Braille-Based Remediation for Dyslexia: No Magic Wand, but an Effective, Non-conventional Solution

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ABSTRACT

In a longitudinal field study, an Experimental group of 20 school students diagnosed as dyslexic, who had failed to respond to a variety of conventional remedial approaches, were taught to read tactile braille, and then used tactile braille to learn approximately 1000 high-frequency words. Visual word recognition, passage-reading rate, passage-reading accuracy and reading comprehension were sampled at three-monthly intervals from commencement of braille training to end of follow-up. The Milton Word Recognition Test and the Neale Analysis of Reading Ability - Revised were used for this purpose.

Braille-based input ceased with the Experimental group when visual word recognition performance on the Milton reached the 18th percentile. Visual reading performance was then observed over a minimum follow-up period of 12 months. Reading performance measures for all experimental group members taken upon entering braille training, upon cessation of braille training and at the end of the follow-up phase were subjected to MANOVA. Results showed that performance standards had improved significantly at each of these stages on all dependent variables. The word recognition protocols of 15 Experimental participants were then subjected to Interrupted Time Series Analysis. These procedures confirmed the improvements demonstrated in the MANOVA for 14 of the 15 participants and provided evidence for permanence of training effect.

In order to demonstrate the inappropriateness of using conventional remedial reading approaches with dyslexia, a Comparison group of 20 dyslexic students, comprehensively matched in terms of demographic characteristics, was identified from archival records. This group did not receive braille-based input as they had completed Year 7 (the upper limit of primary schooling) immediately prior to the commencement of this study. Milton Word Recognition Test results posted by these students across their primary school years were obtained from their files and graphed for visual inspection. These line plots visualize the continuing reading failure experienced by these students in the face of all attempts at remediation.

DECLARATION

This dissertation is entirely my own work and contains no material which has been previously submitted for the purpose of assessment at any University. Except when due reference is made in the text, this dissertation contains, to the best of my knowledge, no material previously written or published by another author.

....

Graham Charles King

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CHAPTER 1: READING PROBLEMS

This chapter presents an historical overview of reading problems and then addresses the problematic issues of terminology and the relationship between "reading" and "learning" disability. The focus then narrows, specifying dyslexia as the phenomenon of interest. Distinguishing characteristics of dyslexia are described and empirical evidence that the tactile modality is intact in dyslexic individuals is cited. Comments on operational criteria, as adopted for this study, and the emerging issue of subtyping reflect the long-standing lack of consensus which characterises the professional endeavour of practitioners in the reading disabilities field.

Historical Overview

Problems with the extraction of meaning from symbolic visual input have in all likelihood been lurking within the intellectual scape of humankind since our emergence as a species endowed with the potential for cognition. It is likely that problems intrinsic to this activity for certain students of the Space Age also bedevilled certain students of the Stone Age and that affected individuals have, down through the ages, "... lost the spoor ... mistied the knots ... entangled the nets ... struggled with the sextant ... and ... missed the target ..." (Barsch, 1992).

With the emergence of writing as the principal means of recording and communicating information, reading became the principal mode of learning, and there was at once established a medium for the manifestation of reading problems. The invention of the first orthographic communications system would have predated only momentarily the appearance of the first reading, and hence learning, disabilities.

Reading disability was first described in the United Kingdom (Morgan, 1896). While early documentation referred to disease processes in adults, accounts of similar symptomatology in children soon followed, cases subsequently being reported in Holland, Argentina, France, Germany, Italy, Japan, Australia, New Zealand, Finland and the United States (Duane, 1983). Prominent among the first professionals to intervene were medical specialists who diagnosed reading failure in physical terms like "congenital word blindness" (Hinshelwood, 1917), "strephosymbolia" or "twisted symbols", "visual-perceptual handicap" and "deviant brain function". By 1909 the nomenclature included terminology such as "legasthenia", "bradylexia", "typholexia", "word amblyopia", "amnesia visualis verbalis", "script blindness" and "analphabetica partialis" (Critchley, 1986). These descriptors were superseded by terms like "minimal brain dysfunction" and eventually "learning disorder / disability", "reading disorder / disability" and "dyslexia" when psychologists, speech pathologists and educators entered the debate.

Throughout the literature, the term "learning" is frequently used synonymously with "reading" and the terms "learning disability (LD)", "reading disability" and "dyslexia" are loosely applied to what appears to be the same phenomenon. Terminology is often unclear and inconsistent (e.g., Rayner & Pollatsek, 1989; Vellutino, 1979). This confusion is probably attributable to the fact that, although all sensory modalities contribute to the acquisition of knowledge, the primary modality involved in learning is vision, and the primary learning process is reading.

Studies Equating Learning Disability (LD) with Reading Disability

Most of the research on learning disorders has focussed on reading (Coplin & Morgan, 1988), numerous studies using the terms "learning disorder / disability" and " reading disorder / disability" interchangeably (e.g., Coles, 1987; Cornwall, 1992; Kirby & Robinson, 1987; Naglieri & Reardon, 1993; Olson, Wise, Conners, Rack & Fulker, 1989; Stanovich, 1991; Swanson & Ramalgia, 1992). Bartoli and Bartel titled their (1988) paper ".. reading / learning disability ..". Swanson (1994), in a study of children and adults with learning disabilities, defined his subjects as learning disabled on the basis of their word recognition scores, stating that " ... students with learning disabilities were selected ... because of primary problems in reading ...". (p.36) Catts (1997) also noted that "... traditionally, reading / learning disabilities have been identified primarily on the basis of reading problems." (p.86)

Thorpe, Lampe, Nash & Chiang (1981) selected their learning disabled experimental group on the basis of reading deficits, as did Hardy, McIntyre, Brown and North (1989) and Bruck (1990). Aaron

(1991) pointed out that the diagnosis of LD is accomplished with the use of standardized tests of reading ability. Stanovich (1988) described reading disability as the most prevalent type of learning disability, while Lyon (1989) acknowledged that children with reading disabilities constitute a large proportion of the LD population. Coman, Murphy and Turner (1989) stated that the most common learning difficulties are reading and writing. Lyon (1995) noted that reading disabilities affect at least 80% of the LD population and thus constitute the most prevalent type of learning disorder.

The National Joint Committee on Learning Disabilities (NJCLD) (1994) definition of LD stated that learning disabilities are "... significant difficulties in the acquisition and use of listening, speaking, reading, writing, reasoning or mathematical abilities ... " (p.65). The generic term "learning disability" thus encompasses the notion of reading dysfunction. "Specific" learning disability implies a narrowing of focus to different types of disability, including reading impairment, which are subsumed beneath the umbrella term "LD" (Leong, 1989; Njiokiktjien, 1994). Shaw, Cullen, McGuire and Brinkerhoff (1995) proposed a new operational definition which would incorporate reading and writing as specific learning disabilities.

Studies Equating Reading Disability with Dyslexia

The terms "reading disability" and "dyslexia" are also used synonymously (e.g., Aaron, 1991; Kamhi, 1992; Stanovich, 1994). Fletcher et al. (1989) commented on the common practice of using the terms "dyslexia" and "specific reading disability" interchangeably. Ehri (1989) specified "reading disability" in the title of her paper, used the term "dyslexia" in the first paragraph and then used the two interchangeably. Ackerman, Dykman and Gardner (1990) equated the two in unequivocal terms "... reading disability (or dyslexia) ..." (p.279), as did Lovegrove (1984), "Dyslexia, or specific reading disability ..." (p. 15), and the DSM-IV (1994) "... Reading Disorder which has also been called dyslexia ..." (p. 48) and "... reading disorder or dyslexia ...". (p.49)

Studies Equating Dyslexia with Learning Disability

Critchley and Critchley (1978) stated that "Developmental dyslexia is a learning disability ..." (p.148). According to Rhodes and Dudley-Marling (1988), students who fail to read may be labelled "learning disabled or dyslexic". Pennington and Smith (1988), surveying research into genetic influences on learning disabilities, referred to dyslexia as a behavioural LD phenotype. Bigler (1992) cited dyslexia as an example of learning disability, as did Galaburda (1989) and Hynd, Marshall and Gonzales (1991). Helveston (1987), and more recently, Shaywitz, Fletcher and Shaywitz (1995), stated that the most common type of learning disability is poor reading ability or dyslexia. The new working definition recently proposed by the Orton Dyslexia Society (1995) opened with a statement that " Dyslexia is one of several distinct learning disabilities" (p.2). Frost and Emery (1995) described dyslexia as the most prevalent form of learning impairment.

In Australia, the term “learning difficulty” is applied to cases of dyslexia (Brock, 1995). “Learning difficulty” is currently stipulated by Education Queensland as an ascertainment category under which the educational needs of dyslexic students are documented. Coltheart (1997) suggested that the term “learning difficulty” has been adopted because it is less stigmatizing than “dyslexia”. Still often called “reading disability” (Catts, 1996), dyslexia has come to be recognized as a prominent and ubiquitous disorder, subsumed under the broader term “learning disability” (Solan, 1993).

Dyslexia - Distinguishing Characteristics

The word *dyslexia* derives from the Latin *dys* (difficult) and *legere* (to read) (Richardson, 1992). The term was introduced by Berlin (1887), a German ophthalmologist, to describe patients who had great difficulty in reading due to cerebral disease. Dyslexic symptomatology was subsequently described by Morgan (1896), Kerr (1897), Thomas (1905) and Hinshelwood (1907, 1911). These early clinicians documented a number of the prominent features which have been substantiated by subsequent studies over the years, in particular difficulty in learning letter names, frequent coexistence with relative strengths in oral verbal expression, mathematics and spatial or manipulative mechanical skills, and persistence of the problem into adulthood.

Most definitions of dyslexia are similar in essence to that developed by the Committee of the World Federation of Neurologists, Dallas, Texas, (1968), which described a cognitive disability, frequently of constitutional origin, manifesting in impaired reading and writing despite normal intelligence, health and emotional status. Causality was ascribed to central nervous system deficits or psychological processing dysfunction which were not attributable to other handicapping conditions or environmental factors.

Hicks (1981) suggested that dyslexics be distinguished by, among other characteristics, right-left confusion. However, such visual-perceptual anomalies, which were originally regarded as key features of the condition, have come to be recognized as peripheral aspects. Geschwind (1982), discussing symptoms such as left-handedness, clumsiness and reversal errors, which are often, but not always displayed by dyslexics, reported that these characteristics can coexist with dyslexia, but are also seen in some normal readers. In almost all cases, they remit spontaneously in time.

A fundamental assumption that has historically characterised definitions of dyslexia is specificity - the notion that deficits should not extend into other domains of cognitive functioning, such as judgement, reasoning, mathematics, problem solving and comprehension. Pennington & Smith (1983) defined dyslexia in largely exclusionary terms as an unexpected difficulty in learning to read and spell, which occurs in the absence of lowered intelligence, emotional disturbance, organic impairment or peripheral handicap. Similarly, according to Winters, Patterson and Shontz (1989), dyslexics should demonstrate a combination of reading age lag, average or better performance in other academic areas and no organic involvement. Gough and Tunmer (1986) defined dyslexia as a serious decoding disability in readers of normal or superior ability in other areas.

Cut-off points relating to degrees of severity are clearly critical in the operational definition of dyslexia. However, just what constitutes "severe" has also to be established. Accumulated evidence currently appears to delineate a continuum of capability in visual and phonological skills from reading efficiency to reading disability (Foorman & Liberman, 1989; Shaywitz, Fletcher & Shaywitz, 1995; Stanovich, 1994). Stipulated cutoff points along this continuum are purely arbitrary, as no naturally occurring divisions or boundaries have yet been identified.

Yong and McIntyre (1992) defined "severe" as a difference of 15 points between standard scores on tests of cognitive ability and achievement, with a mean of 100 and a standard deviation of 15. Cornwall (1992) used a standard score on the *Reading* subtest of the Wide Range Achievement Test-Revised that was at least 16 points below Full Scale IQ. A number of authors have classified children as research-identified reading disabled if they scored 1.5 SDs or more below their predicted reading achievement levels (e.g., Badian, 1996; Shaywitz, Fletcher, Holahan & Shaywitz, 1992; Shaywitz, Shaywitz, Fletcher & Escobar, 1990). Prior (1994) stipulated a discrepancy of more than one SD below Grade average. Dykman and Ackerman (1992) defined impaired readers as those functioning below the 20th percentile and dyslexics as those within this group performing at 1.65 SEs below expected reading level for IQ.

The DSM-IV (1994) defined reading, writing and maths discrepancies as substantially below expected levels when achievement scores fall more than 2 SDs below IQ. The widely accepted operational selection criterion for dyslexia described by Slaghuis, Twell and Kingston (1996) was a reading performance lag of 2.5 years behind chronological age. Masutto, Bravar and Fabbro (1994) applied a 2-year lag in reading performance. Manis, Seidenberg, Doi, McBride-Chang and Petersen (1996) defined their dyslexic experimental group as reading below the 30th percentile in isolated word recognition. Nass (1994) suggested that any child placed below the 20th percentile in reading is at risk for adult illiteracy. Current convention applied within Education Queensland holds the "remedial band" to be 15th percentile - 18th percentile, the latter being regarded as the lower limit of the average range in reading capability. Children functioning at the 18th percentile are regarded as average readers and are not considered eligible for remedial assistance. (With the exception of one student who was functioning at the 14th percentile in word recognition, participants in the present study were placed at or below the 5th percentile).

In 1995, the Orton Dyslexia Society endorsed the following definition of dyslexia for research:

"Dyslexia is one of several distinct learning disabilities. It is a specific language-based disorder of constitutional origin characterized by difficulties in single word decoding, usually reflecting insufficient phonological processing abilities. These difficulties in single word decoding are often unexpected in relation to age and other cognitive and academic abilities; they are not the result of generalized developmental disability or sensory impairment. Dyslexia is manifest by variable difficulty with different forms of language, often including, in addition to problems in reading, a conspicuous problem with acquiring proficiency in writing and spelling."

(Research Committee, The Orton Dyslexia Society, 1995, p. 2)

For the purposes of this thesis, dyslexia is defined as a neurocognitive, developmental disorder, severe and refractory in nature, which manifests as an inability to decode words and thus to learn to read in children of average to above-average intelligence, who have no visual or hearing impairment and no emotional adjustment problems, and who have had regular educational experiences. The symptoms fail to respond to regular classroom instruction and conventional remedial approaches, i.e., those that involve the student looking at print, and persist into adulthood. Severity is defined in terms of percentile ranking in word recognition (see Table 1).

Tactile Integrity in Dyslexia

Very little attention has been devoted in the literature to the integrity of the sense of touch in children with dyslexia. While various tactual functions have been implicated as associated features of both dyslexia and the broader learning disabilities phenomenon, evidence of decreased sensitivity in the fingertip touch receptors has been established only as a symptom of certain medical conditions.

There are, however, occasional references in the literature to the possibility that some form of tactual reading impediment could occur in a percentage of the blind population. In support of this proposition, Silberberg and Silberberg (1971) cited isolated examples of individuals who were first blind, then regained vision, but subsequently manifested an inability to learn to read efficiently, and of blind individuals who had difficulty learning braille. As evidence for a phenomenon of “tactile dyslexia”, however, the data upon which the Silberberg and Silberberg contention is based are insubstantial. The number of cases studied was small and the authors do not convincingly exclude the possibility that the effect could be attributable to other influences.

Postel, G’Stell-Jeannot, Krief and Postel (1972) reported what they termed “tactile dyslexia” in children blind from birth. The “distinguishing features” of this condition, however, included aspects of disorganized braille reading such as numerous vertical and reversing movements and other indicators of impaired motor coordination. Brodlie and Burke (1971) also reported, in a small percentage of blind students, braille sign reversals and confusion of placement in words, analogous to those sometimes displayed by sighted children with printed letters. However, while such problems could constitute an impediment to learning braille, they are not central features of dyslexia.

Tactile defensiveness (e.g., Ayres, 1964) has been identified in some children with reading disabilities. This condition involves a constellation of behaviours such as avoidance of touch, aversive responses to touch and atypical or irregular execution of activities with tactile components like finger painting (Royeen & Fortune, 1990). Wilbarger and Royeen (1988) described tactile defensiveness as one manifestation of the more general condition of sensory defensiveness. Tactile acuity is not specified as a feature of this constellation, however, nor is the transmission and processing of tactual input detected by the fingertip touch receptors.

The view expressed by Cronin (1972), McCoy (1975) and Weiland (1980) encompassed the notion of a compensatory development of tactile acuity in reading disabled children. McCoy cited a study by Doehring (1968), who compared the performance of normal and retarded readers and found that the reading impaired subjects showed significant superiority over the normal group in tactile capability. Denckla and Rudel (1974a, 1974b) and Rudel, Denckla and Spalten (1974, 1976) found that other sensory processes were not selectively impaired in their sample of dyslexic children, and reported that intersensory dysfunction was not present. Mattison, McIntyre, Brown and Murray (1986) reported that visual-perceptual and perceptual-conceptual aspects of the visual-motor system were intact for learning disabled children. Davis, Adams, Gates and Cheramie (1989) reported that dyslexic children posted significantly longer time scores and lower localization scores than non-affected students on the Tactual Performance Test from the Halstead-Reitan battery. This test was applied on the basis of evidence that learning disabled children frequently show deficits in memory, spatial and tactual abilities and speed of processing. The tactual abilities assessed by this instrument, however, do not include fingertip sensitivity.

Subtyping

The probability that reading disabilities are as heterogeneous in aetiology as they are in clinical manifestation now appears generally accepted (Pennington & Smith, 1983). Interest in classifying impaired readers into discrete subgroups on the basis of particular symptoms dates from the early 1960s, when Kinsbourne & Warrington (1963) identified two groups, one exhibiting a language disorder and the other a non-verbal sequential processing problem. Consolidation of interest in subtyping occurred during the 1970s, arguably as a reaction to mounting criticism of unsuccessful attempts to isolate unitary causes, along with growing acceptance of the notion of multiple causality (e.g., Benton, 1978; Boder, 1970). As a strategy for reducing heterogeneity and allowing for multiple explanations of reading disability, subtyping has become the focus of concerted research effort in recent years (e.g., Annent, Eglinton & Smythe, 1996; Borsting et al., 1996; Manis, Seidenberg, Doi, McBride-Chang & Petersen, 1996; Masterson, Hazan & Wijayatilake, 1995; Murphy & Pollatsek, 1994).

Slaghuis and Lovegrove (1985) referred to the existence of two broad subgroups, one characterized by auditory-linguistic deficits in the absence of visual deficits, and the other characterized by visuo-spatial deficits. Lovegrove, Garzia and Nicholson (1990) found that 75% of their specific reading disabled target group manifested a transient (magnocellular) system deficit. They also noted that many of these subjects displayed a phonological coding deficit when attempting to pronounce nonwords that followed regular grapheme-phoneme correspondence rules and concluded that a combination of language and visual processing deficits were likely to occur in a high proportion of such cases.

Research opinion appears to be converging regarding dyslexic subtypes. As Farmer and Klein (1995) pointed out, there is considerable work yet to be done before discrete subgroups can be delineated with confidence. Rourke (1998), however, maintained that specific subtypes can be specified precisely, have excellent reliability, and have been shown to have concurrent and predictive validity.

A complicating factor here is the fact that persons with conditions such as attention deficit disorder and central auditory processing disorder, typically present with a number of symptoms also displayed by people with dyslexia. According to Kavale & Forness (1987) this is a significant problem because it obscures classification boundaries which must be clearly articulated if the potential of subtyping to provide a means of overcoming the difficulties posed by heterogeneity is to be realized.

CHAPTER 2: AETIOLOGY OF DYSLEXIA

This chapter examines the thinking on causes of dyslexia, proceeding from an historical perspective through significant schools of thought which have arisen over the last thirty or so years, with particular attention being paid to recently developed knowledge about the transient visual input transmission system. The importance of phonological awareness in the development of reading is acknowledged and a persuasive body of literature which determines dyslexia to be a neurological phenomenon is reviewed. Two compelling arguments which further inform the case for a neurological basis for dyslexia are presented. Neural plasticity is identified as a potential mechanism for the training effect achieved in this field study.

Incidence

Surveys of the incidence of dyslexia establish the significance of this problem throughout the western world. While conclusive statistics about the prevalence of dyslexia are not available, survey data from Australia (e.g., Coman, Murphy & Turner, 1989; Lovegrove, 1984; Prior, 1994; Slaghuis, Twell & Kingston, 1996), the United Kingdom (e.g., Crispin, 1985; Critchley, 1970) and the USA (e.g., DSM-IV, 1994; Duffy & McNulty, 1990; Solan, 1993) converge upon a learning disabled / reading disabled population of some 15% - 20% of school-aged children, and within this population, a severely affected, dyslexic sub-population of around 3% - 5%.

Historical Overview

Dyslexia was originally believed to be an acquired organic condition, a variant of aphasia (Richardson, 1992), involving impairments in receptive and expressive language. This influence is apparent in the thinking of Orton (1937), who believed that hand preference and "cerebral dominance" were important related phenomena and that poorly established dominance, indicated by ambidexterity, reflected a "weakness in brain function" which manifested as an inability to read. The Dominance Model was discredited between the 1940s and 1950s.

Kirk (1962) considered that learning disabilities were impairments of processing abilities, those psychocognitive constructs such as perception, memory, sequencing and others, which affect the language skills and academic achievements of people of all ages. Kirk believed the cause to be either some form of cerebral dysfunction or emotional / behavioural disturbance. Subsequent thinking about causality focussed on such diverse symptoms as perceptual problems, faulty eye movements, deficits in linguistic processes, impaired attention and deficiencies in memory processes (Hallahan & Reeve, 1980; Ross, 1976; Routh, 1979). Other aetiological factors upon which researchers have speculated include diet, vitamin deficiency, food additives, inner ear problems, visual defects and heredity, all intrinsic factors with the focus being placed on the student. More recently, attention has also been focussed on extrinsic influences such as social context (Sleeter, 1986) and environmental factors (Coles, 1987). The sorts of extrinsic factors that have been implicated include prenatal exposure to alcohol, perinatal complications and lack of parental and environmental stimulation (Pennington & Smith, 1983; Rutter, Tizard & Whitmore, 1970). Interactivity theory (Coles, 1987; Green, 1990; Hadders-Algra & Touwen, 1992; Miller, 1990) posited the dynamic interaction of personal variables, including individual neurology, with socio-cultural and environmental factors. Spafford and Grosser (1993), however, suggested that neurological research findings substantially negated prevailing beliefs in environmental causality and that it is deficient lingual processing caused by neurological impairment that actually triggers social problems.

One of the earliest authors to implicate familial influence as a causal factor was Thomas (1905), who observed that affected children often had relatives who displayed similar problems. Since then the notion of heredity has received considerable attention. The findings of a number of authors, such as Miles (1983), who identified genetic transmission in 122 out of 202 families, and Brock (1995) who cited figures of 35%-40% for familial involvement, indicate strong support for the notion of genetic transmission.

Although there has been criticism of such findings (Bannatyne, 1978; Coles, 1987; Finucci, 1978; Herschel, 1978), the case for genetic origins of phonological deficit was established by Olson, Wise, Connors, Rack and Fulker (1989). Green (1990), citing research findings in behavioural genetics (Angoff, 1988; Capron & Duyme, 1989; McGue, 1989; Plomin, 1989; Tienari et al., 1987) as proof that both nature and nurture are significant aetiological factors where mental and emotional disorders are concerned, argued that a similar relationship should be expected with learning disabilities.

Visual-Perceptual Deficits

During the 1960s a school of thought arose which attributed dyslexia to visual-perceptual deficits. This proposition was subjected to intense scrutiny, the eventual outcome being a failure to establish any such relationship. Hammill (1972) conducted a comprehensive review of the research into the effects of visual-perceptual training on reading, concluding that little correlation existed between measures of visual perception and tests of reading comprehension, and that training prescribed for the development of visual perceptual skills had no positive effect on reading and possibly none on visual perception. Vellutino, Pruzek, Steger and Meshoulam (1973) expressed a similar opinion, "... visual-spatial deficit is an unlikely cause of reading disability ..." (p. 382), as did Vellutino (1979). Stanovich (1982) and Jorm (1983) also found against a causal association between visual processing problems and dyslexia.

