975) or associated with other cognitive linguistic deficits (mixed subtype) (Cole & Kraft, 1964; Boder, 1973). However, in a recent study employing multiple cluster analytic techniques at one age level (Satz, Morris, & Darby, 1979) results revealed a distinct and homogeneous perceptual deficit subtype that was almost as large as two of the language deficient subtype groups. Each of these finding, in summary, illustrates the complexity of neuropsychological components in reading. It is becoming increasingly clear that combinations of both perceptual and verbal factors influence a child's reading level. The current research indicates that there are at least 12 combinations of these neuropsychological skills and that each pattern is independently related to achievement.

For some subgroups it was necessary to consider age effects and their relationship to achievement. Subgroups 2 and 8 are especially unique in that they demonstrate a consistent regression in neuropsychological functioning across time. Subgroup 2 began with average perceptual and slightly above-average verbal skills, while subgroup 8 began at deficient levels and then got worse. The existence of such non-recovering subgroups is contrary to lag theorists (Satz & Sparrow, 1970) who predict that learning disabled children eventually catch up on earlier developing skills such as visual-perceptual and cross-modal sensory integration. These children are further characterized by IQs within the average range and a higher incidence of "affected" ratings on neurological examinations: half of the children in subgroup 2 and fully 100 percent of subgroup 8. Even in the presence of adequate intellectual functioning and early strength on neuropsychological skills, these children proved destined for deficient academic achievement. If subgroup 2 had had a single evaluation at one of the earlier probes, it would have been inadequately represented and possibly classified as unexpected reading failure (Symmes & Rapoport, 1972). An intriguing and very important research project would be to identify children of subgroups 2 and 8 at an early age so that attempts could be made to prevent their academic demise. The detection of subgroup 8 might prove easier because of the high frequency of neurological problems.

Subgroup 2, however, began as a very average group of children. For that reason, little attention was probably called to them, making their delayed development less apparent until later years when intervention is much more difficult.

The pattern of performance of subgroup 5 was unique and interesting because both factor types improved over time. Perceptual skills seemed to have largely reached their eventual level by Probe 2, whereas expressive verbal skills were still improving at Probe 3. It is a pattern such as this that lag theorists have expected to find with developmental dyslexia (Satz & Sparrow, 1970). While evaluations of such theories have proven unsuccessful (Fennell, 1978), this is perhaps because the research concentrated on larger, more heterogeneous groups instead of subgroups derived on the basis of multivariate descriptive procedures.

Darby (1978), using cluster analytic techniques, observed a relationship between depressed arithmetic scores and perceptual-motor performance. A similar relationship was in part demonstrated in the current results. The arithmetic performances for subgroups 4 and 5 were somewhat higher than their reading and spelling scores, just as their spatial-perceptual scores were higher than their conceptual-linguistic scores. The

relationship for subgroups 7 and 11 was in the opposite direction: poorer arithmetic relative to other achievement areas when perceptual skills were also relatively depressed. These results are comparable to those of Rourke and associates (Rourke & Finlayson, 1978; Rourke & Strang, 1978), even though they created their groups based on achievement patterns and then examined external neuropsychological patterns, the reverse of this study. Since Rourke only examined children with learning disabilities, there are no comparison groups for subgroups 5 and 7. However, subgroup 4 is similar academically and neuropsychologically to Rourke's Group 2, and subgroup 11 is like his Group 3. Without more direct evidence as to the functional integrity of the cerebral hemispheres, this study cannot make statements as to right hemisphere superiority for types of calculation abilities (Hecaen, 1962; Dimond & Beaumont, 1972). Nevertheless, the relative strengths of subgroups 4 and 5 and relative weaknesses of subgroups 7 and 11 are consistent with the position (Rutter, 1978) that specific arithmetic calculation skills are due to particular patterns of visual-spatial organization and integration, skills ordinarily thought to be subserved by the right cerebral hemisphere (Reitan, 1966).

Comparisons between the current classification system and those reviewed in the first chapter have proven

difficult. A primary reason for the paucity of comparisons stems from this study's inclusion of children from all performance levels; all other classification systems are based exclusively on disabled populations. Therefore, the six subgroups with average or above performance cannot be contrasted to any subgroups in the literature.