In recent years, however, a number of authors (e.g., Borsting et al., 1996; Breitmeyer, 1984; Hardy, McIntyre, Brown & North, 1989; Lovegrove, Garcia & Nicholson, 1990; Lovegrove, Martin & Slaghuis, 1986; Martin & Lovegrove, 1988; Slaghuis & Lovegrove, 1984, 1985) have revived interest in a causal relationship between dyslexia and visual perception, as represented by defects in the functioning of the transient neural pathway, which transmits visual input from the retinae to the processing centres in the brain. The cells of the transient system are specialized for form, low spatial frequencies, movement and stimulus change. They react immediately to onset and cessation of visual stimuli but cease their activity if the stimulus becomes stationary (Grosser & Spafford, 1992; Lovegrove, 1984; Whyte, 1994). This system has been anatomically related to the magnocellular layers of the lateral geniculate nucleus (Greatrex & Drasdo, 1995; Kubova, Kuba, Peregrin & Novakova, 1995; Stuart & Lovegrove, 1992). Lovegrove (1984) identified a deficiency in transient system functioning in 75 percent of a sample containing more than 150 dyslexic subjects. Martin and Lovegrove (1988) found that children with dyslexia were less sensitive than non-disabled children to visual patterns flickering at rates ranging from 5 - 25 Hz. Such stimuli would be expected to engage transient mechanisms. Lovegrove, Martin and Slaghuis (1986) suggested that a transient system deficit could interfere with transmission of word representations by both visual and phonological routes.

The relationship between dyslexia and transient system deficits is supported by morphological evidence. Livingstone, Rosen, Drislane and Galaburda (1991) found that the two ventral-most layers of the lateral geniculate nuclei in dyslexics contain smaller cells than occur in normal readers. Johannes, Kussmaul, Munte and Mangun (1996), while unable to replicate the findings of Livingstone, Rosen, Drislane and Galaburda (1991), would not discount Lovegrove's (1995) implication of transient system weakness as a causal factor in dyslexia.

Dysfunctional Information Processing

Two models of dyslexia have an information processing orientation. The psycholinguistic model (Ellis & Miles, 1977; Newcomb & Marshall, 1981; Warrington & Shallice, 1980; Wolf, 1984) proposed the cooperation of skills such as word recognition, encoding and naming (the ability to find and apply lexical labels) in the reading process. Greene (1996) argued that dyslexia involves all of the major language processes, including phonology, morphology, syntax and semantics, from word to discourse levels. Richardson (1992) linked psycholinguistics with Frith's (1986) proposal for a logographic, alphabetic, orthographic framework to form an information processing paradigm, conceptualizing dyslexia as a specific developmental language disorder involving deficits in phonological awareness, sequencing, segmentation and naming.

A number of authors (e.g., Aaron, 1982; Bakker, 1972; Das, Kirby & Jarman, 1979; Hooper & Hynd, 1985; Johnson & Myklebust, 1967; Luria, 1966a, 1966b, 1977; Wolf, 1986) have subscribed to what was known as the "imbalance hypothesis", an explanation of dyslexia based on the assumption that the reading process involves two information processing operations, the simultaneous and the sequential. The former process entails immediate word recognition, and the latter the serial or sequential processing of letters within words. Normal reading was said to depend on the effective, balanced cooperation of both processes, any imbalance, or disproportionate usage of either, resulting in reading impairment.

According to this model, simultaneous processing results in the formation of holistic, or unitary, representations, while sequential processing generates successive, or temporal orderings of separate bits of information. Simultaneous processing skills would include visual word memory, word attack strategies, comprehension, spatial tasks where stimuli must be interpreted as wholes and reading tasks where semantic relationships must be identified. Sequential, or temporal, processing skills would include decoding (analyzing words into parts), synthesizing sounds into words, sequential memory tasks and the utilization of syntactic cues to extract meaning from language. Experimental and clinical evidence converge on the conclusion that temporal information processing dysfunction is a physiologically plausible cause in some subtypes of dyslexia (Kirby & Robinson, 1987; Lovegrove, 1995; Shapiro, Ogden and Lind-Blad, 1990; Tallal, 1980; 1985; Tzeng & Wang, 1984; Wolff, Melngailis, Obregon & Bedrosian, 1995).

Phonological Impairment

Phonological awareness is a metalinguistic understanding of the alphabetic principle that letters and punctuation marks represent sounds, that words consist of sequences of such sounds (Australian Association of Special Education, 1989) and that words have an internal structure (Pennington, Van Orden, Smith, Green & Haith, 1990) that can be broken into syllables and phonemes, the smallest sounds distinguishable in conversation (Dunn, 1991). Phonological processing is the manipulation of syllables and phonemes (Solomons, 1992), the conscious analysis and synthesis of the sound structure of words, i.e., segmenting words into their component sounds and blending sequences of separately articulated sounds to create words. According to Vellutino (1991), phonological awareness is a prerequisite for the mapping of alphabetic symbols to sound, and alphabetic mapping is, in turn, a prerequisite for the identification of individual words and thus for higher reading operations.

Phonological awareness appears not to develop automatically in some beginning readers and there appears to be an emerging consensus that phonological deficits represent core dyslexic symptomatology. The phonological deficit hypothesis holds that these deficits lead to problems with short-term memory, sound segmentation and sound blending (Rack, Snowling & Olson, 1992), which manifest themselves in difficulties relating phonemes to written symbols (Phelps, 1998), blending phonemes into words and decoding or recognizing printed words (Fox, 1994; Stanovich, 1986). The ultimate outcome is impaired reading.

Stanovich, Cunningham and Cramer (1984) showed that good readers consistently out-perform poor readers in the area of phonemic awareness. Despite levels of reading comprehension which are often relatively high, dyslexics have difficulty discriminating phonemes, identifying phonemes in specific locations in words (i.e., making beginning, medial or ending errors), combining phonemes to make syllables or words and using syllabic information and context for word identification (Bruck, 1990). Deficient phonemic segmentation has been implicated by a number of researchers investigating dyslexia (e.g., Godfrey, Syrdal-Lasky, Millay & Knox, 1981; Lieberman, Meskill, Chatillon & Schupack, 1985; Pennington, 1989). Bradley and Bryant (1985) demonstrated that performance on phoneme segmentation tasks is powerfully predictive of early successes in reading and spelling.

Catts (1989) proposed defining dyslexia as "... specific deficit(s) in the processing of phonological information". (p. 58) Phonemic discrimination problems disrupt the normal acquisition of alphabetic processing skills (Masterson, Hazan & Wijayatilake, 1995). Kamhi (1992) proposed that dyslexia should be described as a developmental language disorder whose defining characteristic is a life-long difficulty processing phonological information. According to Bruck (1992), dyslexics do not acquire appropriate levels of phoneme awareness, regardless of age.

Phonological impairment is manifested in both real and non-word decoding competencies (Phelps, 1998). Affected children lack awareness of the phonological structure of language (Fox & Routh, 1980), have difficulty naming objects (Fawcett & Nicholson, 1994; Snowling, van Wagtendonk & Stafford, 1988), struggle with functions such as encoding, or representing, phonological information in memory (Catts, 1989; Kamhi, Catts, Mauer, Apel & Gentry, 1988; Simmons, 1992) and can not retrieve phonological information from memory (Katz, 1986), all of which interfere with the acquisition and automatization of word recognition skills. According to Bigler (1992), once intelligence and socioeconomic status were covaried and controlled for, only rapid naming, phonological awareness and non-word reading were found to be significant discriminators for dyslexia.

Word Recognition

Defective word recognition, or impaired lexical access, is widely acknowledged as a fundamental aspect of dyslexia (Cornelissen, Hansen, Bradley & Stein, 1996; Gough & Tunmer, 1986; Munro and Munro, 1993; Stanovich, 1982; Vellutino, 1979; Yap & Van Der Leij, 1993). Lyon (1995) believed that reading disability is most precisely measured at the single word level.

A substantial body of research supports the notion that immediate lexical access, or effective word recognition, is a fundamental element in the extraction of meaning from text (Gaskins, Gaskins & Gaskins, 1991). The more words a reader recognizes on sight, or can decode rapidly, the faster is the reading rate, and the more easily meaning emerges from the text. According to Cunningham (1990), fluent reading is free of the mechanical decoding that impedes comprehension for beginning and less proficient readers.

Whole-language proponents maintain that reading is context-driven and that comprehension is facilitated by prediction based on semantic and syntactic cues. The whole-language approach downplays phonics and word recognition and encourages the employment, of, among other strategies, guessing at unknown words. Code-oriented theorists, on the other hand, maintain that the importance of word recognition lies in the fact that effective utilization of context for the purpose of achieving comprehension is dependent upon effective word recognition. According to Hutchens and Hynd (1987), for children deficient in phonological decoding, no amount of remedial training will result in normal mastery. For this type of child an emphasis on developing a strong sight vocabulary is essential, as it allows some degree of reading success. Vellutino (1991) was another who argued that whole-language theorists have greatly overestimated the role of context and have underestimated in equal proportion the role of word recognition. Referring to extensive research support for the code-orientated position, he asserted that poor word recognition results in a preoccupation with basic mechanics. This subverts the deployment of a disproportionate amount of cognitive resources into decoding, thus inhibiting the development of reading fluency which is an important prerequisite for comprehension.

Most of the variance in reading performance in young children is accounted for by differences in their word recognition skills (Torgeson & Wagner, 1992). According to these authors, it is not the ability to use context in support of word recognition that distinguishes good readers, but rather the ability to use phonological and orthographic codes to identify words rapidly and accurately out of context. Effective word recognition was described by Munro and Munro (1993) as the fundamental problem in dyslexia. This was echoed by Seidenberg (1993) who asserted that word recognition plays an essential role in learning to read, skilled reading and dyslexia.

Neurological Involvement

During the 1980s, the notion of underlying neurological deficits as the structural mechanism of reading impairment, became widely accepted (Galaburda, 1985, 1988, 1989; Hynd, Marshall & Gonzales, 1991; NJCLD, 1987; Pennington, 1989). The neuropsychological paradigm attempts to understand intellectual behaviour such as reading in terms of the intactness and organization of the specific brain systems that support it (Torgeson, 1986). This perspective develops from the assumption that dyslexia is a manifestation of structural deficits, such as abnormal cerebral lateralization patterns and neurological pathology at the cellular level (Anderson, Brown & Tallal, 1993), which affect the processing of information (Coplin & Morgan, 1988; Semrud-Clikeman et al., 1996).

Data supporting a neurological basis for dyslexia are being continually augmented through post-mortem anatomical studies, applications of progressively advancing technology and the enlistment in brain research of hitherto uninvolved disciplines such as optometry (Solan, 1993), cognitive neuroscience, neurology and genetics (Galaburda, 1993). Hitherto unknown cerebral capacities for regeneration and adaptation are being discovered and their functional implications recognized. Magnetic resonance imaging, electrophysiological and anatomical studies of dyslexic brains have confirmed the involvement of neurological abnormalities in the physiology and neural organization of dyslexics (Bigler, 1992; Farmer & Klein, 1995; Galaburda, 1988). There now appears to be widespread support for the view that these deficits are the result of fundamental deficiencies which exist in children prior to the commencement of reading instruction (Stanovich, 1986; Catts, 1989).

Hutchens and Hynd (1987) advanced two compelling and enduring arguments for neurological involvement as a cause of dyslexia. Firstly, on the premise that nervous system structure and function would be common to all humankind, they contended that neurological aetiology is consistent with the occurrence of this disability across cultures. Secondly, they related the diversity of symptoms manifested across the dyslexic population to the range of neurological abnormalities so far detected, postulating that multiple causality would be reflected in multiple symptomatology. More recently, Berndt, Haendiges, Mitchum and Wayland (1996) presented empirical evidence for multiple sources of impairment to a number of cognitive operations that are specialized to support non-lexical reading.

Loci of Neurological Defects

The first anatomical evidence associating cognitive functions with specific cerebral locations was reported by Drake (1968). Drake described an abnormal convolutional pattern and cellular abnormalities within the parietal lobes of a severely learning disabled child. Morphological asymmetries between surface areas of the *planum temporales*, the upper portions of the temporal lobes which have a known auditory-linguistic function, were reported by Geschwind and Levitsky (1968). Similar abnormalities were subsequently found in an adult autopsy patient by Galaburda and Kemper (1979). These cortical zones have been associated with reading and arithmetic (Gaddes, 1980).

Researchers have since identified organic deficits in many cerebral locations. Using computer assisted tomography, Rosenberger and Hier (1980) found parieto-occipital asymmetry in developmental dyslexics. Galaburda (1985, 1986, 1988, 1989) presented autopsal evidence that physical differences exist between brain structures of normal and dyslexic individuals, primarily within the language areas of the left cerebral cortex. Gross-Glenn et al. (1991) suggested that anomalies located in the prefrontal cortex might differentiate between adults of normal reading ability and those with dyslexia. Salmelin, Service, Kiesila, Uutela and Salonen (1996) compared cortical arousal between dyslexic subjects and controls during passive viewing of single words, through whole-head magnetoencephalography. A sharp activation within the left inferior temporo-occipital region was displayed by the controls, while the dyslexic subjects displayed a slow, delayed response or failed to activate in this area.

Sadato et al. (1996) reported that braille reading by the blind activated the medial occipital lobe (Brodman's Area 17). Paules et al. (1996) also studied brain activity in dyslexics and controls on a phonological processing task using positron emission tomography. In the normal controls, Broca's area, the left insula and the temporo-parietal cortex activated in concert during performance of these tasks. This multiple-area activation did not occur with the dyslexic subjects, in whom, in addition, the left insula was never activated. Paules et al. proposed that the defective phonological processing of the dyslexic subjects was due to impaired connectivity between the anterior and posterior language areas.

Hynd, Marshall and Gonzales (1991) posited that, because reading is such a complex task, any disruption to any of the interrelated, contributing systems would compromise the outcome. Similarly, Dautrich (1993) proposed that the processing of complex visual stimuli, as required in reading, involves the interaction of different functional centres, and that an impairment at any point along the transmission pathway would adversely affect the overall process and result in impaired reading performance. In addition to dysfunctional executive sites, dyslexic symptomatology is now being attributed to defects or disconnections in the neural circuitry, such as the magnocellular pathway of the visual system (Livingstone, Rosen, Drislane & Galaburda, 1991), which interrupt the transmission of data between sensory receptors and processing centres in the brain and prevent the linking of functional sites in the production of complex responses such as reading (Ackerman & Dykman, 1993; Geschwind, 1984; Rosenfeld, 1985). According to Duane (1989), even microscopic lesions will significantly degrade cognitive information processing.

Berlin (1991) and Gladstone, Best and Davidson (1989) associated impaired inter-hemispheric transfer of information with reading problems. Wolff, Michel, Ovrut and Drake (1990) outlined a model of developmental dyslexia based on the premise that complex cognitive functions, such as the translation of graphic symbols into a phonemic code, depend on component processes from both cerebral hemispheres, and that at least some subtypes of dyslexia may be due to impaired interhemispheric communication. Flowers (1993) reviewed studies of brain / behaviour relationships conducted over the last decade, concluding that evidence converges in favour of a left hemisphere functional deficit for dyslexia. This relationship was documented at the microscopic level, where anomalous neural organization has been linked to reading, and at the macroscopic level, where atypical hemispheric symmetry in the language-related temporal region has been identified in dyslexic individuals. The pattern of behavioural correlations clearly suggests left temporal involvement in phonological and orthographic skills and left parietal involvement in reading comprehension.

Dyslexia was described by Njiokiktjien (1994) as encompassing a range of manifestations, each related to its own dysfunctional neurology. From a review of research findings, Riccio and Hynd (1996) found impressive evidence for a neurophysiological basis for dyslexia and a heterogeneity of structural causality. Collective research findings appear to describe a widespread scattering of physical abnormalities in the brains of dyslexic subjects, this distribution of impediments being consistent with the highly variable patterns of performance displayed.

Neural Plasticity

Neural plasticity, a characteristic of the brains of all animal species, can be defined broadly as "the adaptive capacity of the central nervous system", a dynamic ability to modify its own organization and function (Bach-y-Rita, 1990). Research data documented over a number of years attest to the ability of nerve cells, glial cells and blood vessels within the mammalian cerebral cortex to change their structural dimensions through childhood (Huttenlocher, 1990) into adulthood (Andersen & Zipser, 1990) in response to stimulation. This effect can be induced experimentally and can endure for up to several weeks. There is a well-established belief that synapses are the basic computational units of the brain (Quartz, 1993), and that synaptic plasticity, the mechanism underlying long-term storage of information (Morris, 1990), is the biological substrate of memory (Teyler & Fountain, 1987). On a microscopic level, the synaptic connection between neurons presents as a likely site for environmental modification. Repeated non-random external stimulation, or training, has been shown to produce significant and enduring changes in cortical neurons and synaptic efficiency (Lynch, Larson, Muller & Granger, 1990; Singer, 1990). The soma increases in size, as does the nucleus, and the post-synaptic junction thickens. The transmission of neural impulses is now known to occur through dendritic junctions as well as synapses (Livingstone, 1989). Studies with the electron microscope have confirmed that increased synaptic potentiation promotes the spouting of dendritic spines (Purvis & Hadley, 1985). External stimulation has also been shown to produce dendritic growth (Huttenlocher, 1990; Squire, 1987). This could well be the mechanism which underlies the formation of alternative neural pathways. Dudai (1989) described dendritic spines as strategic loci for morphological changes that subserve long term memory. According to Gabriel and Moore (1990), functional adaptation, or learning, involves re-structurings of neural architectures through the modification of synaptic connections.

Pulvermuller and Schonle (1993) reported behavioural and neuronal changes in a patient with severe acquired aphasia, which were ascribed to therapeutic input. Learning was explained in terms of neuronal stimulation resulting in synaptic strengthening (Hebb, 1949). Due to repeated activation, fragmented neuronal assemblies supporting phonological representations eventually strengthened their connections. According to Posner (1989) there is considerable scope for plasticity in "connectivity", the points of convergence where interactions between systems occur (LeDoux, 1990). Critical sites for plastic modifications would be those areas where networks converge or interconnect. Convergence of modal transmission channels on target cells is an essential characteristic of neural circuitry which has fundamental significance as a construct underlying cross-modal linkage and functional plasticity.

Accumulated evidence has demonstrated the potential of the brain to promote recovery of function by initiating physiological processes such as neural growth, the formation of new synapses and the unmasking of relatively inactive or under-utilized pathways (Bach-y-Rita, 1990; Kanaka & Kumar, 1990). Pathways may also be activated through an increase in transmission efficiency (Haracz, 1984).

Bach-y-Rita and Bach-y-Rita (1990) cited strong experimental evidence for a causal relationship between unmasking of pathways and specific training. Rapcsak, Gonzales Rothi and Heilman (1987), describing a patient presenting with phonological alexia as a result of an acquired brain insult, proposed that the activation of intact alternative pathways mediated reading by both the lexical and the phonological routes. Duffy and McAnulty (1990) documented both spontaneous and induced changes in brain electrical function in dyslexic subjects representative of different sub-types. Having mapped brain electrical activity produced by external stimulation in areas of the brain where it would not normally occur, these authors concluded that a dyslexic individual's brain could develop alternative pathways or functional capacities.

Teylor and Fountain (1987) believed that the encoding of memory in the mammalian brain is associated with electro-chemically mediated change in elements of the nervous system. Evidence for highly plastic somatosensory cortical maps, which probably account for the acquisition of skills, is compatible with the concept of self-organizing nerve nets, which have been hypothesized to underpin cognitive processes such as recognition, association, learning and memory (Merzenich, 1984). Singer (1990) described learning as a dynamic, stimulus-dependent neuronal process, and memory traces, or engrams, as enduring reorganizations of neural architecture. Ciompi (1983) described neural plasticity as the link between biological and psychosocial functioning and postulated that plasticity may constitute the mechanism underlying learning and memory.

There is now ample evidence that the architecture of the brain is plastic, that all sensory systems as well as underlying neural structures can be modified by external stimulation, and that the brain may use more than one cellular mechanism to alter its functional organization in response to such stimulation for learning and memory (Dudai, 1989; Squire, 1987).

CHAPTER 3: REMEDIATION

This chapter first examines the enormous amount of research effort expended over the last thirty years in fruitless attempts to find a method of overcoming dyslexic impairments. The refractory nature of dyslexia is clearly established. Literature forecasting the outlook for dyslexic students exposed to conventional remedial procedures, i.e., those that entail the child looking at print, is then reviewed. The most promising approach developed to date, multi-sensory engagement, is explored as a precursor to the theme of braille-based remediation. This leads into a detailed examination of three obscure reports of a remedial association between dyslexia and braille. These findings constitute a basis for the experimental hypothesis in the present study.

Conventional Approaches

Psycholinguistic Approach

The early assumption that reading disability was attributable to brain damage or dysfunction found expression in remedial intervention models aimed at alleviating presenting symptoms by reducing inefficiencies in brain processing. Assessment tools such as the ITPA (Kirk, McCarthy & Kirk, 1968) were developed to identify dysfunctional brain processes, and collateral intervention programmes were then devised to correct them. These collective efforts came to be referred to as the psycholinguistic approach.

Sensory Integration

Ayres (1965) suggested that perceptual problems associated with neural integration of input from more than one sensory modality contributed to disabilities such as dyslexia. The processing by the brain of information received through the senses is what Ayres referred to as sensory integration. Ayres' original theorizations attracted widespread criticism (e.g., Cummins, 1991; Densem, Nuthall, Bushnell & Horn, 1989; Hoehn & Baumeister, 1994). Such critics substantially denigrated Ayres' operational concept, concluding that her data provided no validity for either her diagnostic procedures or the remedial programmes developed therefrom. Clark, Mailloux, Parham and Bissell (1989), however, having reviewed Ayres' work, did endorse her view that enhancement of processing functions would promote development of the adaptive, language and cognitive skills which underlie academic success, and that sensory integrative procedures could assist some children with academic learning disabilities.

Perceptual-Motor Training

The perceptual-motor approach (Delacato, 1959; Doman & Delacato, 1968; Frostig & Horne, 1964: Kephart, 1971) was also based on the assumption that learning disabilities were attributable to brain dysfunction. Motor learning was upheld by its proponents as a foundational construct for learning. Unsatisfactory motor development was believed to interfere with academic attainment, and remediation of motor defects was therefore thought to enhance scholastic progress. Exploratory work in the area of perceptual-motor performance commenced in the 1920s with observations of brain damaged adults. This involved an initial assessment of perceptual-motor functioning followed by training in specified skills such as walking along a balance beam or tracing dot-to-dot designs. Efforts were subsequently made to apply this thinking in remedial "patterning" programmes for reading disabled students. Although children below school age can not be diagnosed as dyslexic, sensory and motor impairments can be identified in this age group, and on this basis children were labelled dyslexic as they entered the education system (Meier, 1976).

Perceptual-motor training faced early challenges from educators. Ysseldyke and Salvia (1974), after assessing the predictive efficiency of the most frequently used assessment tools, were unable to validate the approach. A few years later, arguments put by Vellutino (1977a, 1977b, 1979) persuaded the field that data did not support the basic premise upon which the perceptual deficit hypothesis was founded, namely that such deficits contributed to reading difficulties. A meta-analysis of 180 efficacy studies of perceptual-motor training (Kavale & Mattson, 1983) also found this approach to be ineffective.

Unorthodox Interventions

Unconventional approaches which have been applied to the remediation of dyslexia over the years include perceptual training activities ranging from eye exercises to the wearing of empty spectacle frames when reading, therapeutic crawling exercises, sleep position therapy, orthomolecular medication treatment (mega-vitamins, trace elements), hypoglycaemic diet, elimination of food additives, neurophysiological retraining, coloured glasses, vestibular dysfunction therapy and applied kinaesiology (cranial manipulation to synchronize cloacal reflex and release ocular lock). Many parents have embraced these alternatives as a result of uncritical and sensationalist media promotion.

Outcomes to Date

Despite the enormous investment of expertise and effort that has occurred over the last thirty years, no effective remedial approach has yet been developed for dyslexia (Adelman, 1992; Durrant, 1994). McGill-Franzen and Allington (1991) presented the grim statistics that:

- 9 out of 10 children who enter the bottom reading group in Grade 1 remain in that group throughout their primary schooling;
- children (including those who are dyslexic) who fail in either of Grades 1 or 2 have only a 20% chance of graduating from High School; and that
- national evaluations of the efficacy of remedial programmes

- indicate that dyslexic children gain one additional month's growth in reading age for every year they receive remedial tuition. At this rate, from the beginning of Grade 3, they would theoretically require 50 years of remediation to read competently at Year 7 level.

Frost and Emery (1995) also commented that dyslexic children typically make significantly less academic progress, despite their inclusion in remedial assistance programmes, than do non-affected peers of comparable intellectual capability. Further, between the ages of 9 and 19, children with identified phonological deficits improve slightly more than one Grade level in reading, while children with other types of learning disability, who receive similar teaching, improve around six Grade levels. Butler (1991) reported that the majority of children identified as reading disabled in Grade 1 tend to remain so throughout their school years. After a 2-year study into the progress of lower primary reading disabled children, Prior (1994) claimed that reading disability is predictably permanent because there are no effective remedial approaches. Reading disabled children who fall behind are simply unable to claw their way back, and grow up to swell the ranks of illiterate adults. Bigler (1992) made the point that, by their very existence, reading disordered adults prove the ineffectiveness of traditional remedial approaches.

Wilson (1991), reporting the results of a survey of perceptions about classification and programming issues held by support services professionals, including psychologists, social workers and special education consultants, found the great majority of respondents to be clearly sceptical of, and often actively opposed to current reading remediation practices. One of the major reform themes identified was the need for effective intervention programmes. Appendix A lists the conventional remedial approaches applied unsuccessfully with experimental and comparison group members in the present study.

Mainstream Reading Instruction

The whole language approach is a highly effective method of teaching reading to the main stream primary school population. Practitioners take a strict constructivist position and do not differentiate between reading and comprehension (Bear & Cheney, 1991). Because the whole language approach does not address the teaching of words in isolation, however, beginning readers are not directly empowered to decode unfamiliar words (Snowling, 1996; Tunmer, 1994). Many impaired readers resort to contextual guessing, which is of little assistance with the 35% - 40% of words encountered only once in the beginning reading curriculum. In the light of evidence that only poor readers and younger average readers utilize context to compensate for poor decoding skills, Nicholson (1991) suggested that the importance of context might have been exaggerated. Nicholson, in fact, posited that reliance on guessing serves only to confuse emerging readers, the most affected of whom are also the least capable readers.

The research literature does not support the use of whole-language teaching methodologies with dyslexic students (Greene, 1996). According to Prior (1994), continued exposure to this method serves only to progressively denigrate their chances of improvement. A swing back to specific instruction in phonics for reading disabled students is apparent in the recent American literature.

Language knowledge is acquired in incremental expansions of orthography from single letter / sound associations through combination blends representing word structures to word meanings. Kemp (1987) believed this sequence to have an order which can be utilized systematically in teaching. Nicholson (1991) suggested that more instruction in phonics would offer a viable alternative to reliance on guesswork. Evidence suggests that remedial approaches emphasizing phonological awareness training are beneficial for disabled readers (Bradley & Bryant, 1985; Ehri, 1987; Gillam & van Kleeck, 1996; Lundberg, Frost & Peterson, 1988; Snowling, 1996). According to Foorman, Francis, Novy & Liberman (1991), it is the segmenting and blending aspects of letter-sound instruction that facilitate the development of reading skills.

Multisensory Enhancement of Cognitive Functioning

The concept of enhancing the reception and processing of sensory input by engaging multiple sensory modalities is not new. There is a long-established belief that the most effective technique for dealing with the problems experienced by impaired readers is the involvement of all sensory modalities (Blau & Blau, 1968). This is based on the premise that interaction occurs between sensory modalities, and that intersensory links (Ayres, 1972; McCoy, 1975) make it possible to affect one system by facilitating another.

The approach proposed by Fernald (1943) emphasized multi-sensory engagement as a key factor in learning. This approach was based on the assumption that better outcomes would result from the involvement of multiple sensory modalities in learning activities. Fernald's technique was known as the VAKT (for visual, auditory, kinaesthetic, tactile) method. Supplementation of visual and auditory input with kinaesthetic-tactile stimuli was proposed by Gillingham and Stillman (1965). Orton and Gillingham (1968) also advocated using all possible linkages between visual, auditory, kinaesthetic and tactile channels in learning to read and spell.

Thorpe, Lampe, Nash and Chiang (1981) compared the effects of kinaesthetic-tactile (KT) training to visual-auditory (VA) training on the reading performance of three dyslexic high school boys. Following the collection of baseline word recognition data, subjects received KT instruction for 10 minutes per day for 16 days. Subjects were tested daily on sight word reading. The KT method proved more effective for promoting the acquisition of sight-word vocabulary than the VA procedures. Superior performance was maintained for at least 6 months following instruction. This degree of retention was in contrast to retention after VA studies where long-term training effect did not occur.

Guyer and Sabatino (1989) obtained positive results using the Orton-Gillingham method with secondary school and college students. Those exposed to this approach made significantly more progress than either the non-phonetic (non Orton-Gillingham) group or the non-intervention controls. Nash, Thorpe and Lampe (1980), in studies with elementary-level learning disabled students, found multisensory instructional procedures to be superior to those stressing visual-auditory channels. Lockavitch (1981) successfully taught mathematics and grammatical concepts to learning disabled students through a tactile-kinaesthetic approach. Similar findings were reported by Locher (1985), who modified visual scanning strategies in dyslexic children through haptic skills training. Bradley (1981) reported that tactile perception of plastic letter shapes helped eliminate visual, auditory and kinaesthetic confusions associated with print, concluding that the tactile modality was an effective medium for teaching phonetic syllable analysis to dyslexic children.

There is also evidence for multisensory enhancement of the braille reading process when used with sighted readers. Newman et al. (1982), Newman, Hall, Coleman, Craig and Brugler (1986) and Newman, Brugler, Craig, Mann and Woodard (1988) found the learning of braille to be facilitated when symbols were presented both visually and haptically instead of haptically alone.

Increasing interest has been shown since the late 1960s in the involvement of the tactile modality in remedial instruction. The versatility of this modality has been demonstrated by the range of applications to which it has been adapted. The Tadoma method of training in speech comprehension (Norton et al., 1977) was a procedure in which hearing impaired students, placing their hands on the speaker's face, could demonstrate tactile perception of speech. Vibrotactile devices have been shown to produce substantial increments in lipreading comprehension, while both normal and deaf children have acquired substantial vocabularies of words presented tactually through vocoders attached to fingers, forearms or legs (Kirman, 1982). Miletic, Hughes and Bach-y-Rita (1988) concluded that vibrotactile stimulation was effective with congenitally and early-blind children for introducting spatial concepts typically associated with vision.

Braille-Based Remediation

It would appear that no scientific studies of the use of braille with sighted, dyslexic individuals have ever been published. Connor (1994), reviewing the effectiveness of intervention strategies developed for dyslexic students, made no mention of braille being used for this purpose. Nor did any of the authors in Everatt (1999), a review of international research into visual processing - how information on the printed page is transmitted to the brain. Literature searches as part of the present study, through several international databases retrospective to 1966, elicited only two unrelated, anecdotal, single-case studies dealing specifically with this topic (Cronin, 1972; McCoy, 1975). One other author, Weiland (1980) described his use of braille to improve reading with a child who had acquired dyslexic symptomatology as a result of brain damage. All three reported striking successes utilizating braille to enhance print reading capability in their single subjects.

Cronin's subject was a child repeating Grade 1 because he could not learn to read print, despite above-average intelligence, normal vision, a "... fairly stable ..." personality and exposure to conventional remedial tuition. Details of the braille programme are sketchy and the approach was seemingly somewhat unsystematic. Intervention commenced when "... the teacher wrote four words in braille at the top of the page ..." (p. 72), and told the child that the first word was "elephant", a word the child had said he wanted to learn. Cronin went on to describe the preparation of ".. special materials ..", consisting of the same reading material used by the other children with braille embossed on transparent sheets superimposed over the print, but gave no account of content, process or time span. Results, however, were described as ".. overwhelming .." (p. 72).

The subject of McCoy's paper was her 15-year-old daughter who, when intervention commenced, displayed maximum auditory memory of four digits, poor visual digit memory, a hazy time concept, persistent reversals of letters and numbers, confusion of concepts such as left/right, and low WISC *Verbal* scores. Relative strengths included superior auditory comprehension, musical and artistic talent, well-developed logical and deductive reasoning abilities, high WISC *Performance* scores and a positive, optimistic attitude. Over the years she had been subjected to all of the remedial techniques available through the education systems of California and Colorado, as well as input from private practitioners and Doman-Delacato patterning, none of which were successful. Reading and writing skills did not improve beyond a mid-second grade level. Intervention commenced with unspecified tactual evaluation and sensitization procedures "... one hour per day throughout the school year ...", followed by 10 months of instruction in braille which comprised braille pre-reading activities, braille alphabet study, pre-primer, Dr. Suess books and the Dolch Basic Word List, initially for 5 hours per week, subsequently increased to 7 hours per week. This exercise was described as highly successful.

Weiland's subject was a 10-year-old boy who had sustained brain damage at the age of 14 months and, at the time of the study, was on daily medication to control *grand mal* epilepsy. Vision and hearing were normal, and intellectual capability as determined by the WISC was within the average band. He was substantially reading-disabled and a variety of remedial approaches had been tried in Grade 1 and Grade 2 without success. Letter reversals were frequent, blending and sequencing were poor, and his general behaviour was characterized by anger, resentfulness and aggression.

Weiland chose to by-pass the visual reading modality during the initial stages and to use tactual reading as an alternative. The first braille symbols taught were *a, b, c*, and *l*. Upper word signs from the braille alphabet, such as *b* for *but* and *c* for *car*, were introduced via the peg board. From these initial letters and words, simple phrases, such as "a little cab" were built. As letters and words became established, further letters and word signs were introduced until the student had a "working knowledge" of them. From the peg board he progressed to the pin board, consolidating the information learned. Simple sentence construction occurred at this stage. At an unspecified point he commenced using braille. Once he had developed an unspecified degree of skill with tactual braille reading, vision was involved in the learning process, and printed single letters were introduced. From simple three-letter words, family words were introduced, first in braille, then simultaneously with print. These words were followed by consonant blends such as *st* and *sh* in initial and ending positions. At this stage, the student showed a desire to read printed, rather than brailled, text.

Weiland's training phase lasted 16 weeks. The amount of time spent daily or weekly was not specified. At the conclusion of this period, the student's visual reading performance on the Neale Analysis of Reading had improved from his being unable to read a passage to his having a Reading Age of 6 years 6 months. Weiland reported acquisition of sound-symbol association, not only in the auditory-tactile area but also in the auditory-visual area. Blending and sound sequencing had improved, *b* and *d* reversals had diminished in frequency, there was considerable improvement in discrimination of medial and ending sounds and social behaviour was described as much improved.

Cronin accounted for the successful outcome of his case study in terms of latent learning, the child being unaware of the fact that "... while he was learning ... braille, his eyes were also being trained to recognize print letters and words" (p73). Cronin stated that, in the course of this process, "... the transference from the tactile to the visual mode of reading was taking place" (p 73), proposing a "... transference of informational modes ..." (p.71), that is, a demonstrated understanding of certain input received via an unimpaired modality (the tactile) when the same data, received via a non-functional channel (the visual), was not understood.

This proposition was based on observations of newly-blind adults, who, when first learning braille, associate each new cell with the memory of its corresponding letter. Once the braille code has been mastered, the visual images of printed letters are no longer needed and are discarded. According to this principle, dyslexic children should learn braille letters tactually, then associate the tactile perceptions of letters and words with their printed counterparts, thereby establishing the transference of understanding which enables the recognition of printed text independently of tactile representation. Weiland agreed that transfer of learning from the auditory-tactile modality to the auditory-visual supported the cross-modal or intersensory transfer theories advanced by Cronin.

In arguing the application of braille as a reading instruction aid with dyslexic students, all three of these authors proposed that access to the information processing systems of the brain could be achieved via an alternative neural pathway. Given the complex "crossing-over" mechanisms linking the visual and auditory pathways, and because both the visual and auditory pathways involve similar reverberating circuit links within the cerebellum, McCoy postulated the existence of a similar constellation of linkages connecting the tactile and visual modalities.

CHAPTER 4: BRAILLE

This chapter introduces the independent variable and commences construction of the theoretical backdrop against which the project is conducted. The physical structure and orthography of braille are detailed, haptic processing is examined and comparisons are drawn between the processing of visual and tactual text. The notions of reciprocal co-activation of visual and tactual sensory modalities and the learning of braille by sighted students are also explored.

Description

Braille is an ingenious tactual communication system that permits the blind to read and write. It substitutes arrangements of small raised dots for printed letters and is "read" by touch in a similar spatial sequence to print.

The essence of braille reading is recognizing embossed braille signs by touch (Pring, 1982). These are specific configurations of one to six dots within the structure of each cell. In various combinations these groups of dots represent letters of the alphabet, numbers, punctuation marks, entire words (contractions) and abbreviations. In each braille cell, embossed dots are arranged in two vertical columns of three, identified by the numbering sequence:

1 . . 4

2 . . 5

3 . . 6

Within the scope of this 2 x 3 matrix, a minimum of one dot and a maximum of six yields 63 discrete patterns, or signs, each tactually distinguishable from the others (Hall & Newman, 1987; Knowlton & Wetzel, 1996).

Extensive research has been conducted on the optimal structure of the braille cell, in terms of size, number of dots and dot placement. The centres of vertically or horizontally adjacent dots in each cell are 2.3 mm apart. This distance is just outside the minimum two-point threshold of 2.0 mm for the fingertip. The external dimensions of a braille cell are approximately 4 mm x 6 mm. The centres of dots at corresponding positions in adjacent cells in the same line of writing are 6.4 mm apart. The height of a braille dot is between .2 mm and .5 mm and the diameter of each dot is approximately 1.5 mm. The discriminability of braille characters is better than that of embossed Roman letters, and appears to be near optimal in terms of characteristics such as dot spacing and dot height (Heller, Nesbitt, Scrofano & Daniel, 1990; Phillips, Johansson & Johnson, 1990). Braille character recognition is directly related to the number of dots involved. It has been shown that the time needed for braille readers to identify a word is a function of its length (Foulke, 1982).

Braille is structured in three levels of complexity. Grade 1 is a letter-by-letter translation which is space-consuming and impractical for general usage. In Grade 1 braille, each of the 26 letters of the alphabet is represented by a unique braille character. The 13-letter word “understanding” is thus compiled by arranging the 13 braille equivalents in the appropriate sequence - (u) (n) (d) (e) (r) (s) (t) (a) (n) (d) (i) (n) (g). Grade 2 is the standard, every-day version in which books and magazines are embossed. In the interests of speed and space, Grade 2 braille combines the one-to-one equivalents of Grade 1 with more than 200 logograms, which represent orthographic units - clusters of letters, individual words and groups of words - rather than phonetic units. These are referred to as *contractions*. In contracted format, "understanding" is represented by only five signs - (under) (st) (and) (ing). A number of contractions have multiple meanings as do certain words in the English language. The contraction used to denote "one", for example, also represents the word "honey", determination of meaning depending on context. As with print, some braille symbols can be written logographically as well as alphabetically. Numbers, for example, can be expressed alphabetically in uncontracted braille, that is, spelled out in individual signs and also logographically by using the appropriate symbol. Grade 3 braille is a shorthand form which is very difficult to master and is seldom used.

Braille has been described by some authors (e.g., Pring, 1985) as difficult to learn, not just because of the modality of input but also because braille presents little redundancy (Millar, 1985, 1990). Incorrect orientation of the text has also been shown to cause recognition difficulties and it has been suggested that there are optimal touching angles and spatial juxtapositions for reader and braille text (Heller, 1987, 1992). Each component of each sign is essential for correct identification, so that an error in perceiving a dot in one position of a letter, or rotation of the sign past a critical point, will always lead to misidentification of that letter. Reading errors made by blind people are nearly always of this type (Pring, 1982). Effective braille reading demands efficient motions of the hands and fingers. Unnecessary movements, too much fingertip pressure and poor posture are among the "reader" factors which can cause reading problems for the blind.

Haptic Processing

Touch was described by Vortherms (1991) as the most fundamental of the five senses. Touch is the modality through which infants first experience and explore their world. As other communication skills are acquired in the course of growth and development, however, touch comes to be used to elaborate what other senses are perceiving, rather than as a primary sensory tool.

Tactual, or haptic, processing is the integration of cutaneous (touch) and kinaesthetic (body movement) information (Lockavitch, 1981), acquired sequentially through active use of the hands and fingers (Warren, 1982). Blind readers run the tip of either index finger along the rows of dots from left to right as the visual reader runs the eyes along rows of print. Braille input is low-frequency, successive and constantly changing. Only the index fingers are used ordinarily for reading braille, as tactual sensory capacity diminishes progressively from index finger to little finger (Foulke, 1982) and reading braille with the thumb is extremely awkward. Self-initiated movement is essential for detection of braille dots (Heller, 1986; Heller, Rogers & Perry, 1990; Lederman, 1982), skilled braille readers scanning each line of text in a smooth motion that is only occasionally interrupted by regressions to already explored text.

Reading speeds are typically much slower for the blind than the sighted, braille readers averaging around 78 words per minute at 11 years of age and 103 words per minute at 16 years of age, whereas sighted readers average 250 to 300 words per minute. The blind read braille at about a third of the pace that sighted readers read print (Greaney, 1996).

Braille Reading-Cognitive Aspects

The orthography of braille - the arrangement of graphemes in phonological units of meaning - is the same as that of print. Grade 1 braille maps letter-for-letter to print, and, like print, is an alphabetic, phonologically irregular script (Millar, 1990). Presumably, braille reading and print reading do not differ to any substantial degree with respect to higher-level comprehension processes that evaluate syntactic structures, compute propositional content and construct representations for memory storage. While the unique tactual-perceptual characteristics might limit the speed with which braille can be read, the subsequent information processing efficiency is comparable to that for the printed word (Bertelson, Mousty & Radeau, 1992). In spite of differences in learning, levels of reading skill ultimately attained are similar for blind and sighted children at equivalent stages of development (Pring, 1994).

The ability to comprehend braille is significantly and positively correlated with the ability to understand verbal material presented orally (listening comprehension) and with working memory capacity (Daneman, 1988). A blind reader, given a block of data in braille, can extract the same bits of information therefrom as a sighted reader can extract from the same block of data in print. Both readers can then perform the same higher cognitive operations - judgements, comparisons, deductions, inferences and conclusions. Despite the significant differences between tactually dependent braille and visually dependent print, both must ultimately conform to a code that can access the same linguistic and memory systems (Daneman, 1988).

According to Barraga (1986), visual and haptic exploration yield input data with common characteristics. Millar (1975) found evidence that blind children, who cannot create a visual representation, can encode both tactual and phonological features of braille letters into a format which can directly access the lexicon. Eilers, Ozdamar, Kimbrough Oller, Miskiel and Urbano (1988) found striking similarities between speech perception through the tactual modality and speech perception through normal audition. Other findings which support the functional association between visual and tactual processing include those of Sasanuma (1974), who reported that adults with acquired dyslexia can sometimes "read" by tracing the letters of words or by hearing them spelled aloud.

Hamann (1996) reported that functional similarity in priming, an attentional process associated with stimulus detection, occurs between visual, auditory and tactile domains. Tactile and visual perceptual systems respond similarly to variations in temporal and spatial stimulation (Zakay & Shilo, 1985). Braille is encountered and perceived in serial fashion (Daneman, 1988). Braille word recognition, the end result of a piecemeal, sequential accumulation of input data (Harley, Truan & Sandford, 1987; Pring, 1982) depends on spatial and temporal factors (Shimuzu, 1982). Individual signs are identified sequentially, being assembled as the area of each cell is explored by the fingertip and the location of each dot plotted in space. As braille text can not be assimilated in units larger than the individual letter or contraction, readers must recognize and process each individual character in a series, remember them in sequence, then integrate them to form each word. This implies that each letter, and each cluster of letters, is represented phonologically in the tactual reading process, and that braille reading also involves phonological coding. Lexical access also appears to occur serially, via the non-lexical (phonological) route, with the reception of each bit of phonetic input (Bertelson, Mousty & Radeau, 1992).

Tanenhaus, Flanigan and Seidenberg (1980) argued that both phonological and orthographic codes are accessed in visual and auditory word recognition. It is therefore likely that this also applies during the tactual reading of braille. Pring (1982) reported a phonological effect in blind children's reading of single words and concluded that lexical access occurs similarly with tactual and visual input. Differences found by Dodds (1983) between the performances of blind and blindfolded sighted subjects on a shape-matching task are consistent with the existence of two alternative information processing routes. The better performance of the sighted subjects was attributed to their having access to both lexical and phonological routes, while the blind subjects had access only via the phonological route.

Because haptic perception involves the synthesis of sequentially processed information, similar demands to those imposed by visual reading are placed on cognitive processes. Newman, Brugler and Craig (1988) found a high degree of similarity in the performances of blind and sighted subjects on the immediate recall of haptically examined braille signs and concluded that the same processes operate for both groups, as did Knowlton and Wetzel (1996). Comparisons of miscues made by blind and sighted readers (Sowell & Sledge, 1986) revealed that print and braille readers made approximately the same proportion of substitutions, omissions, insertions and reversals. Warren (1982) found that error patterns were very similar on both haptic and visual letter recognition tasks. The development of haptic exploration strategies, although delayed temporally, is similar to the development of those for visual exploration. Haptic information has also been shown to decay in the same way as visual information, leading to the tentative conclusion that haptic input could be visually encoded and stored.

Interestingly, the letters which are commonly confused or reversed by sighted braille learners (and probably by blind braille learners) decoding by touch alone, are different from those reversed or confused by visual readers of print. For the latter, *b* : *d*, *p* : *q*, *n* : *u* and *m* : *w* are the classic difficulties, whereas for tactual readers, problems are commonly encountered with *i* : *e*, *d* : *f* : *h* : *j* and *r* : *w*. Coincidentally, there are eight letters in each of these groups.

Previous experience with structural and grammatical aspects of language plays a critical role in braille reading, as does intellectual capability (Griffin & Gerber, 1982). Successful braille reading requires adequate attention, concentration, comprehension and memory (Miletic, Hughes & Bach-y-Rita, 1988). The importance of attention in the perception of tactile stimuli was emphasized by Post and Chapman (1991), who found that attention exerts a generalized enhancing effect upon both visual and tactile perception.

Remembering and synthesizing are particularly important when reading braille, as the gestalt of phrases, sentences, graphics and pictorial illustrations is not available. Braille readers do not have recourse to whole-word perception or to the instantaneous access to the adjacent words on either side of the word being decoded, as is the case with visual reading. This is because of the relative sizes of the perception window for each modality. The tactual perception window is extremely narrow, the unit of perception for braille being the individual dot whereas the visual perception window is wide enough to accommodate several words simultaneously at each fixation.

Rudel, Denckla and Spaltern (1976) investigated intersensory communication and processing in a study which involved paired associate learning of morse code and braille letter names by normal and dyslexic children. While substitution of one modality for the other was not considered useful, these authors stated that this conclusion should not be interpreted as implying that dyslexic children would not be aided by supplementary other-sensory input.