The second major obstacle to comparisons stems from differences in data bases. Since some classification systems were derived from clinical experience and no validating data, comparisons were restricted to their general statements describing each group. Differences also occurred on the type of data upon which classification systems were based. As an example, Rourke and Finlayson (1978) differentiated their groups on the basis of achievement and then looked at differences in the neuropsychological measures. In contrast, the current classification system was based on neuropsychological measures and validated with achievement scores. Since opposite sequences were used, comparisons between studies proved more difficult. And finally, even when other classification systems were based on neuropsychological measures, comparisons were limited if different tests were used. To illustrate this point, Doehring and Hoshko (1977) and Petrauskas and Rourke (1979) used measures of conceptual flexibility, linguistic coding, temporal

sequencing, memory, auditory-visual matching, etc., all of which had nothing comparable in this study. Because of reasons such as these, comparisons to the results of other studies have been restricted.

Secondary External Validation

A third major issue in the study was addressed to external validation of the 12-cluster solution from nonachievement measures. The measures used for these comparisons included intelligence, maternal and paternal reading levels, neurological ratings, and socioeconomic status. The relationships were significant for all measures with the exception of the fathers' reading scores. The children from the subgroups with the lowest neuropsychological scores had the lowest IQs, mothers who were the poorest readers, were most frequently evaluated as having neurological difficulties, and were of lower SES. The opposite pattern was found for children with high neuropsychological performance skills. As a whole, these results provided additional support for the validity of the neuropsychological subgroups.

The high incidence of positive neurological findings with deficient achievers has long been reported (Cole &

Kraft, 1964; Benton, 1975); this study added further confirmation. That proportionally more children in this study received an "affected" rating is not surprising given the high frequency of poor achievers (roughly one-third of the original sample). Furthermore, the type of examination conducted for this project included extensive procedures designed to detect even very subtle deviations in neurological status. The results are, therefore, probably not equivalent to those of other studies..

The significant relationship between maternal reading level and the neuropsychological subgroups is interesting because it is consistent with the familial nature of dyslexia. Even after the confounding effects of the mothers' educational level and SES were removed through a covariate analysis, it was still evident that children with poor neuropsychological performance and low academic achievement also had mothers who could not read well. With this study's focus on the identification of subgroups, it was unable to explore the genetic versus environment controversy more fully. Other recent studies, however, have attempted to do this.

In a well-controlled study, Owen (1978) created 76 quartets of children, with each quartet consisting of a learning disabled child, a matched academically successful child, and one like-sex sibling for each. The results

showed that the parents and siblings of the learning disabled children were more similar than the academically successful children on a variety of achievement and neuropsychological tests. Although the results were compatible with genetic and/or environmental modes of transmission, additional evidence in favor of the genetic factor came from the aggregation of neurological immaturities in the siblings of disabled learners.

Taylor, Satz, & Friel (1979) also addressed this issue by examining the reading and spelling percentiles of the parents of normal and disabled readers. Since the parents of probands were from lower SES and educational backgrounds, an analysis of covariance was used. Results showed that the parents of probands were significantly lower in both academic areas, regardless of parental sex. Of special note was the wide discrepancy between the spelling skills of the two groups, suggesting that the parents of the poor readers may have compensated to some extent for their more severe reading problems as children. Since compensations in spelling are more difficult, spelling disability may be a more sensitive indicator of adult language disability than reading. Again, the results gave credence to both social and genetic mechanisms in the transmission of reading disabilities.

A crucial problem to all studies of familial factors has been the failure to operationally identify subgroups of the index children (Taylor et al., 1979). It is foolhardy to think that a single mode of transmission exists in all types of readers. Owen (1978) attempted to identify categories on the basis of WISC IQ patterns but found that the subgroups overlapped too much. Therein lies this study's solution to this problem. The empirically-derived classification system of this study may subsequently be used as the framework for determining which subgroups have specific genetic or cultural modes of transmission.

An unexpected finding was the absence of a significant relationship between subgroups and fathers' reading levels. Conceivably, the relationship with the fathers failed to reach significance because data were available on just under half of the fathers. Consequently, some of the subgroups were represented by as few as four fathers. Table 4 shows that the subgroup grade equivalents for the fathers ranged from 10.43 years to 15.48 years. For mothers, however, the range was from 8.71 years to 13.25 years. It appears, therefore, that the fathers were not represented by as many poor readers. Conceivably, the fathers who failed to participate in the examination were also the poorer readers and they were attempting to avoid what was seen as a potentially embarrassing situation. Such an absence of one extreme of the distribution would

be adequate to remove statistical significance. Naturally, reading information would ideally have been gathered on all parents, thereby strengthening the study. Such an endeavor, however, is very difficult in this type of longitudinal research.

Additional improvement in this study would have come from use of more precise socioeconomic measures. Despite differences on this variable, the use of a dichotomous measure of SES has not been particularly useful at the present stage of knowledge (Rutter, 1978). Also desirable would be complete Wechsler intelligence scores and measures of reading comprehension on each child, but such ideal situations quickly fall prey to practicality in a project of this scope.