The reading process appears to be very similar in the tactual and visual modalities (Wilkinson & Carr, 1987), differences resulting mainly from the slower tactual encoding process, rather than from the establishment of a separate system for processing braille input.

Cross-Modal Integration

Cross-modal integration refers to the process by which information can be translated from one sensory modality to another (Bryant, 1975). In reading, connections must be made between visual and auditory systems as well as memory and comprehension systems. The fact that the blind can read with braille means that the tactile modality is similarly inter-connected. Carr (1985), considering the relationship between visual reading comprehension and listening comprehension, suggested that visual encoding mechanisms must be integrated into a comprehensive system already established for listening.

Experimental evidence exists for the occurrence of "cross-talk" (Millar, 1987) between widely different processing operations. The mechanism for this cross-modal activation capacity would appear to be found, at the cellular level, in the overlapping of receptive fields of cells, which are the surrounding structural areas from which sufficient sensory stimulation will elicit a response, and at a higher level, in the possible overlapping of neuronal systems that subserve tactile and visual processing operations (Rapcsak, Gonzales Rothi & Heilman, 1987).

Cross-modal transfer occurs reciprocally between haptic, visual and auditory modalities (Squire, 1987; Streri, Spelke & Ramiex, 1993). Having palpated an object, an individual can then discriminate it visually from an array of other objects. Butter (1979) found haptic training a successful strategy for reducing impulsiveness and improving application to task in third and fourth grade boys. He reported that problem-solving techniques learned in the haptic modality transferred across to the visual, concomitant improvements in application and outcomes occurring in the performance of each type of task. According to Warren (1982) there is a large literature on cross-modal integration of haptic and visual information. Eilers, Ozdamar, Kimbrough Oller, Miskiel and Urbano (1988) found a close correspondence between tactual and auditory discrimination and identification of vowels and consonants, and suggested that similarities in coding might account for cross-modal similarities in perception.

Bach-y-Rita (1972, 1987, 1990) and Bach-y-Rita, Collins, Saunders, White, & Scaddes (1969) described the activation of sensory substitution systems in congenitally blind subjects, whereby visual information (printed text) was delivered to the brain tactually, via intact cutaneous receptors and pathways. Subjects not only discovered visual concepts such as perspective and shadow, but also developed the ability to use visual analytic strategies such as parallax, zooming and spatial localization. They could clearly process visual information presented tactually.

Braille Learning by Sighted Readers

The performance of haptic tasks by sighted individuals usually depends on the availability of visual frames of reference, sighted people invariably recoding tactile impressions into visual images (Heller, 1989). Visual involvement is one explanation for superior performance by blindfolded sighted and late-blind individuals, compared with that of the early blind, on tactual perceptual tasks. Heller (1987) cited experimental support (Newman et al., 1982) for the notion that braille signs are coded by touch as outline configurations, a process enhanced by the involvement of vision for sighted braille learners.

Denckla (1986) reported that discrimination between "same" and "different", while palpating braille signs, was performed better with the left hand by right-handed normal, sighted subjects over the age of 10 years. Wilkinson and Carr (1987) agreed that individual letter and word recognition in braille reading might involve perceptual processes that tend to be right-lateralized and that the underlying neurophysiology of cognition confers a right hemisphere advantage for braille reading which implies that the left hand should be used. A right hemisphere specialization for tactile information processing was also proposed by Perrier, Belin and Larmande (1988). Heller, Rogers and Perry (1990) reported evidence from sighted subjects that improved braille pattern identification was obtained with the left hand.

The next chapter will address issues concerning the application of braille as a remedial medium with dyslexia.

CHAPTER 5: THE PRESENT STUDY

This chapter describes a field study conducted to test the effectiveness of braille training as a remedial technique with a group of sighted, dyslexic, school students. The study has raised a number of ethical and methodological issues. In particular, reasons are advanced for not incorporating a control group in the research design, thus eschewing the status of true experiment. A rationale for inclusion of a comparison group, assembled from archival records, is presented.

Aims

The aims of this study were to document and evaluate an innovative approach to the remediation of dyslexia. The rationale incorporates aspects of the multi-sensory approach and the use of braille with dyslexic students, neither of which appear to have ever been taken as seriously as they deserved, and draws heavily upon recently developed neurological knowledge about the cerebral mechanisms of dyslexia. The alignment of these perspectives offers to advance empirical knowledge about this enigmatic disorder.

The study aimed to demonstrate a training effect, i.e., improvements in word recognition, passage-reading rate, passage-reading accuracy and reading comprehension, following a period of braille-based remediation. In order to achieve this aim, a programme of braille training (the independent variable) was developed and applied with each participant.

The design employed was a single intervention with baseline, treatment and post-treatment follow-up phases, a format that is eminently practical for school settings according to Willson (1982). Performance on single word recognition, passage-reading rate, passage-reading accuracy and reading comprehension (the dependent variables) was measured at 3-monthly intervals. This study replicated and extended previous non-experimental, single-case studies of the effects of braille training on the reading performance of dyslexic students.

The following research questions were addressed:

1. Can dyslexic students learn braille?
2. Will braille training improve the visual word recognition,passage-reading rate, passage-reading accuracy and reading comprehension of dyslexic students?
3. How long will it take for braille training to bring about improvement in these skills?
4. Is there any similarity in the occurrence of training effect across participants?
5. Is there a critical level of competence which must be attained before improvement can continue without support?
6. Will any improvement persist after braille input has ceased?
7. Will the findings of the present study generalize to the wider dyslexic population?

On the basis of the findings of previous, non-scientific, endeavours, the research hypothesis predicted that augmenting visual reading with tactual input via the medium of braille would improve visual word recognition, passage-reading rate, passage-reading accuracy and passage-reading comprehension between *Entry* and *Exit*. *Entry* refers to the point at which participants commenced braille training. *Exit* refers to the point at which participants reached or passed the 18th percentile in single word recognition and when braille-based input ceased. In relation to the stability of training effect over time, the research hypothesis predicted maintenance of improved reading skills independent of training support. The term *Maintenance* refers to the post-intervention follow-up phase.

The study, as a field intervention, raised a number of ethical and methodological issues. Some of those issues arose directly from the fact that a longitudinal design for studying the effects of braille training was used, while others arose from the theoretical understandings of dyslexia that are apparent in the literature. These ethical and methodological issues are now discussed.

Control Groups - Ethical Considerations

A control group was not incorporated in the experimental design. It was considered that assigning participants with an identified educational need to a non-treatment group would have amounted to the premeditated denial of access for those students to an arguably effective programme designed, and expected, to remediate that need (Connor, 1994).

It was anticipated that specific benefits would accrue to members of the experimental group and it was considered that, in addition to denying members of a no-treatment group the opportunity to enjoy similar benefits, there would also be a calculated imposition of costs such as affronts to personal dignity, loss of autonomy and self-determination and further lowering of self-esteem. Such costs could not be alleviated at the conclusion of the study because the deleterious effects could not be reversed, given the ineffectiveness of known, conventional, remedial treatments. In this situation, assignment to a no-treatment condition would have been tantamount to deliberately exposing students already handicapped by reading disability to pre-planned, continuing failure. This would have contravened current government policy with respect to social justice and equal opportunity.

The longitudinal nature of the study effectively precluded condition reversal, under which design controls eventually experience treatments. There was no compensation which could be applied to redress this comparative disadvantage. Vulnerability to litigation was seen as an attendant risk to the use of control group methodology in these circumstances.

Control Groups - Methodological Considerations

Control group methodology in the study of dyslexia has come under increasing attack in recent years. As pointed out by Farmer and Klein (1995), the heterogeneity in the reading disabled population is such that the formation of control groups is fraught with difficulties and characterized by potential contradictions. According to Martin (1995), the basic problem with the group study approach is that it is theoretically unjustifiable to average the performance of individuals who possibly have different functional deficits. A statistically significant difference between experimental and control groups could mean, on the one hand, that this difference characterizes all or most of the experimental sample, but it could also be due to substantially overlapping distributions and small differences between group means becoming significant with large enough samples. Another potential problem with applying group study methodology to samples whose members have different underlying deficits is non-replicability. Although this problem might be avoided in theory by classifying dyslexic students into homogeneous sub-groups, developed knowledge is not yet at the point where such classification can be effective.

Comparison Groups - Methodological Considerations

In order to redress the lack of a formal control group in the experimental design, to demonstrate the inneffectiveness of conventional remedial approaches, to establish the validity of the results of braille-based intervention, and to differentiate the effect of controlled intervention from that of other factors which might be impacting upon the participants, a comparison group was assembled from archival records. Data were collected from files held in the education district central records repository. The comparison group graphs depict the course of word recognition development in a matched group of dyslexic students, who, while not observed contiguously with the experimental group, were nonetheless exposed to the same mainstream teaching practices and conventional remedial opportunities as were the experimental group. Members of the comparison group, however, were not exposed to braille training. It is believed that the ethical quandary of deprivation of benefit was avoided by using a cohort of students who had completed their primary school education immediately prior to the commencement of this programme.

Reference to a comparison group addresses the issues of history, the major threat to internal validity encountered with longitudinal studies, by differentiating between the learning patterns of two groups of dyslexic students over a given time span; and selection, by supporting the notion that the experimental group was not identifiably different in some way that affected the outcome. The closer two events are in time, space and measurement on any or all dimensions, the more they tend to follow the same laws (Campbell & Stanley, 1963). According to Graziano and Raulin (1993), groups which are removed in both space and time from the experimental group are still acceptable for statistical comparison as long as equality along key dimensions can be established. The only dimension on which the two groups in the present study differ is time, and on this point it is argued that they are practically contiguous.

Comparison group members were matched on age, sex, IQ, educational opportunities, academic achievement, failure to respond to protracted remediation, race / ethnicity, socio-economic status, and test used to assess word recognition performance. Although some members of the experimental group were monitored across some years of High School, overall, comparison group observations spanned a somewhat longer period than did experimental group observations.

Both samples were assembled individual by individual, neither constituting a naturally-formed or pre-existing group. While there was no random assignment of participants to either of the treatment or no-treatment conditions, neither was there any element of self-selection to either group. Participants were included in only one of the two conditions. Because determination of group membership was unbiased, it is argued that the purpose of random assignment was achieved.

Design of Field Experiment

This longitudinal study employed a group design for the primary statistical analysis and single-case design for the supplementary individual analyses.

According to Wilson (1987), single-case designs are invaluable tools for determining whether improvement is a result of treatment or of some other cause, and are usually more effective than group studies for evaluating training interventions (Wilson, 1987).

According to Hersen and Barlow (1976), the power of the single-case design to isolate the independent variable as responsible for treatment effect approaches that of the experimental group-control group design. Single-case research allows a more comprehensive explanation of intra-subject variability than group designs (Savard et al., 1998), permitting individual outcomes to be taken into account while still comparing the treatment condition with baseline behaviour (Callery & Morris, 1993). According to Wacker, Steege and Berg (1988), single-case designs are appropriate for educational intervention research because both the internal validity of the intervention and the applicability of the intervention to on-going school programmes can be established.

Despite a belief, attributable to the influence of Fisher (1925), that findings from small-N studies are neither valid nor generalizable, it has been repeatedly demonstrated over the years that such results are, in fact, obtainable from studies of individuals. Although sample size is a valid concern in the scientific evaluation of interventions upon complex human behaviour, historically in neurology, single case studies have provided valuable insights into mechanisms of function and dysfunction (Duane, 1989). Among the more influential of such studies are Broca's (1861) presentation of his patient, "Tan", which heralded the beginning of modern neuropsychology, and the expositions of Scoville and Milner (1957) about their amnesic patient

"M.H.", which have contributed enormously to present understandings of human memory.

Planning and conduct of the present study were guided by principles such as analysis of intra-subject variability, replicability, repeated measurement, specification of conditions and design flexibility, which distinguish single-case from group designs and enhance evaluation of intervention outcomes (Gresham and Kendell, 1987). In the present study, application of single-case methodology was considered appropriate in view of the documented heterogeneity of dyslexic sufferers and the current lack of scientific procedures for delineation of discrete sub-groups.

Time series designs permit the assessment of change, not in terms of deviation from a group mean, but as a departure from an established pattern (Jensen, 1990), and as such are appropriate for evaluating performance improvement (Morgan, 1996) following training. If a control group is not possible, the best alternative evaluation strategy is a time series design (Graziano & Raulin, 1993), as repeated measures of the dependent variable before, during and after intervention can control for many threats to internal validity. Time series designs are appropriate when a treatment can not be manipulated experimentally due to pragmatic or ethical considerations (Braden, Gonzales & Miller, 1990). Where participants can not be assigned to a non-treatment control group, a major advantage of the time series design is elimination of the need for random assignment of participants (Marston, 1988; Savard et al., 1998), as each participant acts as his or her own control. This type of design is particularly appropriate for research in schools (Campbell & Stanley, 1963).

Clinical vs Normative Evaluation of Interventions

The clinical effectiveness of a performance enhancement intervention relates to the importance or pragmatic effectiveness of the outcome achieved for the target population, whereas statistical significance relates to the likelihood of that outcome being achieved by chance. Even if changes are statistically significant and clearly result from the intervention, they will not necessarily be clinically significant. Similarly, small improvements in performance, for which statistical significance can not be established, can be extremely important (clinically significant) in real life.

Herson and Barlow (1976) maintained that demonstration of effectiveness in behavioural research should not be constrained by the strict application of the principles of precision and specificity which characterise true experimentation in the physical sciences. Shapiro (1987) proposed that several clinical parameters, including treatment effectiveness, treatment integrity and treatment acceptability should be accorded due weight in evaluating intervention research, and that the maintenance and generalization of change following cessation of treatment are additional parameters by which the effectiveness of any behavioural intervention should be assessed.

The experimental procedure required cessation of braille-based training once participants reached or passed the 18th percentile in visual word recognition. Although the attainment of this percentile ranking represents a substantial improvement in word recognition, all participant had a substantial degree of improvement still to be made. In order to obtain an adequate number of participants for statistical analysis, it was necessary to cease braille training at some point so new participants could be commenced. The 18th percentile in single word recognition, the lower extreme of the average band, was selected as this point. Because of the ethical responsibility of social science researchers to protect the welfare and rights of participants (Kidder, 1981), all were offered resumption of braille-based training at the conclusion of the study.

CHAPTER 6: METHOD

Participants

Experimental Group

Members of the experimental group were all students referred to the education district School Support Centre by Class Teachers and Learning Support Teachers because of severe and refractory reading problems. Every student in the education district who exhibited these characteristics was eligible for inclusion in this study. The reporting of demographic variables followed the guidelines set out by the Committee for Learning Disabilities (CLD) Research Committee (Smith et al., 1984), Durrant (1994) and Wolery and Ezell (1993) (Table 1).

Inclusion in experimental and comparison groups occurred where there was evidence of a significant discrepancy between average or above-average cognitive capability and sub-average reading achievement, in students:

- who evinced no visual or hearing problems,
- who displayed no significant manifestations of emotional maladjustment or behavioural disturbance,
- who had access to the same educational opportunities as were available to the wider school population and
- whose files documented protracted and unsuccessful remedial intervention.

Table 1.

Experimental and Comparison Group Demographics

	Experimental gp	Comparison gp
Number		
Males	18	18
Females	2	2
Total	20	20
Age at Entry		
Mean	10 years 0 months	N/A
Range	7 6/12 - 15 6/12	
First identified	6 years 10 months	6 years 8 months
Remediation		
Mean	2 years 9 months	5 years
Range	6 mths - 5 yrs	3 6/12 - 7 0/12
SES		
Blue Collar	7	7
White Collar	10	9
Rural	3	1
Unknown	0	3
Geog. Location		
Urban	5	0
Country-Urban	13	17
Rural	2	3
IQ		
Mean	103	96
Range	90 - 133	90 - 115
Word Recog. At Entry		
Mean	3rd %ile	4th %ile
Range	0 %ile - 14th %ile	0 %ile - 15th %ile
Reading Rate at Entry		
Mean	9th %ile	N/A
Range	0 %ile - 21st %ile	
Reading Acc. at Entry		
Mean	7th %ile	N/A
Range	0 %ile - 27th %ile	
Read. Comp. at Entry		
Mean	27th %ile	N/A
Range	0 %ile - 74th %ile	

Standard referral procedure within the state education system stipulates that written permission must be obtained from parents or guardians before support personnel can have direct contact with any child. Full disclosure of belief, intent and expectation was made to parents of potential experimental group participants following referral. The ethical requirement of voluntary informed consent was thus met in all cases.

Age at Entry. With the exception of one female who was aged 15 years 6 months and was enrolled in High School, all participants were Primary School students. Other ages at Entry ranged from 7 years 6 months to 11 years 5 months, with an average of 9 years 4 months. The average age at which these students were initially identified as experiencing significant academic achievement problems, calculated from the dates that the first assessment data were placed on file, or from the year of Grade repetition, was 6 years 10 months. Two students commenced braille training while in Grade 2, one while in Grade 3, nine while in Grade 4, four while in Grade 5, three while in Grade 6 and one while in Grade 10.

Remedial Exposure. Sixteen members of the experimental group had received remedial assistance prior to commencing braille training, the periods of remediation ranging from 6 months to 5 years, with a mean exposure of 2 years 9 months. The Grade 2 students had received no such support and the duration could not be calculated in two cases. Various remedial strategies were tried (See Appendix A), in all cases without success. Experimental group members did not receive learning support during the braille training phase.

Socio-Economic Status. Socio-economic status, judged on the basis of parental occupation as recorded in departmental files, reflected a cross-section of society, the majority of participants representing blue- and white-collar strata, (7 blue-collar, 7 white-collar), with minorities from the business / professional sector (3 students) and the rural sector (3 students).

Geographic Location. Five participants attended suburban schools in the state capital. The remainder were located in, and adjacent to, a provincial city. Schools attended were a representative sample of the state education system - one Band 5 rural school (33 enrolments), four Band 6 schools (98, 165, 197 and 215 enrolments), two Band 7 (298 and 301 enrolments), one Band 8 (662 enrolments), two Band 9 (610 and 627 enrolments) and one Band 10 (950 enrolments). One student was enrolled with the School of Distance Education. All but the latter were placed in regular classrooms for the duration of their participation in this study.

IQ. All participants were functioning within or above the normal range of intellectual capability, as measured by standardized tests, mostly the Wechsler Intelligence Scale for Children-Third Edition (WISC-III) and the Wechsler Intelligence Scale for Children-Revised (WISC-R), but also the Stanford-Binet Intelligence Scale-Fourth Edition (SB-4) and the McCarthy Scales of Children's Abilities (MSCA). Eleven of this group were assessed by this author. In 17 cases, WISC Full Scale scores fell between 90 and 110. One student scored 112 (WISC-R), one 115 (McCarthy) and one 133 (WISC-R). The mean IQ of those assessed with Wechsler tests was 104. The mean of the three SB-4 Test Composites was 103.

Academic Achievement. Attainment levels for the experimental group at Entry were as follows:

Word recognition scores for these participants ranged from the 0 percentile in four cases to the 14th percentile in one case, with a mean ranking at the 3rd percentile.

Reading rate achievement levels ranged from the 0 percentile (one child was unable to attempt the base level of passage reading) to the 21st percentile, with an average placement at the 9th percentile.

Passage-reading accuracy attainments at Entry ranged from the 0 percentile (one child was unable to register a score), to the 27th percentile, with a mean placement at the 7th percentile.

There was a much wider distribution of scores on passage reading comprehension. Results ranged from the 0 percentile to the 74th percentile, with a mean placement at the 27th percentile.

Ability-Achievement Discrepancy. The WISC-R / WISC-III Full Scale IQ range was 90 - 133. This equates to a percentile range of 25 - 99, the group mean being the 51st percentile. It would be expected that students functioning at these levels of cognitive capability would display comparable competence at reading.

Experimental group Entry level means for word recognition, reading rate, passage reading accuracy and passage reading comprehension were the 3rd, 9th, 7th and 27th percentiles respectively.

<u>School Placement.</u> Eighteen members of the experimental group were enrolled in state schools for the duration of this project. Two attended private schools for the entire period and three transferred from state schools to private schools during the treatment phase. Students in both state and private schools, however, all experience the same curriculum.

<u>Race / Ethnicity</u>. All participants were of Caucasian extraction. There was no intention to control for race / ethnicity, but no students of other racial / ethnic backgrounds were referred for support with literacy when participants were being accepted. English was the language spoken at home in all cases.

<u>Vision and Hearing.</u> From both file notations and clinical observations it was established that no experimental group members suffered visual or hearing problems which might have contributed to their reading difficulties.

<u>Behaviour and Emotional Adjustment.</u> No members of the experimental group had been referred for clinical emotional maladjustment during the pre-intervention period and there were no indications in their personal presentation that intervention for such problems was required. Marital problems did surface between the parents of two participants during the training phase, and are considered to have adversely affected their reading performance.

<u>Comparison Group</u>

In order to demonstrate that a group of students who manifested a similar reading attainment profile had not benefited from conventional remedial procedures, the word recognition performance of a matched comparison group was tracked across the course of their primary school years. All members of the comparison group had been referred by class teachers for specialist assistance from the then Special Education Division of the State Education Department, following the identification of significantly deficient reading performance. Students were included in the comparison group if the selection criteria which described the experimental group were met. Reading performance data were extracted from department archives.

Age at Entry. Comparison group members were all primary school students. The average age at which these participants were initially identified as experiencing significant reading problems, calculated from the dates when the first assessment data were placed on file, or from the year of Grade repetition, was 6 years 8 months.

Remedial Exposure. The comparison group received longer periods of learning support than the experimental group. The non braille-based remedial opportunities offered to these students were similar to those offered to the experimental group (see Appendix A). Time in receipt of such support ranged from 3 years 6 months to 7 years, with an average of 5 years. In all cases, these interventions were ineffective. (Appendix E)

Socio-Economic Status. On the basis of parental occupation, this group also reflected a cross-section of society. Seven were from blue-collar backgrounds, five were from white-collar backgrounds, four were from the business/professional sector and one was from the rural sector. In three cases no determination of SES could be made from information recorded on file.

Geographic Location. The comparison group all attended state schools within, or adjacent to, the same provincial city as most of the experimental group.

IQ. All comparison group members were functioning within or above the normal range of intellectual capability, as measured by the WISC-R, the Stanford-Binet Intelligence Scale, Form L-M and the McCarthy Scales of Childrens' Abilities. In 14 cases, WISC-R Full Scale scores fell within 92 and 115, with a mean of 100. The SB L-M IQ score was 97. The two McCarthy GCIs were 90 and 91.

IQ data were not available for three students. However, one of these was described in a file notation as being "average" at maths, the oral reading comprehension of another was described as "good", and the general comprehension of the third was recorded as "satisfactory". Moreover, there were no notations in any of their files which indicated concern about general ability and not one of these participants was ever referred for assessment of IQ. Given the propensity of teachers to request assessments of general ability with poorly-performing students and the ready availability of this service, it is considered a reasonable assumption that these three were all functioning within the average range of intellectual capability.

Academic Achievement. Milton Word Recognition Test scores, obtained by Learning Support Teachers and Guidance Officers, were available for the comparison group. Results ranged from the 0 percentile - 15th percentile with the group mean at the 4th percentile.

Ability-Achievement Discrepancy. The average IQ range for those tested with the WISC-R was 90 - 115. This equates to a percentile range of 25th percentile - 84th percentile, the group mean being the 52nd percentile. McCarthy scores approximated the 28th percentile - 29th percentile. A percentile ranking for the Binet IQ was not available, but would have fallen within this overall range. While comparable levels of reading skill would be expected, the comparison group mean for word recognition was, as mentioned above, the 4th percentile.

School Placement. All members of the comparison group were placed in regular classrooms throughout their primary school years. Two were supported through Special Education Units in addition to receiving regular Learning Support Teacher assistance.

Race / Ethnicity. All members of this group were Caucasian. English was the language spoken at home in all cases.

Vision and Hearing. From file notations pertaining to 15 members of this group it was determined that both vision and hearing were within normal limits. In the remaining cases, no specialist data indicated problems in these areas.

Behaviour and Emotional Adjustment. File notations relating to comparison group students attested specifically to the absence of behaviour and emotional adjustment problems in some cases. As behaviour is a major concern for class teachers, absence of negative comment was interpreted as indicating acceptable behavioural adjustment for the remainder.

Materials

<u>Measures of Reading Ability</u>

Aspects of reading ability studied were individual word recognition, measured by the Milton Word Recognition Test (Milton WRT), and reading rate, passage-reading accuracy and passage-reading comprehension, measured by the Neale Analysis of Reading Ability-Revised (Neale-R) (Neale, 1990; Neale, McKay & Childs, 1986).

The Milton WRT is used extensively throughout the state by Guidance Officers and Learning Support Teachers to assess literacy skills among the primary school population. It is designed to assess a child's ability to recognize single words in isolation, i.e., without the aid of contextual cues, and to decode unfamiliar words correctly, i.e., to analyse words into individual sounds and to synthesize or blend these sounds into the correct pronunciation. This test is made up of 90 words, graded in difficulty and selected for their diagnostic value in representing the common letter group sounds. Words are mostly of five-letters and greater, are mostly irregular and are mostly of low frequency. Students being assessed are instructed to read as many words as they can from the list before them and are given no feedback on their responses. Performance on this type of test is therefore not influenced by practice effect. This facilitates documentation of progress over time through periodic re-testing. Performance is expressed as a percentile rank for Grade.

The Neale-R is a passage-reading exercise which examines fluency in terms of reading rate, punctuation and passage-reading accuracy, and comprehension in terms of being able to register facts, grasp concepts and make inferences from text. According to Greene (1996), these are key aspects to consider when assessing reading. Performance in each area is expressed in percentiles. The Neale-R was designed for the measurement of performance over time (Neale, 1989).

Braille Resources

In order to promote the development of tactile acuity, the initial tactual phase when participants acquired the capability to read braille, was structured in a down-stepping sequence over four stages. Three-dimensional models, measuring approximately 30mm x 45mm in external dimensions and proportional to standard braille with respect to dot size and dot placement, were constructed for the initial learning stage. Similarly proportional models measuring 12mm x 22mm externally were used in the second stage. A commercially available variant, Jumbo braille, measuring approximately 5mm x 8mm, embossed on adhesive film with a Perkins Brailler; was used for the third stage. In the fourth stage, the single-letter materials culminated in Standard braille, which measures approximately 4mm x 6mm. This was also embossed on adhesive film. The Jumbo and Standard braille signs were attached individually to small cards that were notched at the top for correct spatial orientation.

Stimulus words were all brailled in adhesive film. Twenty-six two-letter words were presented individually on small notched cards. The three-letter words were arranged on 10 cards, each containing 16 words. Four-letter words, 160 in all, were presented similarly. Five-letter words were arranged on 10 cards containing three sets of four words. Ninety-six 6-letter words, 56 seven-letter words, 240 words of eight or more letters and sets of theme words provided by class teachers were all presented in this format. Each brailled card was accompanied by a text card, on which the printed words were arranged in the same sequence. Each set of cards was accompanied by a purpose-designed worksheet for the recording of responses. In all, approximately 1000 words were taught.

Procedure

<u>Braille Training</u>

The approach taken here incorporated visual and tactual training components. Participants, although substantially reading disabled, brought to the task their own unimpaired vision and a range of established procedural conventions such as left-to-right scanning, letter awareness, an understanding that letters combine to form words and the awareness that words are units of meaning.

The programme called for students to learn Grade 1 braille minus numbers, capitals and punctuation marks. Participants first learned the visual patterns for individual braille letters, then used this knowledge to facilitate tactual learning. During the first stage, participants palpated the models with the palms of their left hands and fingers. In the second stage, the "reading" surface area was reduced to the inner face of the top joint of the left index finger, and in the third and fourth stages the "reading" surface was further reduced to the tip of the left index finger. Light pressure and constant movement were emphasised throughout. Visual inspection of braille patterns occurred simultaneously with tactual exploration of individual braille signs.

Visual learning of braille patterns was facilitated by teaching participants about the internal relationships in the configuration of individual braille letter signs. The first 10 signs (A - J) have dots only in the top and middle rows. When the next 10 signs (K - T) are aligned below A to J, thus:

A	B	C	D	E	F	G	H	I	J
K	L	M	N	O	P	Q	R	S	T

the second line of letters is created by adding dot # 3 to each of the first 10 signs. Similarly, when U, V, X, Y and Z are arrayed below K, L, M, N and O, the former are created by adding dot # 6 to each of the latter. The exception to this rule is W, which was created arbitrarily when braille was translated from French, where there is no representation for W, to English.

During the initial stages, learning activities employed included manually reproducing braille letter signs on purpose-designed worksheets, matching tactual perception to the corresponding visual pattern for individual signs, and feeling through all 26 models to find those corresponding to specified visual braille patterns. Once the braille alphabet had been mastered, this activity was varied to requiring participants to match models, out of sight, to specified Roman letters. From this point, the programme focussed on the tactual recognition of words in standard braille, learning progressing in an up-stepping sequence through two-letter words, three-letter, four-letter, and so on, up to words of twelve letters or more. Words taught were from the Dolch, Edwards and Bookwords high-frequency lists. Once students had reached the eight-letter stage, teachers provided lists of theme words from topics currently being covered in class. These were brailled and learned by touch.

Once students had reached criterion on three-letter words, a different approach was adopted for succeeding levels. With four-letter words and greater, students were first presented with the print cards and asked to read the words visually. Incorrect responses were recorded, and these words were then learned in braille, by touch. As each word was being learned, letter-by-letter, in braille, participants were visually inspecting the accompanying printed version.

Visual inspection of words "read" by touch provided immediate confirmation of correct decoding and facilitated retrospective error analysis with incorrect responses. The criterion of 90% mastery determined progression from stage to stage throughout the programme. Once students could correctly identify 22 out of the 26 letters of the alphabet at the single-letter levels, or 90% of the words presented in each of the subsequent word sets, they progressed to the next stage.

The visual braille patterns were quickly mastered by all participants. It then became necessary to force them to use the sense of touch and not resort to vision, an automatic reaction in most cases. An apparatus permitting brailled items to be presented and palpated out of sight was designed for this purpose. This apparatus was an open box, placed so the open side faced away from the students, who inserted both hands through small apertures at the two lower corners. Models and cards were then passed to the students through the open side. The notch in the top of each card enabled students to orient the braille correctly. They were then required to identify by touch each braille letter or word.

In accordance with Heller's (1989) suggestion that tactile learning could be significantly enhanced through slower rates of stimulus presentation, participants were not subjected to time limits for tactual exploration and were allowed to progress through the programme at their own pace. Training was conducted on average during three sessions of thirty minutes per week. Braille training phases ranged from 9 - 24 months, with an average of 15 months.

Data Collection

Successive measures of performance on the dependent variables were taken at 3-monthly intervals. Braille training was discontinued when each participant's word recognition performance (Milton WRT score) reached or passed the 18th percentile (Exit). During the subsequent Maintenance phase, participants received no further braille training, but experienced the usual range of teaching strategies employed in their respective classrooms as they had done prior to entering the programme. The post-intervention phase varied from 12 months to 39 months. Observations were taken during this period for the purpose of evaluating permanence of training effect.

Word recognition percentile scores for the experimental group were graphed for visual inspection. Graphs provide a pictorial representation not only of the unfolding of treatment effect, but also of any systematic patterns which might occur, and of any directional tendency in the data. These latter phenomena are often most easily detected by visual inspection of series plots.

Data Preparation

To support the assessment of overall effectiveness of braille-based remediation, as well as to document the sequence of change in individual cases, interrupted ARIMA time series analyses (Box & Jenkins, 1976, see Appendix B) were performed as complementary evaluations on each experimental group word recognition data set. The data processing package Statistica 1998 was used to perform these intervention analyses. Interrupted time series analysis operates on multiple measures of a dependent variable from single subjects, both before and after some manipulation or intervention. The ARIMA process requires a minimum of 10 observations before and after intervention (Statistica, 1995), and it is desirable to assemble a complete data set (Willson, 1982). To bring data sets into line with this requirement, Statistica replaces missing observations by one of four alternative methods.

A feature of the data collected for this study was a paucity of pre-intervention observations for most of the experimental group. The Milton WRT was the instrument of choice because it is appropriate for the age range of the experimental group, because comparison group Milton scores extending over several years were readily available, and because the Milton is widely used in the educational setting to which the present findings seek to generalize. The Milton WRT, however, is seldom used below Grade 3 because there are other tests designed specifically for use with younger children. Additionally, it is difficult to draw meaningful conclusions about the ability of infant grade students from results that are expressed in terms of Year-level equivalence. Reading assessment of this nature is therefore rarely conducted with Year 2 students and almost never with Year 1 students.

In order to present pre-intervention reading development in a form upon which the Statistica Time Series Analysis module could operate, missing baseline observations were replaced with values computed in accordance with the system default for missing data replacement, interpolation from adjacent points. These values conform closely to a line connecting the observation preceding the missing data with the observation immediately following the missing data. It was necessary to generate these values manually and present them for analysis as actual observations. While the Statistica default would project such values in a single series, the module would not perform an interrupted time series analysis with a pre-intervention series containing so many missing observations. According pre-Entry observations the status of missing data was appropriate in view of the fact that such data were missing due to circumstances beyond experimenter's control. While most of these students were referred for specialist intervention prior to the commencement of the present study, that intervention did not always involve the testing of reading ability.

The interpolation from adjacent points method is based on the assumption that the data are serially correlated, that is, each observation is related to and most similar to adjacent data points. The veracity of the extrapolated values is established by comparing the lag correlations in the ACFs for the augmented and un-augmented series. (See Appendix C) The extrapolated replacement values differ only marginally from missing values interpolated by the system default. The ACFs also establish that the serial dependency characteristic of the un-augmented series is retained in the augmented series.

In addition, all experimental group plots are characterized by an upward trend across the raw score series. This secular characteristic is maintained in the extrapolated data. Zero is an appropriate start point because this is where reading development starts. In the vast majority of cases, the word recognition ability of children commencing Grade 1 is accurately represented as zero. Milton WRT results are widely accepted as reliable measures of reading ability at particular points in time, educational support provisions being determined, as standard operating procedure, on the basis of single assessments. In the context of reading disability it is documented that dyslexic children are students who fail to learn to read. They are not previously-better readers whose performance has deteriorated. The observation immediately prior to Entry is, therefore, of itself, a reliable measure of each child's word recognition ability at that point in the time series. For the purpose of extrapolating data points to pad the initial phases of these time series, therefore, zero and the Entry observation represent valid limits. As the Statistica Time Series Analysis module does not recognize zero as a data value, 1 was adopted as the start point of each augmented series.

All extrapolated values fell within the bounds of actual observations (Willson, 1982). The pre-intervention linear trend was thus not misrepresented in order to enhance the experimental outcome, the significance of which was established separately by MANOVA on the original data that did not include extrapolated observations. Baseline padding simply made possible the supporting statistical analysis of treatment effect in individual cases.

Further theoretical support for this procedure obtains from the fact that visual word recognition is not a phenomenon that fluctuates widely about a mean over short periods of time. Rather it is a steady incremental process that results only from exposure to educational opportunities. The developmental course of normal reading acquisition across the primary grades is represented numerically by norms for the Milton WRT and other reading tests.

Analysis of Data

<u>Descriptive Statistics: Data Plots</u>

Percentile rankings in word recognition (scores generated by the Milton WRT) were plotted over the primary school years for both Experimental (Appendix D) and Comparison Group members (Appendix E). The graphs visualize ordered sequences of actual observations, taken at 3-monthly intervals from the beginning of Year 1 to the end of the post-braille follow-up periods for the experimental group, and from the beginning of Grade 1 to the end of Year 6 (the extent of the Milton WRT norms) for the comparison group. Horizontal markers at the 18th and 50th percentiles define, for the purpose of comparison, performance standards of non-dyslexic students reading at the lower extreme and median of the average band respectively. Vertical markers indicating Entry and Exit points are included in the experimental group plots. These multiple line plots compare the progress of normal and dyslexic readers, and contrast the patterns of experimental and comparison group participants.

Inferential Statistics: MANOVA

The data processing package *SPSS* was used to evaluate the effect of braille-based remediation on the combined word recognition, passage-reading accuracy, passage-reading rate and reading comprehension profiles of the experimental group. The significance of this global effect was determined by 3 x 4 doubly multivariate, repeated measures MAVOVA. Pillai's Trace was used as the multivariate test. Values for the four dependent variables taken from 20 participants were compared at three points - Entry, Exit and the end of the Maintenance period. These values represent the progressive effect of braille-based remediation upon general reading performance. No formal statistical comparison between experimental and comparison groups was conducted.

Individual Profile Evaluation: Interrupted Time Series Analysis

The Statistica Time Series module follows the standard Box-Jenkins procedure - tentative model identification based on pre-intervention data, estimation of parameter values for the optimum model, intervention analysis and diagnostic checking. A one-parameter gradual-permanent impact intervention was modelled for each member of the experimental group. After differencing to achieve stationarity where necessary, each series was transformed into a first-order autoregressive (1,0,0) or (1,1,0) process. A regular ARIMA model was first fitted to observations taken prior to the introduction of braille training (Entry). An intervention component was then added and the complete series analysed. Because lapses in various aspects of academic performance following the long Christmas vacation are commonly displayed by students receiving educational support, it was suspected that seasonality could occur at a lag of 12 months. Autocorrelation (ACF) and partial autocorrelation (PACF) functions, however, supported series plots in indicating that this was not the case.

Time series analyses were not performed for passage-reading accuracy, passage-reading rate and reading comprehension as there were insufficient pre-intervention data. This is because the Neale-R is rarely used with substantially reading impaired students in the lower primary grades.

CHAPTER 7: RESULTS

Braille Learning Timelines

Table 2

Weeks Taken to Master Braille to the Three-Letter Word Stage

Stage	Participants																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1 30 x 45 mm models	3	8	5	3	3	2	4	2	3	3	8	*	*	5	3	5	*	1	*	1
2 12 x 22 mm models	3	7	4	2	2	2	3	2	2	3	4			4	3	5		1		1
3 Jumbo braille	3	5	4	1	1	2	3	1	1	2	5			2	2	4		1		1
4 Standard braille	3	4	3	1	3	1	3	2	1	1	4			1	2	4		1		1
5 2 - letter words	6	8	7	2	3	3	4	4	2	2	4			2	5	3		1		1
6 3 - letter words	12	18	13	6	11	6	9	8	9	12	12			9	9	10		6		1
TOTAL TO THIS POINT	30	50	36	15	23	16	26	19	18	23	38			23	24	31		11		6

* Missing data

Table 2 documents weeks taken by experimental group members to acquire the ability to read three-letter words in braille by touch alone. Stages 1 - 4 involved the learning of single letter signs of decreasing size. The criterion of 90% mastery was applied to determine progression from stage to stage. From the three-letter word stage, participants used braille to learn words they could not decode visually, as they worked through sets of words of increasing length. When they reached their respective Exit points, experimental group members were able to read by touch words of up to twelve braille characters. Although the early records for Participants 12, 13, 17 and 19 were unfortunately lost, the remaining data clearly show, in answer to Research Question 1, that dyslexic children can learn braille.

Reading Improvement Timelines

Table 3, which summarises the word recognition improvement timelines illustrated in the percentile plots at Appendix D, addresses Research Question 3. School vacations and periods when no braille-based remediation was conducted were taken into account when calculating these timelines. Three participants had not reached the 18th percentile in word recognition when they were required to Exit the programme so that the stipulated Maintenance phase (minimum 12 months) could be applied. All, however, had achieved clinically significant improvements on the reading measures used. All three showed continued improvements in word recognition raw scores across the Maintenance phase. On the bases of this post-Exit improvement and the improvement patterns of eight other participants who took between 52 and 102 weeks to reach criterion, it is considered probable that these three simply needed more time in braille-based instruction before they could demonstrate similar gains. There is considerable spread (22 weeks to 102 weeks) between participants who did reach criterion. Participant No. 2, who ultimately proved to be one of the strongest performers, began to show

Table 3

Experimental Group Word Recognition Progress: Weeks to Reach the 18th %ile

Partic. No.	Wks to 18%ile
1	54
2	102
3	68
4	54
5	52
6	42
7	34
8	30
9	45
10	56
11	54
13	30
14	32
15	68
17	51
18	22
20	22
Total	816
Mean	48

improvement only after some 18 months of braille training. In six cases, progress was apparent after only 3 months. This variation is partly due to the fact that, in some cases, early progress was obscured by an artifact of the Milton Word Regognition Test, which contains only 4 words of two letters, 4 words of three letters and 6 words of four letters, the remaining 76 words ranging in length from 5 to 12 letters. Most participants did not therefore demonstrate gains in word recognition until they were working through brailled words of five letters.

Delays in onset of training effect are also attributed to factors such as severity of the presenting problem at Entry, and, although no attempt was made to classify participants into subtypes, the heterogeneous nature of dyslexia. In addition, it was concluded from informal observations made during the training phase that several of those who took longer to reach criterion were not completing homework assignments, whereas others, such as Participant No. 20, diligently completed sessions on a daily basis with parental supervision.

On an individual level, visual examination of experimental group word recognition raw score plots (Appendix F) provides an affirmative answer to Research Question 4. In 15 cases, word recognition attainment profiles unfolded to approximate a shallow ogival, or S-shaped configuration. This configuration is consistent with the implementation, then cessation, of an effective intervention. Given the individual (time-linked) differences displayed in response to braille-based input, it is considered likely that all participants would have produced a similar profile if more observations could have been taken.

Extracted for the purpose of addressing Research Question 5, the figures presented in Table 4 are equivocal. No patterns emerge. There is no support here for a critical level of competence in word recognition, at, or beyond which, students are able to make progress

Table 4

Experimental Group: Post-Exit Word Recognition Improvement

Partic. No.	Exit %ile	%ile Gain
1	18	19
2	26	9
3	20	17
4	20	8
6	26	32
8	20	15
9	26	9
10	18	2
11	19	26
13	25	6
14	12	18
15	18	0
17	14	-2
18	18	-1
20	15	3

without external assistance.

Primary Statistical Analysis: MANOVA

Table 5 describes experimental group performance at successive stages of intervention. Using MANOVA there was a significant difference overall in test scores at Entry, at Exit, and at end of Maintenance - Pillai's Trace F (2, 18) = 62.36, $p < .001$. In response to Research Question 2, these results indicate that braille-based remediation improved the visual word recognition, passage-reading rate, passage-reading accuracy and reading comprehension of the dyslexic participants.

Table 5

Raw score Means and SDs for dependent variables at successive stages of intervention

	Entry		Exit		Follow-up	
Variables	Mean	SD	Mean	SD	Mean	SD
Word Recog.	25.95	10.23	53.25	12.29	61.55	11.45
Reading Rate	31.30	12.99	51.40	14.72	61.10	20.92
Reading Acc.	18.45	9.95	39.35	13.02	49.40	19.71
Reading Comp.	12.35	7.02	24.85	9.30	30.65	8.84

Figure 1 illustrates those differences for each dependent variable.

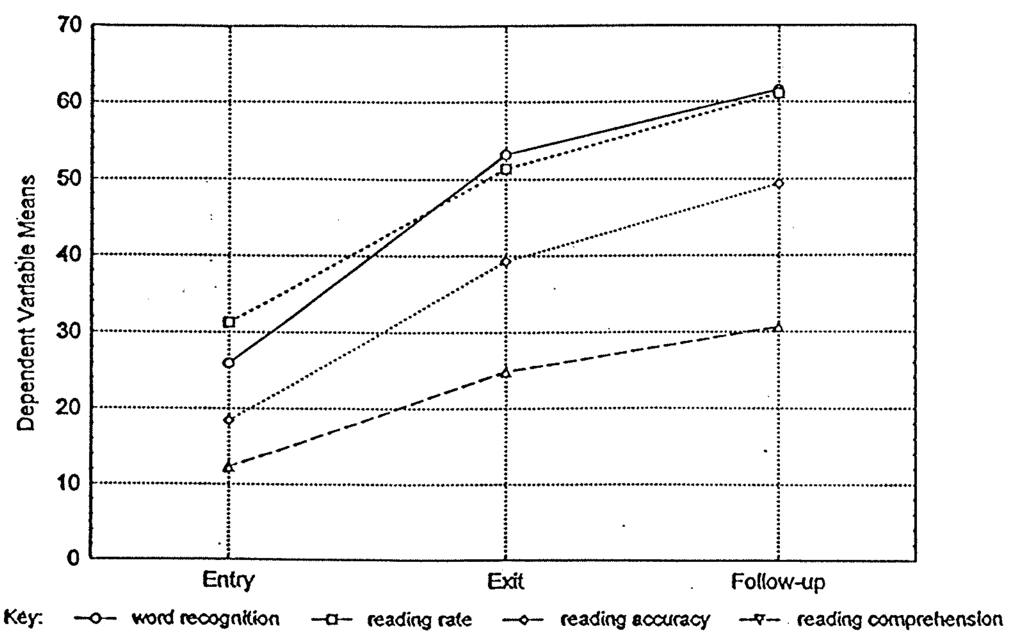

Figure 1. Improvement in reading skills as a function of braille-based intervention.

The univariate tests, summarized in Table 6, provide an affirmative answer to Research Question 6.

Table 6

Univariate comparisons between successive stages of intervention

Variables	Entry vs Exit		Exit vs F/up	
	F	Sig.(<)	F	Sig.(<)
Word Recog.	139.91	.001	27.67	.001
Reading Rate	31.14	.001	9.30	.01
Reading Acc.	59.54	.001	19.86	.001
Reading Comp.	69.61	.001	21.70	.001

These figures demonstrate the occurrence of the intervention effect across all four dependent variables, and show that, on the whole, word recognition, reading accuracy and reading comprehension continued to improve after braille-based input had ceased. It is emphasised that these statistically significant improvements in reading skills were demonstrated by students who had not previously responded to a wide variety of traditional remedial approaches. Pairwise comparisons presented in Table 6 show the substantial gains made in all reading measures, particularly word recognition, during the training phase. Research Question 6 is addressed by the Exit /

Follow-up comparisons, which document continuing improvement following the cessation of braille-based input.

Supplementary Analysis: Interrupted Time Series ARIMA

To compliment the MANOVA of group treatment main effect, individual word recognition records of 15 members of the experimental group were subjected to interrupted time series analysis.

This proceedure could not be performed with five participants because of insufficient observations in their data series. One of these was the youngest participant, who entered the programme in Year 2. In his case, too few baseline observations could be extrapolated. The other four participants progressed so rapidly through the programme they reached the minimum 12-month post-intervention criterion, which also signified the end of the field study, before enough observations could be collected.

Observations taken at Entry, Exit and end of Maintenance (Table 7), together with percentile plots (Appendix D) for these five participants, reveal that all made clinically significant gains in word recognition raw scores from Entry to Exit and from Exit to end of follow-up. The youngest student (No. 16) did not reach the 18^{th} percentile. Of the others, one showed a drop in percentile ranking when he advanced to the next Year level (but continued to improve in raw score), one maintained at her Exit percentile ranking, and two continued to improve their percentile ranks across the follow-up period.

Table 7

Experimental Group Word Recognition Raw Scores at Entry, Exit and end of Maintenance Period

Partic. No.	Entry	Exit	End Maint.
1	43	62	72
2	19	65	70
3	22	52	72
4	27	63	67
5	12	59	64
6	50	66	78
7 *	33	55	55
8 *	31	63	70
9	30	66	68
10	28	62	60
11	32	52	76
12	8	23	36
13	27	45	54
14	22	48	62
15	3	62	62
16 *	9	34	38
17	20	50	61
18 *	28	62	61
19	23	42	47
20 *	28	57	62

* Insufficient data points for time series analysis.