If adequate funding were available, cluster analytic investigation should be cross-validated on all children in a geographical area, independent of sex or race. Increasing the overall sample size would proportionally increase the subgroup sample sizes. This would make it possible to evaluate separate hypotheses for each homogeneous subgroup, such as specific neurological patterns, patterns consistent with lag theorists, possible differences in cognitive strategies, etc. If subgroups were large enough, it would be interesting to perform separate stepwise discriminant function analyses to

determine if different subgroups have different rankings of predictor variables obtained at kindergarten. For each subgroup, then, it could be determined if variables from a particular factor-type were better predictors of reading outcome. Another project might use Zigler's approach to mental retardation (1969) and compare a subgroup of deficient readers to an achievement-matched group of younger average readers. Such an approach might clarify whether the deficient children are simply delayed on the tasks or if there is an actual difference in their skills.

In summary, the present results lend further credence to the position that reading is a highly complex activity which is dependent upon many cognitive skills (Maliphant et al., 1974; Benton, 1978; Rutter, 1978; Fletcher & Satz, 1979). Anyone who assumes that a unitary mechanism (rate, deficit, or otherwise) accounts for a major proportion of the variance in reading has simply been misled. Consequently, it has not proved easy to determine the relative importance of each skill in either reading competence or reading difficulties. Twelve independent patterns of neuropsychological performance were identified by this investigation and related to 12 patterns of achievement. Through the use of factor scores, credence was given to the position by Cruickshank (1977) and Fletcher and Satz (1979) that both visual-spatial and conceptual-linguistic processes interact with

developmental factors in reading proficiency. A high frequency of neurodevelopmental subtype patterns was associated with an increased risk of poor achievement.

The present results, while promising, still demonstrate the complexity and ambiguities associated with reading competency. Systematic studies using homogeneous, well-defined developmental subgroups seem to offer the greatest hope for an understanding of the mechanisms and processes of learning to read. From that may come more effective preventive and remedial reading programs.

APPENDIX

Factor Score Standard Deviations for Neuropsychological Subgroups

Cluster	P1	P2	P3	V1	V2	V3-Rec	V3-Expr
1	0.52	0.41	0.51	0.36	0.38	0.37	0.37
2	0.38	0.44	0.40	0.38	0.37	0.36	0.43
3	0.40	0.43	0.40	0.34	0.35	0.51	0.50
4	0.38	0.49	0.34	0.48	0.57	0.57	0.34
5	0.54	0.34	0.41	0.40	0.46	0.43	0.58
6	0.43	0.43	0.45	0.41	0.44	0.51	0.60
7	0.44	0.48	0.54	0.37	0.41	0.39	0.51
8	0.40	0.44	0.61	0.26	0.44	0.41	0.37
9	0.55	0.59	0.33	0.60	0.58	0.52	0.61
10	0.62	0.42	0.48	0.41	0.36	0.41	0.54
11	0.38	0.47	0.64	0.35	0.32	0.50	0.60
12	0.35	0.36	0.39	0.52	0.42	0.49	0.40
Total	0.72	0.82	0.81	0.79	0.69	0.89	0.85

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BIOGRAPHICAL SKETCH


Charles A. Schauer was born in Brady, Texas, on April 8, 1949. He lived in Tomball, Texas, and graduated from Tomball High School in 1967. He attended Southern Methodist University, receiving a Bachelor of Arts in psychology and mathematics in 1971 and a Master of Arts in psychology in 1972. The next three years were spent in the Clinical Psychology program at the University of Florida. An additional three years were spent at Lafayette Clinic in Detroit, Michigan, one year in the Clinical Internship Program and two years as a staff psychologist. He returned to Gainesville in 1978 and received his doctorate in clinical psychology from the University of Florida in December, 1979.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.



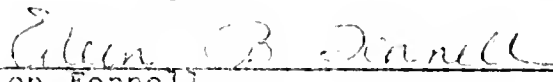
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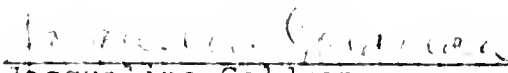
Randy Carter
Assistant Professor of Statistics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.



Eileen Fennell
Assistant Professor of Clinical Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.



Jacqueline Goldman
Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.



Carol VanHartesveldt
Associate Professor of Psychology

This dissertation was submitted to the Graduate Faculty of the Department of Psychology in the College of Liberal Arts and Sciences and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December, 1979

Dean, Graduate School