Table 8 lists parameter values from Interrupted Time Series Analyses for the 15 participants who had sufficient observations for the application of this procedure.

Table 8

Interrupted Time Series Analysis intervention parameter values: Gradual-permanent impact

Part. No.	Model	Autoreg. p	Sig.	Omega	Sig.	Delta	Sig.
1	(1,1,0)	-.4770	p<.001	9.1486	p<.001	.5224	p<.001
2	(1,0,0)	.9644	p<.001	3.0071	p< . 05	1.0121	p<.001
3	(1,1,0)	-.3902	p<.001	4.5809	p<.001	.9359	p<.001
4	(1,1,0)	-.4097	p<.001	6.8512	p<.001	.8709	p<.001
5	(1,0,0)	.7570	p<.001	5.7706	p< .01	.9717	p<.001
6*	(1,1,0)	.9965	p<.001	2.9868	p<.052	.9656	p<.001
9	(1,0,0)	.9876	p<.001	5.6584	p< .01	.9140	p<.001
10	(1,0,0)	.9802	p<.001	4.0010	p< .05	.9563	p<.001
11	(1,0,0)	.9806	p<.001	3.4162	p< .05	1.0022	p<.001
12	(1,0,0)	.9779	p<.001	1.8672	p< .01	1.0533	p<.001
13	(1,0,0)	.9665	p<.001	4.3921	p< .05	.9189	p<.001
14	(1,0,0)	.9251	p<.001	4.3076	p< .05	.9841	p<.001
15	(1,1,0)	.2433	p<.001	4.7095	p< .05	.9685	p<.001
17	(1,0,0)	.9586	p<.001	5.7658	p< .01	.9332	p<.001
19	(1,0,0)	-.0124	p<.001	2.9542	p< .05	.9159	p< .01

* ns

The experimental group data series were identified as first-order autoregressive processes, some of which required differencing. That others did not is explainable in terms of intra-series data behaviour (M. Druzic, Statsoft Pacific, personal communication, September 17, 1999). Null hypotheses predicted no significant intervention effect. Diagnostic criteria (M. Druzic, Statsoft Pacific, personal communication, November 8, 1999) required :

i the value of the single autoregressive parameter p to lie between -1 and +1, to satisfy the requirement of series stationarity,

ii both intervention parameters, Omega and Delta, to be significant, and

iii residuals (observed minus predicted values) to be independent.

Statistics used to establish these conditions were the p (autoregressive parameter), Omega and Delta values generated by the interrupted time series analysis (Table 8), and the residual ACFs and PACFs. (Appendix G)

Delta values which lie between 0 and 1 satisfy requirements for system stability, that is, an indication that there is no excessive variability among the data points in the series being analysed. Models were accepted in the cases of Participants 2, 11 and 12, as the Delta values fell only marginally beyond 1, and because other diagnostic criteria were met. Diagnostic criteria were satisfied in 14 of the 15 cases analysed, meaning that model fit was adequate in these instances and that the null hypothesis could be rejected. These results indicate that braille-based remediation brought about a significant improvement in word recognition capability, gradual in onset and permanent in respect of the stipulated duration of the Maintenance phase. In fact, retention was documented from 12 months in all cases to 39 months in one case.

With one participant, No. 6, a model producing a significant Omega value could not be identified, albeit only marginally (see Table 8), so diagnostic tests were not applied. This participant entered the programme recognizing words at the 14^{th} percentile, well above the others, the only one performing at this standard. Non-significant Omega with significant Delta is considered to indicate that, while clinically significant improvement in word recognition did occur, there was insufficient post-intervention discontinuity, or change in level, in the data series to establish statistical significance for this parameter. This is also understandable in terms of the behaviour of the data in individual series, and in terms of the sensitivity of interrupted time series analysis to the amount of data used. In this study the number of data points was close to the stipulated minimum for all participants. With a few more post-intervention observations, the outcomes of all analyses could well have been successful (McDowall, McCleary, Meidinger & Hay, 1980).

CHAPTER 8: DISCUSSION

This study set out to demonstrate a training effect for braille-based remediation with dyslexia. Research predictions that this intervention would improve single word recognition, passage-reading rate, passage-reading accuracy and reading comprehension, and that these improvements would maintain after cessation of braille-based input, were supported by statistical analyses. These outcomes are consistent with those of three earlier, non-scientific studies into the applicability of braille as a remedial technique with dyslexia. Although it can be argued that the absence of a control group reduces confidence in the attribution of outcome to intervention, in this instance this strict experimental shortcoming was addressed by the inclusion of a comparison group.

Despite a number of predictions to the contrary, but in accord with earlier findings that other sensory modalities were intact in dyslexic samples, Research Question 1 was answered in the affirmative when all participants mastered Grade 1 braille. Research Question 2 was answered similarly when the dyslexic participants then went on to use this acquired capability to achieve statistically significant improvements in word recognition, passage-reading rate, passage-reading accuracy and reading comprehension. Results of the MANOVA of group scores at Entry, Exit and end of Maintenance were supported substantially, though not completely, by interrupted time series analyses of individual protocols. These outcomes attest to the effectiveness of braille-based input as a remedial approach for dyslexia.

Percentile plots visualize the variation in the rate of improvement across the experimental group, which is probably attributable to individual difference factors such as degrees of severity of dyslexia and dyslexic subtypes. The onset of intervention effect also varied considerably. This was probably due to the same factors, and also to the inability of the Milton Word Recognition Test to reflect improvement until participants were reading words of four to five letters. Informal observations which occurred throughout the training phase suggest that increased frequency and stricter regularity of practice sessions could reduce overall time frames. For these reasons predicting onset of training effect and time to reach a specified criterion are problematic (Research Question 3).

A distinct ogival pattern is apparent in most of the overall experimental protocols. (Research Question 4) Statistical verification of a common acquisition pattern is available in the form of the gradual-permanent impact profiles identified for all cases submitted to time series analysis. Further contributions to commonalities in training effect are provided by other analyses. Percentile plots for both experimental and comparison groups (Appendix D; Appendix E) clearly show the increasing divergence from the norm that is characteristic of the dyslexic reading acquisition profile. It is apparent from these plots that intervention did not cause an abrupt change in word recognition performance, but that a steady improvement did begin from that point, or shortly after that point, for 17 members of the experimental group. Baseline performance plots for those experimental group members who had lengthy remedial exposure prior to commencing braille, were very similar to the entire series plots for comparison group members. (Appendix D; Appendix E) Milton Word Recognition Test scores began to improve when participants were able to read words of four to five letters in braille. At all levels of braille acquisition, there was very little deterioration in single word recognition ability. Once established, both sight recognition and improved visual decoding capability showed minimal deterioration. This suggests that a similar acquisition pattern occurred with the experimental participants through the tactile modality as occurs with normal beginning readers through the visual modality, whereby words, once acquired, tend to be retained.

Ten participants improved past their Exit levels after braille-based support had been terminated, and a further eight maintained at, or about those levels. The percentile ranks of only two participants fell below their Exit scores. In one of these cases, raw scores continued to increase, and in the other there was a small decrease. Although no formal analysis was attempted, the data in Table 4 do not support a critical level of competence in word recognition, at or beyond which students have sufficient capability to continue improving through their own efforts (Research Question 5). This notion remains intuitively appealing, however, and as the capacity to nominate completion points for remedial programmes would be extremely valuable for programme planning and resource allocation purposes, further investigation of this question is warranted. In the interim, information about reading improvement time frames (Table 3) will provide guidance as to the expected duration of such programmes.

Substantive evidence for permanence of training effect (Research Question 6), is illustrated by experimental group percentile plots which depict minimal deterioration in visual word recognition following intervention. Seventeen participants maintained at, or continued to improve above, their Exit levels for periods of between 12 and 39 months. In two of the remaining cases, slight falls in performance below group average were considered to be attributable to the eruption of marital problems. The level of braille reading performance was also maintained, even after the long Christmas vacation, when braille-based instruction was interrupted for around 9 weeks. The achievements of those participants whose word recognition percentile rankings continued to improve after braille training had ceased constitute evidence for generalization of training effect (Research Question 7). As the words in the Milton Word Recognition Test were not taught explicitly during the training phase, the progressively improving raw scores on this instrument are interpreted as further evidence for generalization.

At the present time there appears to be an on-going wastage of material resources and intellectual effort in the continued widespread adherence by educational support professionals to conventional remedial approaches that fail to address the essential nature of dyslexia. The finding that all participants in the present study were able to learn braille suggests that students affected by all subtypes of dyslexia may be helped by this approach. The applicability of braille-based remediation for the school setting is established by the fact that the field phase of this study was developed and delivered in schools in response to referrals of dyslexic students by Classroom and Learning Support Teachers.

Braille-based word recognition training as applied here, directly addresses the manipulation of syllables and phonemes, and thus supports the importance of phonological awareness in the reading process. The present training effect was manifested in improved sequential skills such as word recognition, decoding and blending. While this may seem to accord with empirical conclusions that temporal information processing dysfunction is plausibly associated with some subtypes of dyslexia, it is considered that such sequential skills would be more appropriately regarded as aspects of transmission, rather than processing, of sensory input. The process entails focussing on each letter in a sequential transaction of analysis and synthesis, in which tactual and visual sensory representations are closely associated. The occurrence of a cross-modal effect (visual word recognition improving as a result of tactile modality involvement) is consistent with the research literature dealing with the superiority of multi-sensory learning for reading disabled students. The improvements in visual word recognition demonstrated by most participants constitute further support for multisensory approaches in the learning disability context, and support the recent revival of interest in a causal relationship between dyslexia and visual perception. This outcome also provides qualified support for a neurological basis for dyslexia. The agent of change could well be neural plasticity, engaged by exercising the tactual system and thence stimulating concomitant cross-modal excitation of the visual network such that this hitherto defective pathway became functional, arguably through change in neural morphology.

Potential Threats to Validity

<u>Fluctuations in Reading Performance</u>

Key confounds by which validity in longitudinal studies can be compromised include non-stationary drift in dependent variable/s (e.g., random fluctuations in reading capability), fluctuations in measurements reliably associated with changes in the individuals under study, and fluctuations in the dependent variables not due to treatment. These confounds do not threaten the integrity of the present study for a number of reasons.

Reading ability does not fluctuate widely over short time spans, as illustrated by the test norms for the Milton Word Recognition Test and the Neale Analysis of Reading-Revised, and by the series plots for both experimental and comparison groups. Nor does reading ability develop spontaneously. Reading development can only occur through active participation in systematic, purpose-specific, classroom training activities. While studies over the past 12 years have shown unequivocally that children are born with innate capacities for discriminating among the variety of auditory contrasts exploited by the multitude of human languages (Rapin, 1996), and while there are visual capacities which do not have to be taught, such as automaticity and constancy of spatial perception, this repertoire of innate capabilities does not include a capacity specific for reading. As Bakker (1992) pointed out, a cup, rotated 180 degrees, remains a cup, but a *p*, rotated 180 degrees, resembles a *d*.

History, perhaps the most common of the confounds to which longitudinal time series data are vulnerable (Braden, Gonzales & Miller, 1990), implies that specific beneficial experiences, which could befall study participants outside the classroom, might account for changes in the dependent variable/s. It is highly unlikely, however, that such factors would affect only the experimental group in the present study. If external factors which could produce improvements in word recognition did exist, it would be expected that dyslexic individuals everywhere would also be encountering such experiences, and that reading disabilities would be remitting across the entire dyslexic population. Such improvements would therefore be expected to appear in the pre-treatment profiles of experimental group members and at various points in the records of comparison group members. No such trends were apparent in the present data. Percentile plots for comparison group members clearly demonstrate that no such effects occurred in the absence of braille-based remediation for the entirety of their primary school years. (See Appendix E) According to developed knowledge, no such remission occurs in the wider dyslexic population (Scott, Scherman & Phillips, 1992), the persistence of dyslexia being well documented into adulthood. The fact that dyslexia persists into adulthood also raises questions in some instances about the role of maturation. The threat of maturation is further denigrated by the fact that treatment and comparison group members were equivalent in capability when first identified, and could be expected to mature at an equivalent rate over the duration of the study.

Practice Effect

While certain aspects of reading as measured by the Neale-R could possibly be influenced by frequent testing, one exposure every 3 months is not considered likely to contaminate performance outcomes. This reasoning is based on the fact that practice effect is intentionally engaged through repetition as an active component of several of the remedial approaches listed in Appendix A. Rote learning, a standard memorization strategy, is a prime example. As all such approaches have failed to correct the reading problems of both experimental and comparison groups, it is argued that, in the case of periodic monitoring with the Neale-R, repetition at the rate of once every 3 months constitutes minimal feedback, and does not present as a realistic alternative explanation for the occurrence of visual reading improvement.

Other evidence that counters the threat of practice effect emerges from an examination of the recorded errors made on the Neale-R across the observation period. Test prompts notwithstanding, participants frequently misread the same word/s, often making the same mispronunciations on several successive occasions. There were also many occasions when participants misread words they had previously decoded correctly, apparently being so engrossed in the effortful business of decoding, their attention and concentration so disproportionately engaged in this task, that they were not receptive to the single-word prompts (Cunningham, 1990; Vellutino, 1991).

Hawthorne Effect

Reference to the comparison group percentile plots (Appendix E) allays concern about possible confounding effects of social investment or special treatment. These plots, which all show a similar flat trend, illustrate that a sample of demographically similar dyslexic students, who received no braille input but who participated in numerous other remedial programmes, made only minimal gains in word recognition over a somewhat longer time span.

Conclusions

- Acknowledged limitations in the supplementary analyses notwithstanding, the outcomes of this study indicate that there are statistically significant differences in reading achievement for the experimental group before, during and after intervention. Primary data analysis indicates that braille-based remediation was indeed an effective intervention for 17 out of 20 participants where conventional remedial strategies had failed. There is a clinically significant difference between the post-intervention performances of the experimental group and the performance profiles of the comparison group across the entirety of their primary school years. The effect may well be permanent.

- Four of the five closed research questions, Q1, Q2, Q4 and Q6, were answered in the affirmative. Questions 3 and 5, pertaining to the time interval between intervention and onset of training effect and to whether there is a critical level of competence that must be attained before students can forge ahead without external support, could not be answered unequivocally from the outcomes of this study. These outcomes, however, do not constitute grounds for discounting either of these notions.
- The follow-up observations obtained in this study, and in particular the minimal relapse rates that occurred, engender confidence in the effectiveness of braille-based remediation as a lasting solution for dyslexia.

Future Directions

There are several possible explanations for the occurrence of the training effect in the present study:

- It might be due to a transient neural transmission infrastructure subserving both visual and tactual modalities,
- and to visual and tactile transmission sub-systems sharing the same tract or section of the main network, or converging at some point prior to entering the processing circuit in the brain.
- It might be a product of the visual transmission process in the dyslexic participants being "blocked" by some morphological defect.
- It might have resulted from the tactile sub-system being exercised by external stimulation in the form of braille-based input, and,
- by virtue of spatial proximity, either while sharing the common tract or at the point of convergence, the firing of the tactile transmitter cells exciting the cells of the visual sub-system so as to stimulate either dendritic spouting or structural neuronal growth (neural plasticity), thus remedying the defect and rendering the visual sub-system functional.

Future research might profitably focus on these possibilities. Initial a priori reasoning proceeds as follows:

1. There is convincing evidence that, in a substantial percentage of cases, dyslexia is associated with defects in the visual transient system (Lovegrove, Garzia & Nicholson, 1990).

2. This system operates on serially-encountered stimuli, responds to weak contrast, short duration, lower spatial frequency input and is activated by stimulus change (Stuart & Lovegrove, 1992).

3. Farmer & Klein (1995) reported considerable evidence for a deficit in dyslexics in temporal order judgements of syllables and tones in both the visual and auditory modalities that is consistent with defective sound-symbol association or phonological impairment, now widely regarded as core dyslexic symptomatology.

4. Reading braille involves moving the fingertip continuously across spatial patterns of raised dots. If the finger stops moving, the receptors rapidly habituate and no sensation can be detected. Braille word recognition is thus an accumulation of information over a temporal interval (Harley, Truan & Sandford, 1987), braille reading requiring continuous stimulus change. This would exercise the transient system.

5. The reading process appears to be very similar in the visual and tactile modalities (Pring, 1982; Wilkinson & Carr, 1987) for dyslexic and blind readers. According to Barraga (1986), visual and haptic exploration yield input data with common characteristics. For both, the processes of assembling transmission and lexical representation codes for each word occur serially, as each bit of input data is acquired. This serial coding characteristic further supports the notion of transient pathways

subserving both visual and touch receptors.

6. Blind and dyslexic readers can access the lexicon only via the phonological route, as neither can utilize the direct sight-word or lexical route (Cornelisson, Hansen, Bradley & Stein, 1996; Beech & Awaida, 1992; Dodds, 1983; Hodgson, 1992; Seidenberg & McClelland, 1989).

7. The neurophysiological differences between the visual and tactile modalities make little difference to the information-processing task of reading. This is explainable in terms of blind readers exercising a functional tactile transient system and of a common transmission code for both modalities.

8. The primary visual cortex, which receives input via the visual transient system, activates during braille reading by blind readers (Sadato et al., 1996). This is evidence that tactual input activates visual processing mechanisms. As visual transient pathways do not serve touch receptors, this finding also supports the notion of a system capable of transmitting linguistic information from the fingertip touch receptors to the brain in a format that can be processed in the visual cortex.

9. The fact that participants in the present study could improve their visual word recognition after first learning braille then learning unknown words through braille is consistent with the notions (a) that dyslexics possess a functional tactile transient system and (b) of correspondence between tactile and visual modalities. The site

of such correspondence could well be a shared tract or section of the transmission network or some point at which the pathways converge.

10. A common tract shared by both visual and tactual transmission pathways is a logical location for dendritic growth or the plastic modification of neural structures. According to Posner (1989) and LeDoux (1990), convergence of modal transmission channels is an essential characteristic of neural circuitry that has considerable capacity for the occurrence of both cross-modal linkage and functional plasticity.

With respect to the findings of the present study, it is suggested that braille-based input via the tactile transient pathway may enable input transmitted by the visual transient channel to access the auditory value adding circuit and then the lexicon, strengthening sound-symbol association in the process and resulting in improved visual word recognition. Moreover, the transient magnocellular structures present as a possible common infrastructure subserving both tactile and visual modalities. The effect of braille-based input on visual transient pathway cells thus appears to be an area worthy of investigation. Such a position would link improved reading ability with increased functional efficiency of the transient visual pathway following braille-based remediation. Comparisons of primary visual cortex activation between normal sighted readers reading print, normal sighted readers reading braille, dyslexic readers attempting print, and dyslexic readers reading print after braille-based remediation, may also shed new light upon defects in the functional mechanisms of reading.

The present findings also appear to have broad implications for literacy education. Braille-based word recognition training was effective for the majority of the experimental group and improved the word recognition ability, albeit to lesser degrees, of the remainder of participants in the study. It is suggested that learning letter-sound associations and words might be enhanced similarly for non-dyslexic children through engagement of the tactile modality in conjunction with the visual modality. This raises the interesting possibility that tactile learning of phonological representations by all sighted Grade 1 children might decrease substantially the incidence of dyslexia as well as enhance reading acquisition among the non-dyslexic majority. Accelerating the reading acquisition of non-dyslexic children through tactile input might be a topic for future research that involves the inclusion of a reading age-matched control with reading age-matched and dyslexic treatment groups.

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APPENDIX A

Unsuccessful Conventional Remedial Strategies used with Members of Experimental and Control Groups

The following lists of conventional remedial interventions were abstracted verbatim from entries in the participants' Guidance files. These recommendations were made by the different specialists to whom these children were referred. Detailed explanations are not available in most cases. Many of these strategies were prescribed for both experimental and control group members. The longer comparison group list reflects their much longer exposure to standard remedial support.

Experimental Group

LST support (remedial tuition) - withdrawal; individual and small group

Assessments by Guidance Officers - attainment and IQ

Guided reading

Cloze techniques

Rote learning / memorization

Pre-reading discussion of text

Word building

Re-telling stories in own words

Repeated readings of same text

Revision of phonics

Grade repetition

Hearing tests

Vision tests

Medical assessments

Medication

Use of charts, diagrams and pictures

Use of associative memory clues

Teaching using a visual format

Activities focussing on repetition of basic literacy skills

Self-esteem programmes

Home programmes

Speech therapy

Relating new information to what is already known

Memory training

Training in word attack skills

Peer tutoring

Private tutoring

Use of word processor

Oral and written activities

Instruction in discrimination and visualization

Theme-based teaching

Neurological Impress Method

Special activities group

Male / female teacher

Sight word revision

Contracts

Language experience approach

Pause; Prompt; Praise

Transformation activities

Occupational therapy (fine motor training activities)

Pre-reading preparation

Daily reading sessions

Vestibular stimulation (swinging)

Acupuncture

Homeopathy

Morphographic and other spelling programmes

Comparison Group

LST support (Remedial tuition) - withdrawal; individual and small group (up to 6 years)

Assessments by Guidance Officers - attainment and IQ

Referral to the Developmental Assessment Team (Health Department)

Placement in Special Education Unit

Phonics training

Training in word attack skills

Re-tell stories - oral and written

Sequencing stories - picture and text

Determining relationships and consequences

Teaching Dolch words (visually)

Own time reading practice

Grade repetition

Hearing tests

Vision tests

Coloured glasses

Coloured celophane sheets over text

Medical assessments

Speech therapy

Join the Public Library

Structured writing sessions

Sound recognition training

Decoding instruction

Teaching contextual cues and prediction

Wordbuilding

Neurological Impress Method

Total visual approach

Repeated readings of same text

Language arts instruction

In-class support

Language / learning Experience Approach

Whole word approach

Structured programming

Occupational therapy (fine motor training activities)

Use of strongly visual techniques

Activities involving the aural modality

Focus on contextual cues

Meta-cognitive strategies

Cloze exercises

Visual discrimination training

Visual sequential memory training

Puzzles

Visual perceptual training

Positive reinforcement of attending behaviour

Frostig Visual Perceptual Development Programme

Spatial awareness training

Vestibular and other sensory stimulation

Sound order sequencing

Directed writing programme to aid both functional reading and writing skills

Programmes with built-in success outcomes

Programmes with short sequential steps

Using strengths as part of remediating deficits

New information strongly linked to what is already familiar

New learning shown in as many contexts as possible

Use of concrete, interactive materials

Testing for colour blindness

Enriching experiences in all areas

Peer tutoring

Activities to foster listening and visual discrimination skills

Programme to develop readiness skills

Psycholinguistic approach

Counselling

Listening to prepared taped material and reading along

Retell stories in own words and answer questions about them

Feingold diet

Male / female teacher

Traditional type of classroom

Various spelling programmes

Single-class classroom

Private tutoring

Reading aloud

Process writing approach

Look .. Say .. Cover .. Write .. Check

Daily reading sessions

Glynn et al. - tutoring techniques

Memory training exercises

Visual memory training

Thematic language stimulation activities

Language Master activities

Focus on task completion

Conference approach to reading

Strategies to improve comprehension

Morphographic Spelling Programme

Oral vocabulary development

Self-image enhancement

Pause .. Prompt .. Praise

Using word processor

Computer activities

Medications

Home programmes

Transformation activities

APPENDIX B

Time Series and Time Series Analysis: Theoretical Rationale

This Appendix was compiled with reference principally to McDowall, McLeary, Meidenger and Hay (1981) and the Statistica (1995) manual. References to other authors are attributed individually.

Time Series

Time series are sequences of data points ordered in time (Anderson, 1976) that follow non-random orders. Successive values in the series portray variations in variables over time (Chou, 1975). Generally, time series are a mixture of four components - secular trend or long-term movement, fluctuations about that trend of varying regularity, seasonal variation and a residual, irregular, or random effect (Kendall, 1973). It is assumed that the data consist of a systematic pattern (usually a set of identifiable components) and an element of random noise (error) that usually obscures the pattern.

Measures of performance by one individual, repeated over time, are likely to be correlated, or serially dependent, events occurring in one time frame being related to those in adjacent time frames. The extent to which there is dependency among successive observations can be assessed by examining autocorrelation (or serial correlation) in the data (Kazdin, 1982). Autocorrelations that deviate significantly from zero indicate serial dependency. Lack of such dependency indicates that a data point below the "average" value is just as likely to be followed by a high value as by a low value.

Many time series are autoregressive (AR), in that consecutive elements of the series can be described in terms of previous elements. In respect of this process, each observation is made up of a random error component (random shock) and a linear combination of prior observations. Another common form of serial correlation is the q^{th} order moving average (MA). Each element in a time series can also be affected by past error (random shock) that cannot be accounted for by the autoregressive component. In respect of the MA process, each observation is made up of some random error or shock and a linear combination of prior random shocks.

Time Series Methodology

Time series designs are longitudinal variations of the pre-experimental one group pretest-posttest design (Kidder, 1981), in which the same subjects are measured in different conditions in order to assess developmental changes, data being collected successively at approximately equal time intervals (Willson, 1982). The design format includes the development of mathematical formulae, or models, that define underlying processes and remove error components.

The relationship, or correlation, between adjacent time series observations biases the outcome of hypothesis testing (Jensen, 1990). Serial correlation can inflate the standard errors of ordinary least squares parameter estimates, precluding the use of many conventional statistical techniques. Time series design takes account of the dependency between successive data points along the series

(Box & Jenkins, 1976; Jones, Ghannam, Nigg & Dyer, 1993; Kazdin, 1982; Kendall, 1973; Savard et al., 1998), thus permitting the difference between pre- and post-intervention levels to be estimated and tested for statistical significance in a straightforward manner. **A**uto**R**egressive **I**ntegrated **M**oving **A**verage (ARIMA) models (Box & Jenkins, 1976) model, and thereby control for serial correlation as a time series process, thus obviating the threat posed by serial dependency to statistical conclusion validity.

ARIMA models have three structural parameters, termed *p, d* and *q*, which describe the relationships between underlying components of data series. Structural parameter *p* denotes the number of autoregressive structures in the model (the number of past observations used to predict the current observation). A first-order autoregressive model would specify that the value of the series at any point is influenced both by fluctuation occurring at that point and the value of the series at the previous point. A second-order autoregressive model would contain two autoregressive parameters, one for time *t-1* and one for time *t-2.* The order of autoregression indicates how far back in time one needs to go to predict a future value for the series.

The integration parameter, *d*, indicates whether and to what degree the series needs differencing, the term given to the transformation of a series from non-stationarity (drifting behaviour) into stationarity (non-drifting behaviour). For the analysis to be successful, time series must be stationary, that is, they must contain no increasing or decreasing trends, and must have relatively constant variance throughout. Differencing involves subtracting the first observation of the series from the second observation, the second observation from the third, and so on. The **I** component of the model indicates the degree of differencing necessary to achieve stationarity.

Structural parameter *q* denotes the number of moving average structures in the model. The moving average element is similar to the autoregressive component, except that the value at any time (t) is predicted from the random error, or disturbance, occurring at that time and the disturbance at time (t-1). This would represent a first-order process. An equation which included moving average specification for times (t-1) and (t-2) would be a second-order process. Once again, the order of the moving average function indicates how far back in time one needs to go to predict a future value for the series from past disturbances. Moving average smoothing involves local averaging of data points to replace each observation with the simple or weighted average of *n* adjacent observations.

Models specified for different series will contain different combinations and different levels of these parameters. An ARIMA (1,1,0) model, for example, describes a first-order autoregressive process that has been differenced once and contains no moving average parameter. Where a time series contains seasonal patterns or variations, substantial autocorrelation effects will be apparent at multiples of the seasonal lag. Additional seasonal transformations are necessary to counter this contingency. The seasonal ARIMA model (0,1,2) (0,1,1), for example, describes a model that contains no autoregressive parameters, two regular moving average parameters and one seasonal moving average parameter, computed for the series after non-seasonal differencing with lag 1 and seasonal differencing at a specified lag.

Time series designs permit the assessment of change, not in terms of deviation from a group mean, but as a departure from an established pattern (Jensen, 1990), and as such are appropriate for evaluating performance improvement (Morgan, 1996) following training. If a control group is not possible, the best alternative evaluation strategy is a time series design (Graziano & Raulin, 1993), as repeated measures of the dependent variable before, during and after intervention can control for many threats to internal validity. Time series designs are appropriate when a treatment can not be manipulated experimentally due to pragmatic or ethical considerations (Braden, Gonzales & Miller, 1990). Where participants can not be assigned to a non-treatment control group, a major advantage of the time series design is elimination of the need for random assignment of participants (Marston, 1988; Savard et al., 1998), as each participant acts as his or her own control. This type of design is particularly appropriate for research in schools (Campbell & Stanley, 1963).

Interrupted Time Series Analysis

In the social science context, interrupted time series analyses assess the effects of specific interventions on observed performance. These designs are more informative than group designs when dealing with samples of limited size (Savard et al., 1998), as is the case in the present study, where scores on word recognition recorded during a baseline phase were compared to measures of the same dependent variable after braille training with members of the experimental group. Following the identification of a satisfactory noise component for the time series, an appropriate intervention component is selected and coupled additively to the noise component. This requires identification of the model which best describes or fits that portion of the time series preceding intervention (Hull, Clarkin & Alexopoulos, 1993). A decision is made in advance, upon as objective and logical a basis as possible, as to the equation that best accounts for the nature of the data series (Croxton & Cowden, 1956). This entails the estimation of parameters additional to the autoregressive or moving average parameters to account for the effect of the intervention.

The intervention analysis consists of three phases - identification, estimation and diagnosis. Identification is the empirical specification of the most appropriate structural parameters to represent the series, i.e., how many times to difference the data and how many autoregressive or moving average parameters to estimate. Model parameters are specified according to the patterns of serial correlation revealed through the autocorrelation function. Autocorrelation and partial autocorrelation functions are the most important tools for identifying an appropriate ARIMA model. The goal is to find a set of parameters that will minimize the residual sums of squares. In the present study, this operation was performed on the transformed (differenced) data by the Statistica 98 software package. Diagnosis is the process of analysing residuals to assess the statistical adequacy of the tentative model. Residuals are deviations of individual observations from the straight-line trend that best fits the series (Chou, 1975), in other words, differences between the observed values and the values that are predicted by the model. Thus they represent the variance that is not explained by the model. The better the fit of the model, the smaller the values of the residuals, i.e., if the ARIMA model adequately reproduces the observed values in the series, no partial autocorrelations will be present in the data. Models must be statistically adequate and parsimonious (contain as few as possible parameters) or application will lead to invalid inferences. Models should also generate statistically independent residuals that contain only noise and no systematic components, i.e., the correlogram of the residuals should reveal no serial dependencies. The ARIMA process is based on the assumptions that the residuals are normally distributed and independent of each other.

Intervention analysis involves developing mathematical models of the series, identifying the optimum model by testing these against the data to determine whether parameters differ significantly from chance variability, then determining whether post-intervention measures depart significantly from the course projected from pre-intervention data. In a process which ensures that random fluctuations are not interpreted as intervention effects (Type I error), ARIMA models are specified, examined for any significant autocorrelations which indicate that the model has not been adequately specified to account for change across time, and adjusted until a good fit is obtained. Rival hypotheses are eliminated logically and sequentially and internal validity is strengthened (Jensen, 1990). Once accepted, the model can be taken to impact assessment. The analysis then focuses on the testing of the null hypothesis, which, in the present instance, predicted that braille-based remediation would cause no significant change in word recognition capability in the experimental group.

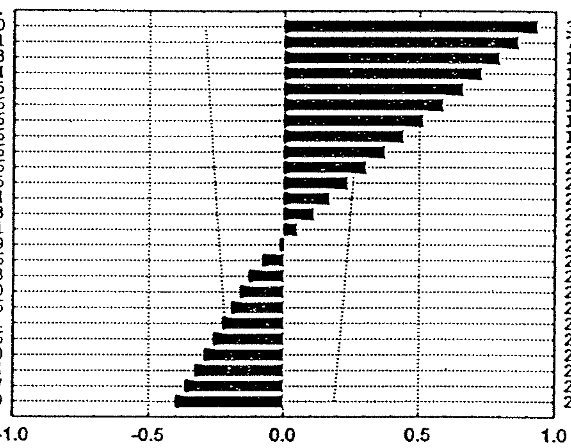
As the nature of the impact can be specified on the basis of theory, interrupted time series analysis can establish both the statistical significance and the form of that impact. Impacts have two characteristics - onset and duration. Onset can be gradual or abrupt. Duration can be permanent or temporary. Three main types of impact are possible - abrupt permanent, gradual permanent and abrupt temporary. An abrupt permanent impact pattern implies that the overall mean of the series shifted after the intervention. The overall shift is denoted by the parameter *omega*. For abrupt permanent effects, *omega* can be interpreted as the amount of permanent change that occurred at the point of intervention. The gradual permanent impact pattern implies that the increase or decrease due to the intervention is gradual, and that the final permanent impact will become evident only after some time. This pattern is denoted by the two parameters *delta* and *omega*. If *delta* is near zero, then the final permanent amount of impact will be evident after only a few more observations. If *delta* is close to 1, then an asymptotic (eventual) change will be realized quite gradually, and the final permanent amount of impact will only be evident after many more observations. The abrupt temporary impact pattern implies an initial, sudden increase or decrease in observed values following intervention, which then slowly decays, leaving no permanent change in the mean of the series.

The impact of any training intervention on a social process is likely to be gradual, and, if successful, permanent. However, as the time interval between commencement of treatment and onset of effect increases, so too does the plausibility of competing explanations. In respect of the present study, from observations taken during a pilot study conducted with a single participant prior to the formation of the experimental group, some delay between introduction of braille training and the manifestation of training effect was anticipated. The gradual permanent impact parameter, which was therefore specified, addresses this threat by accommodating for a delay between introduction of treatment and improvement in performance.

APPENDIX C

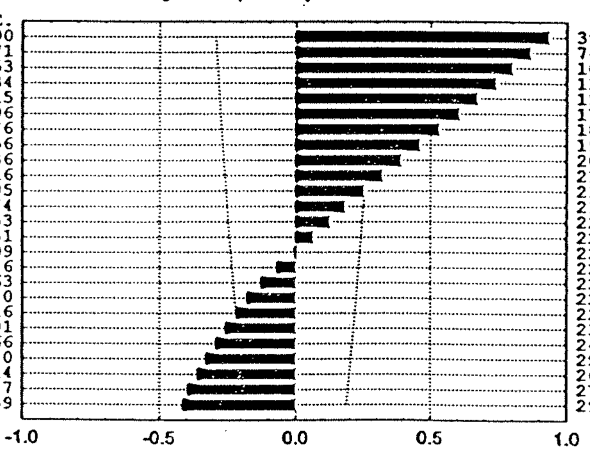
Autocorrelation Functions (ACFs) for Original and Augmented Word Recognition Data Series: Experimental Group

Experimental Group No. 1
Autocorrelation Function
Un-augmented pre-Entry raw scores



Lag	Corr.	S.E.	Q	p
1	+.932	.1490	39.13	.0000
2	+.863	.1471	73.56	.0000
3	+.795	.1453	103.5	.0000
4	+.729	.1434	129.4	.0000
5	+.660	.1415	151.1	0.000
6	+.587	.1396	168.8	0.000
7	+.513	.1376	182.7	0.000
8	+.442	.1356	193.3	0.000
9	+.372	.1336	201.1	0.000
10	+.303	.1316	206.4	0.000
11	+.235	.1295	209.7	0.000
12	+.166	.1274	211.4	0.000
13	+.109	.1253	212.1	0.000
14	+.047	.1231	212.3	0.000
15	-.012	.1209	212.3	0.000
16	-.077	.1186	212.7	0.000
17	-.126	.1163	213.9	0.000
18	-.159	.1140	215.8	0.000
19	-.191	.1116	218.8	0.000
20	-.223	.1091	223.0	0.000
21	-.257	.1066	228.8	0.000
22	-.291	.1040	236.6	0.000
23	-.327	.1014	247.0	0.000
24	-.363	.0987	260.5	0.000
25	-.398	.0959	277.7	0.000

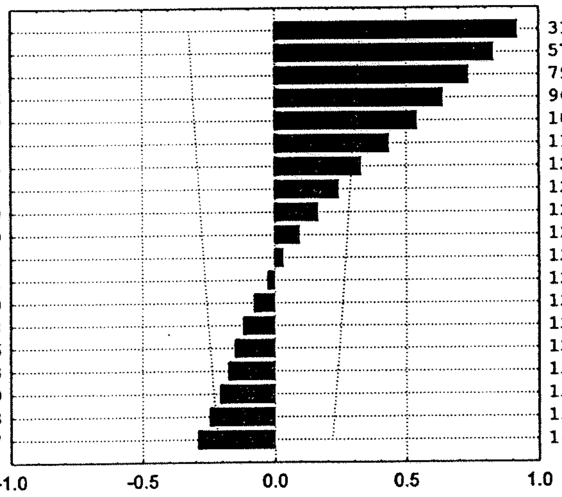
Experimental Group No. 1
Autocorrelation Function
Augmented pre-Entry raw scores



Lag	Corr.	S.E.	Q	p
1	+.933	.1490	39.20	.0000
2	+.868	.1471	74.01	.0000
3	+.800	.1453	104.4	.0000
4	+.742	.1434	131.1	.0000
5	+.673	.1415	153.8	0.000
6	+.607	.1396	172.7	0.000
7	+.531	.1376	187.6	0.000
8	+.460	.1356	199.1	0.000
9	+.390	.1336	207.7	0.000
10	+.321	.1316	213.6	0.000
11	+.252	.1295	217.4	0.000
12	+.181	.1274	219.4	0.000
13	+.126	.1253	220.4	0.000
14	+.063	.1231	220.7	0.000
15	-.001	.1209	220.7	0.000
16	-.069	.1186	221.0	0.000
17	-.127	.1163	222.2	0.000
18	-.178	.1140	224.6	0.000
19	-.215	.1116	228.3	0.000
20	-.255	.1091	233.8	0.000
21	-.290	.1066	241.2	0.000
22	-.327	.1040	251.1	0.000
23	-.358	.1014	263.6	0.000
24	-.393	.0987	279.5	0.000
25	-.412	.0959	298.0	0.000

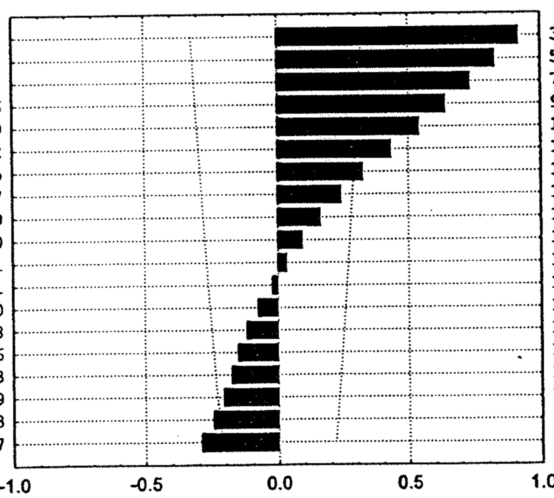
Experimental Group No. 2
Autocorrelation Function
Un-augmented pre-Entry raw scores

Lag	Corr.	S.E.	Q	p
1	+.919	.1642	31.36	.0000
2	+.831	.1617	57.79	.0000
3	+.738	.1591	79.27	.0000
4	+.641	.1566	96.04	.0000
5	+.542	.1539	108.4	.0000
6	+.434	.1512	116.7	.0000
7	+.326	.1485	121.5	.0000
8	+.242	.1457	124.3	.0000
9	+.164	.1429	125.6	.0000
10	+.095	.1400	126.1	.0000
11	+.032	.1371	126.1	.0000
12	-.026	.1341	126.2	.0000
13	-.078	.1310	126.5	.0000
14	-.119	.1278	127.4	.0000
15	-.151	.1246	128.8	.0000
16	-.175	.1213	130.9	.0000
17	-.206	.1179	134.0	.0000
18	-.245	.1143	138.6	.0000
19	-.289	.1107	145.4	.0000

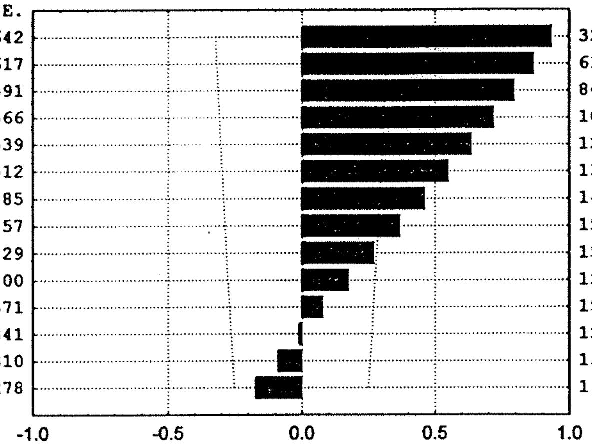


Experimental Group No. 2
Autocorrelation Function
Augmented pre-Entry raw scores

Lag	Corr.	S.E.	Q	p
1	+.919	.1642	31.33	.0000
2	+.830	.1617	57.70	.0000
3	+.737	.1591	79.16	.0000
4	+.643	.1566	96.03	.0000
5	+.543	.1539	108.5	.0000
6	+.434	.1512	116.7	.0000
7	+.326	.1485	121.5	.0000
8	+.243	.1457	124.3	.0000
9	+.164	.1429	125.6	.0000
10	+.096	.1400	126.1	.0000
11	+.034	.1371	126.2	.0000
12	-.021	.1341	126.2	.0000
13	-.077	.1310	126.5	.0000
14	-.120	.1278	127.4	.0000
15	-.153	.1246	128.9	.0000
16	-.176	.1213	131.0	.0000
17	-.207	.1179	134.1	.0000
18	-.245	.1143	138.7	.0000
19	-.290	.1107	145.6	.0000

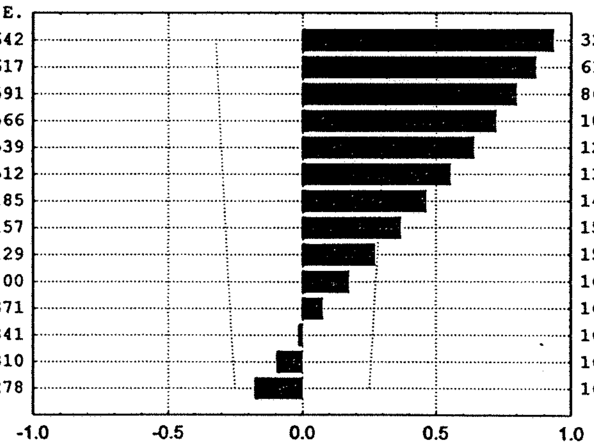


Experimental Group No 3
Autocorrelation Function
Un-augmented pre-Entry raw scores



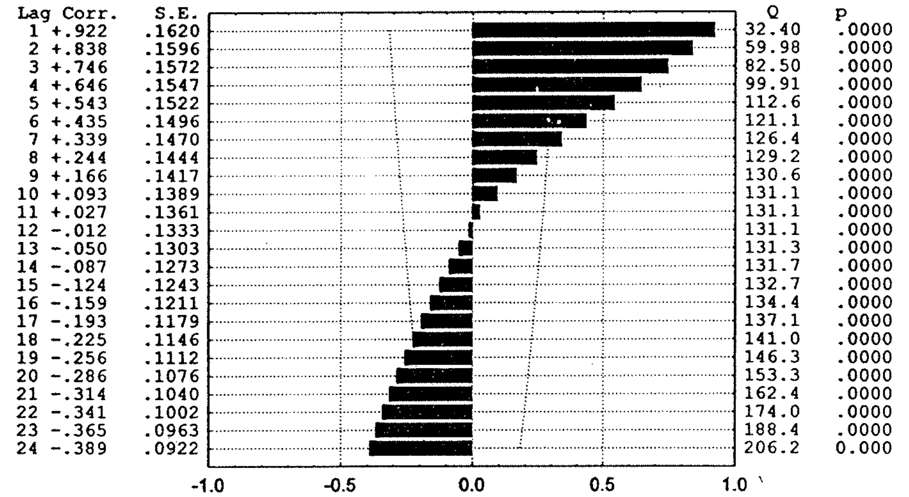
Lag	Corr.	S.E.	Q	p
1	+.935	.1642	32.41	.0000
2	+.869	.1617	61.30	.0000
3	+.796	.1591	86.34	.0000
4	+.720	.1566	107.5	.0000
5	+.637	.1539	124.6	.0000
6	+.551	.1512	137.9	.0000
7	+.461	.1485	147.5	.0000
8	+.369	.1457	153.9	.0000
9	+.272	.1429	157.5	.0000
10	+.175	.1400	159.1	.0000
11	+.079	.1371	159.4	.0000
12	-.009	.1341	159.4	.0000
13	-.089	.1310	159.9	.0000
14	-.171	.1278	161.7	.0000

Experimental Group No. 3
Autocorrelation Function
Augmented pre-Entry raw scores

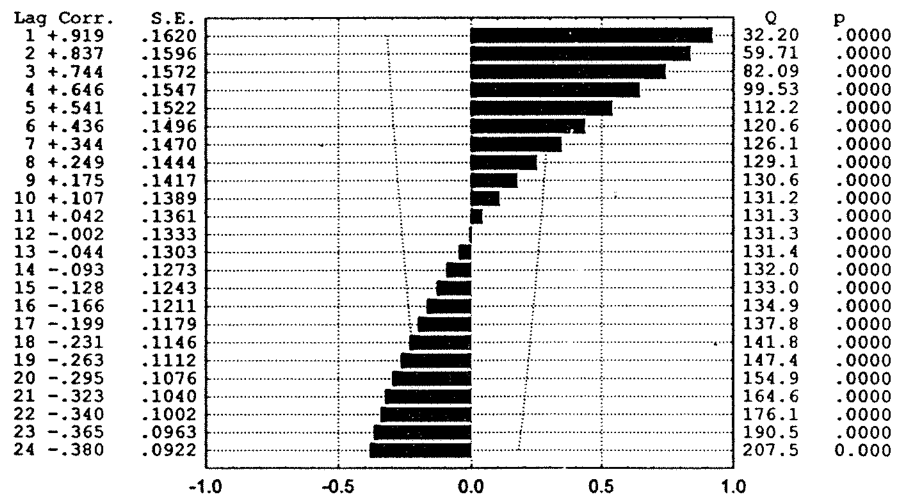


Lag	Corr.	S.E.	Q	p
1	+.935	.1642	32.41	.0000
2	+.871	.1617	61.39	.0000
3	+.799	.1591	86.60	.0000
4	+.723	.1566	107.9	.0000
5	+.641	.1539	125.3	.0000
6	+.554	.1512	138.7	.0000
7	+.464	.1485	148.5	.0000
8	+.370	.1457	154.9	.0000
9	+.272	.1429	158.5	.0000
10	+.174	.1400	160.1	.0000
11	+.076	.1371	160.4	.0000
12	-.013	.1341	160.4	.0000
13	-.093	.1310	160.9	.0000
14	-.176	.1278	162.8	.0000

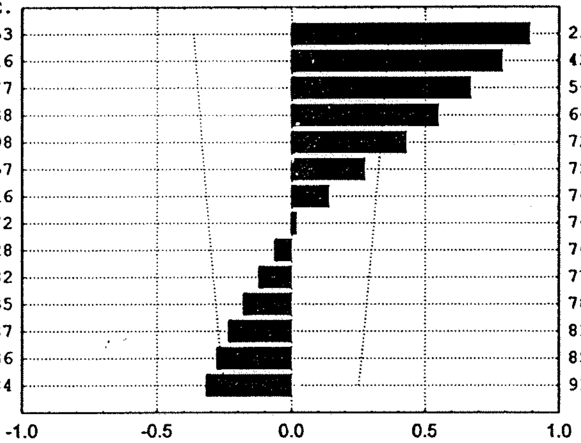
Experimental Group No. 4
Autocorrelation Function
Un-augmented pre-Entry raw scores



Experimental Group No. 4
Autocorrelation Function
Augmented pre-Entry raw scores

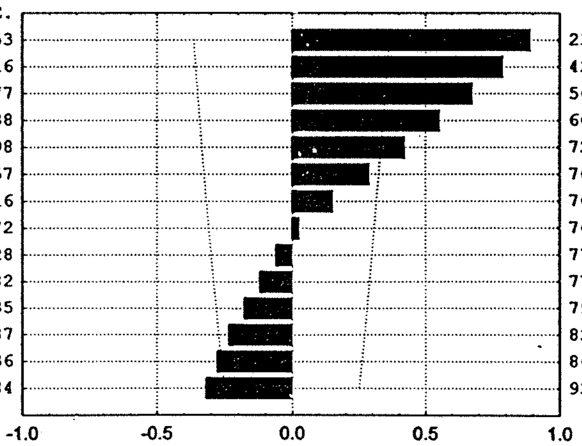


Experimental Group No. 5
Autocorrelation Function
Un-augmented pre-Entry raw scores



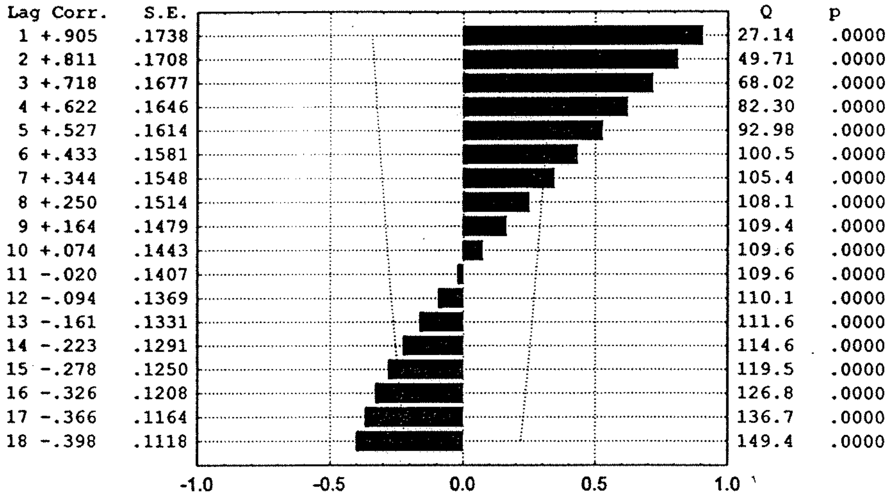
Lag	Corr.	S.E.	Q	p
1	+.891	.1853	23.10	.0000
2	+.790	.1816	42.04	.0000
3	+.672	.1777	56.34	.0000
4	+.550	.1738	66.36	.0000
5	+.429	.1698	72.75	.0000
6	+.275	.1657	75.49	.0000
7	+.141	.1616	76.25	.0000
8	+.018	.1572	76.26	.0000
9	-.063	.1528	76.44	.0000
10	-.122	.1482	77.11	.0000
11	-.178	.1435	78.64	.0000
12	-.233	.1387	81.47	.0000
13	-.276	.1336	85.74	.0000
14	-.315	.1284	91.78	.0000

Experimental Group No. 5
Autocorrelation Function
Augmented pre-Entry raw scores

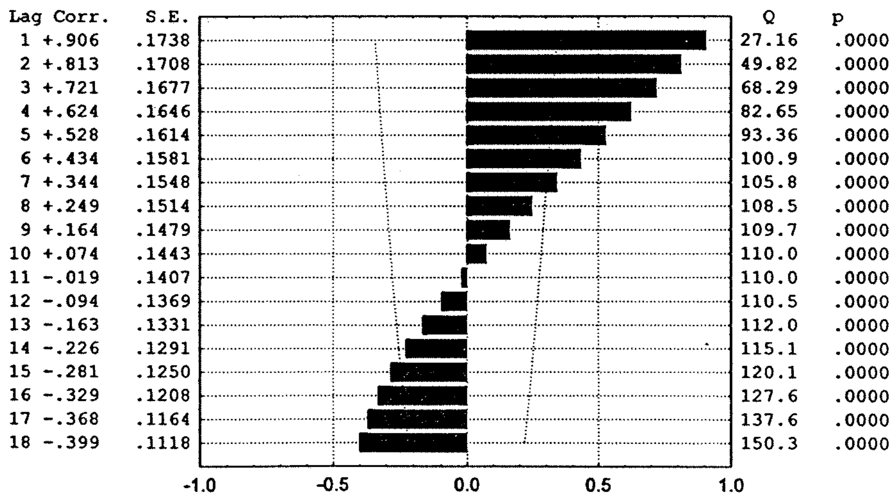


Lag	Corr.	S.E.	Q	p
1	+.891	.1853	23.13	.0000
2	+.790	.1816	42.07	.0000
3	+.677	.1777	56.57	.0000
4	+.554	.1738	66.73	.0000
5	+.423	.1698	72.93	.0000
6	+.290	.1657	76.00	.0000
7	+.153	.1616	76.90	.0000
8	+.026	.1572	76.92	.0000
9	-.060	.1528	77.08	.0000
10	-.119	.1482	77.73	.0000
11	-.177	.1435	79.25	.0000
12	-.234	.1387	82.11	.0000
13	-.277	.1336	86.40	.0000
14	-.318	.1284	92.54	.0000

Experimental Group No. 6
Autocorrelation Function
Un-augmented pre-Entry raw scores

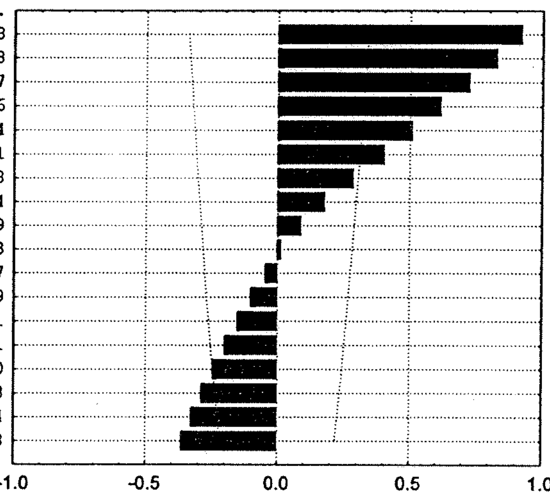


Experimental Group No. 6
Autocorrelation Function
Augmented pre-Entry raw scores



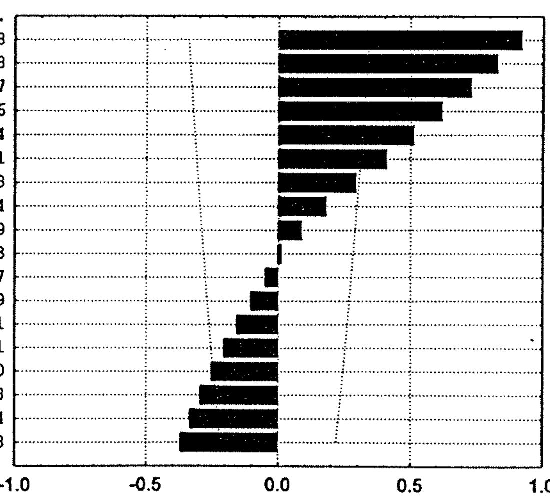
Experimental Group No. 9
Autocorrelation Function
Un-augmented pre-Entry raw scores

Lag	Corr.	S.E.	Q	p
1	+.921	.1738	28.10	.0000
2	+.830	.1708	51.69	.0000
3	+.726	.1677	70.46	.0000
4	+.619	.1646	84.60	.0000
5	+.510	.1614	94.56	.0000
6	+.403	.1581	101.1	.0000
7	+.287	.1548	104.5	.0000
8	+.178	.1514	105.9	.0000
9	+.090	.1479	106.2	.0000
10	+.013	.1443	106.2	.0000
11	-.047	.1407	106.4	.0000
12	-.102	.1369	106.9	.0000
13	-.152	.1331	108.2	.0000
14	-.199	.1291	110.6	.0000
15	-.244	.1250	114.4	.0000
16	-.287	.1208	120.1	.0000
17	-.327	.1164	127.9	.0000
18	-.363	.1118	138.5	.0000

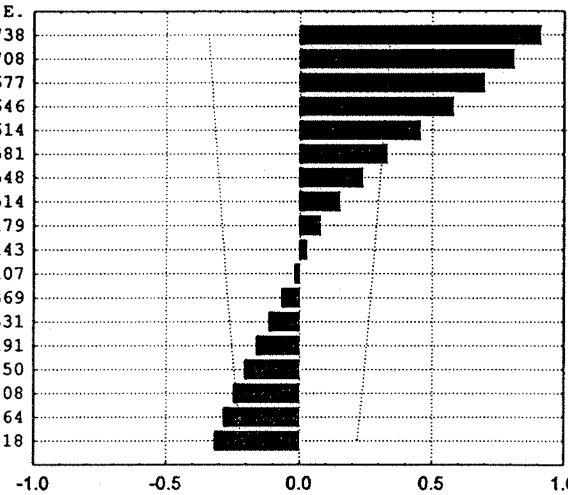


Experimental Group No. 9
Autocorrelation Function
Augmented pre-Entry raw scores

Lag	Corr.	S.E.	Q	p
1	+.921	.1738	28.07	.0000
2	+.830	.1708	51.69	.0000
3	+.731	.1677	70.69	.0000
4	+.621	.1646	84.92	.0000
5	+.512	.1614	95.01	.0000
6	+.409	.1581	101.7	.0000
7	+.294	.1548	105.3	.0000
8	+.181	.1514	106.7	.0000
9	+.090	.1479	107.1	.0000
10	+.012	.1443	107.1	.0000
11	-.048	.1407	107.2	.0000
12	-.103	.1369	107.8	.0000
13	-.156	.1331	109.2	.0000
14	-.205	.1291	111.7	.0000
15	-.252	.1250	115.8	.0000
16	-.293	.1208	121.7	.0000
17	-.333	.1164	129.8	.0000
18	-.368	.1118	140.7	.0000

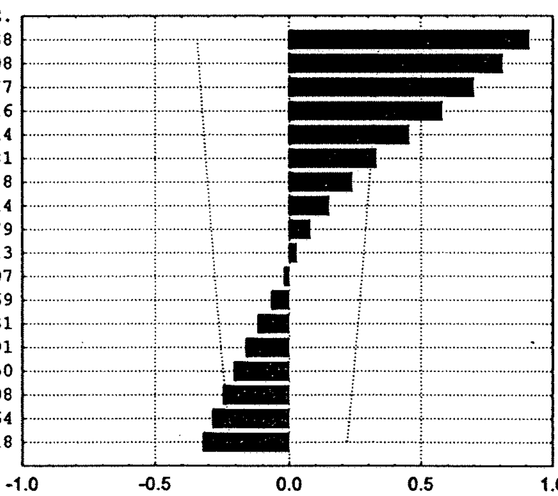


Experimental Group No. 10
Autocorrelation Function
Un-augmented pre-Entry raw scores



Lag	Corr.	S.E.	Q	p
1	+.911	.1738	27.45	.0000
2	+.809	.1708	49.88	.0000
3	+.697	.1677	67.16	.0000
4	+.581	.1646	79.62	.0000
5	+.455	.1614	87.56	.0000
6	+.330	.1581	91.91	.0000
7	+.239	.1548	94.30	.0000
8	+.152	.1514	95.31	.0000
9	+.079	.1479	95.60	.0000
10	+.028	.1443	95.63	.0000
11	-.018	.1407	95.65	.0000
12	-.065	.1369	95.88	.0000
13	-.115	.1331	96.62	.0000
14	-.161	.1291	98.18	.0000
15	-.205	.1250	100.9	.0000
16	-.245	.1208	105.0	.0000
17	-.283	.1164	110.9	.0000
18	-.316	.1118	118.9	.0000

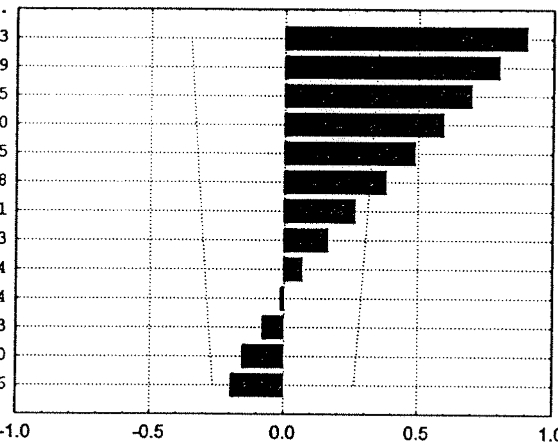
Experimental Group No. 10
Autocorrelation Function
Augmented pre-Entry raw scores



Lag	Corr.	S.E.	Q	p
1	+.911	.1738	27.45	.0000
2	+.810	.1708	49.96	.0000
3	+.701	.1677	67.45	.0000
4	+.581	.1646	79.93	.0000
5	+.455	.1614	87.87	.0000
6	+.330	.1581	92.24	.0000
7	+.239	.1548	94.62	.0000
8	+.151	.1514	95.62	.0000
9	+.079	.1479	95.91	.0000
10	+.028	.1443	95.95	.0000
11	-.017	.1407	95.96	.0000
12	-.066	.1369	96.20	.0000
13	-.116	.1331	96.95	.0000
14	-.160	.1291	98.50	.0000
15	-.205	.1250	101.2	.0000
16	-.244	.1208	105.3	.0000
17	-.284	.1164	111.2	.0000
18	-.319	.1118	119.4	.0000

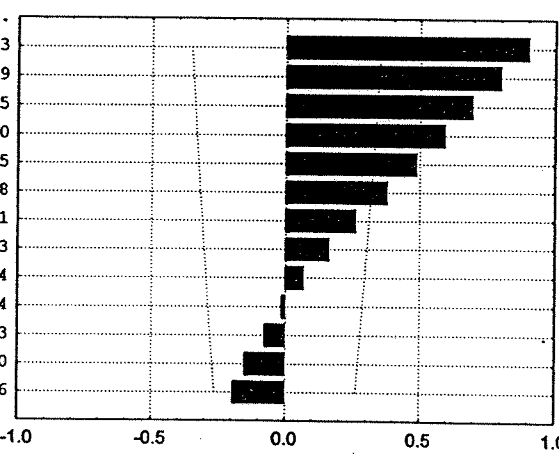
Experimental Group No. 11
Autocorrelation Function
Un-augmented pre-Entry raw scores

Lag	Corr.	S.E.	Q	p
1	+.902	.1793	25.30	.0000
2	+.801	.1759	46.04	.0000
3	+.699	.1725	62.47	.0000
4	+.597	.1690	74.94	.0000
5	+.490	.1655	83.72	.0000
6	+.379	.1618	89.21	.0000
7	+.264	.1581	91.99	.0000
8	+.163	.1543	93.11	.0000
9	+.069	.1504	93.31	.0000
10	-.011	.1464	93.32	.0000
11	-.078	.1423	93.62	.0000
12	-.152	.1380	94.83	.0000
13	-.195	.1336	96.97	.0000

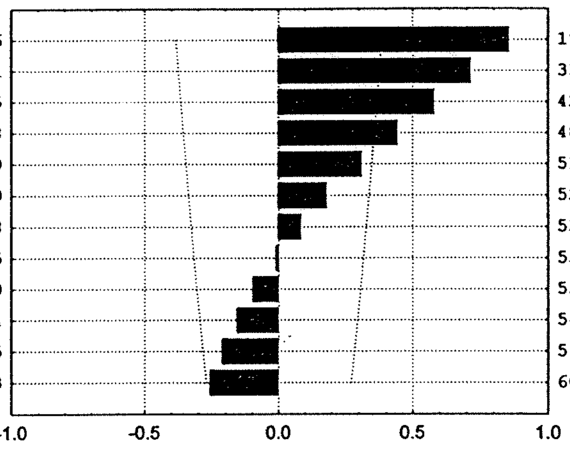


Experimental Group No. 11
Autocorrelation Function
Augmented pre-Entry raw scores

Lag	Corr.	S.E.	Q	p
1	+.901	.1793	25.28	.0000
2	+.801	.1759	46.00	.0000
3	+.698	.1725	62.37	.0000
4	+.595	.1690	74.78	.0000
5	+.489	.1655	83.52	.0000
6	+.378	.1618	88.98	.0000
7	+.261	.1581	91.72	.0000
8	+.162	.1543	92.82	.0000
9	+.068	.1504	93.02	.0000
10	-.012	.1464	93.03	.0000
11	-.076	.1423	93.31	.0000
12	-.149	.1380	94.48	.0000
13	-.193	.1336	96.56	.0000

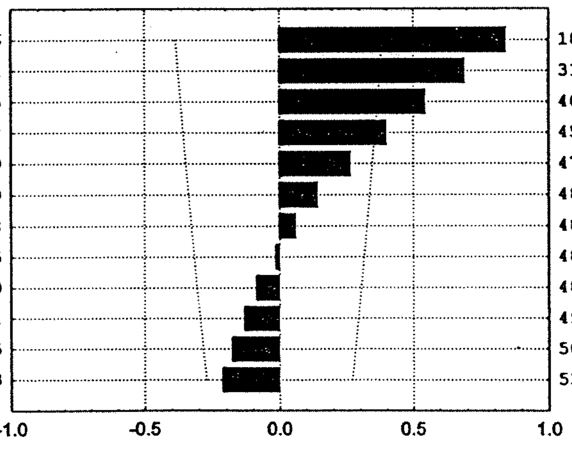


Experimental Group No. 12
Autocorrelation Function
Un-augmented pre-Entry raw scores



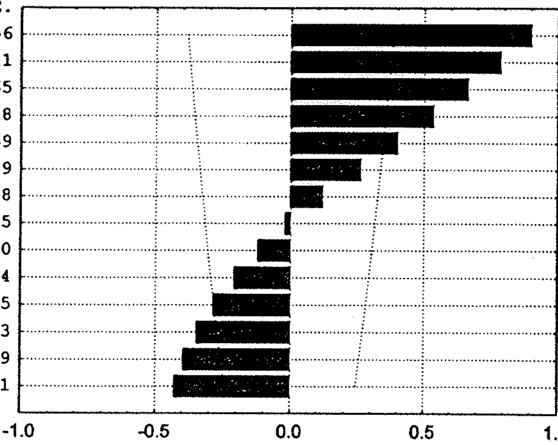
Lag	Corr.	S.E.	Q	p
1	+.856	.1956	19.13	.0000
2	+.716	.1911	33.16	.0000
3	+.581	.1865	42.87	.0000
4	+.443	.1818	48.82	.0000
5	+.310	.1769	51.88	.0000
6	+.180	.1719	52.98	.0000
7	+.085	.1668	53.24	.0000
8	-.007	.1615	53.24	.0000
9	-.096	.1560	53.62	.0000
10	-.155	.1504	54.68	.0000
11	-.211	.1445	56.81	.0000
12	-.256	.1383	60.23	.0000

Experimental Group No. 12
Autocorrelation Function
Augmented pre-Entry raw scores



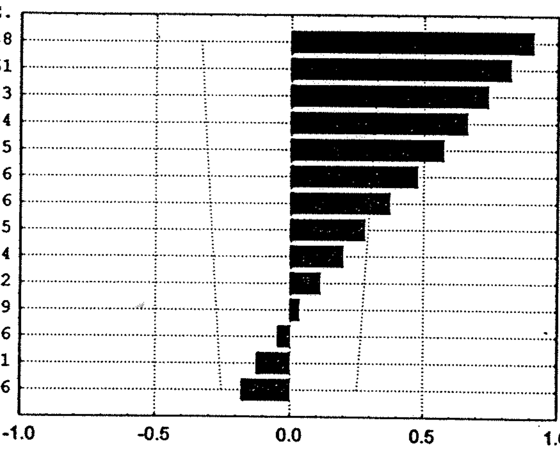
Lag	Corr.	S.E.	Q	p
1	+.844	.1956	18.60	.0000
2	+.692	.1911	31.69	.0000
3	+.546	.1865	40.27	.0000
4	+.399	.1818	45.09	.0000
5	+.267	.1769	47.36	.0000
6	+.143	.1719	48.05	.0000
7	+.061	.1668	48.19	.0000
8	-.013	.1615	48.19	.0000
9	-.085	.1560	48.49	.0000
10	-.130	.1504	49.24	.0000
11	-.176	.1445	50.73	.0000
12	-.211	.1383	53.06	.0000

Experimental Group No. 13
Autocorrelation Function
Un-augmented pre-Entry raw scores



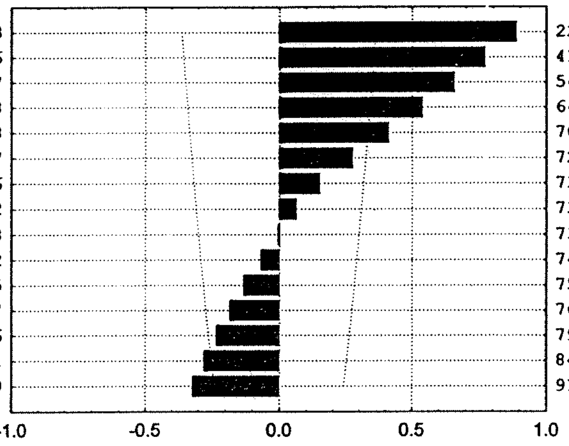
Lag	Corr.	S.E.	Q	p
1	+.900	.1956	21.17	.0000
2	+.788	.1911	38.17	.0000
3	+.666	.1865	50.94	.0000
4	+.536	.1818	59.64	.0000
5	+.401	.1769	64.78	.0000
6	+.264	.1719	67.13	.0000
7	+.121	.1668	67.65	.0000
8	-.019	.1615	67.67	.0000
9	-.120	.1560	68.26	.0000
10	-.208	.1504	70.18	.0000
11	-.284	.1445	74.03	.0000
12	-.346	.1383	80.30	.0000
13	-.394	.1319	89.24	.0000
14	-.428	.1251	100.9	.0000

Experimental Group No. 13
Autocorrelation Function
Augmented pre-Entry raw scores



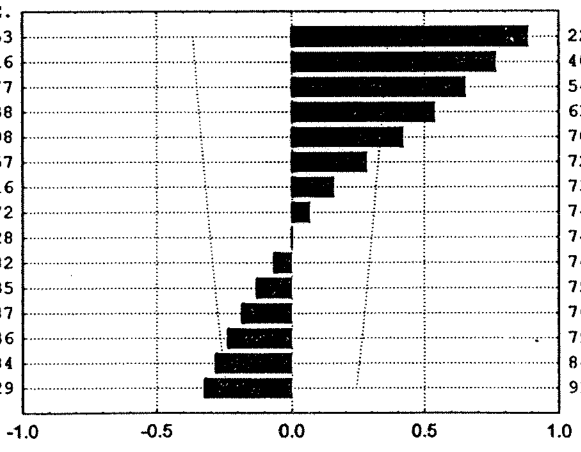
Lag	Corr.	S.E.	Q	p
1	+.909	.1688	29.02	.0000
2	+.826	.1661	53.75	.0000
3	+.742	.1633	74.44	.0000
4	+.665	.1604	91.63	.0000
5	+.576	.1575	105.0	.0000
6	+.477	.1546	114.5	.0000
7	+.374	.1516	120.6	.0000
8	+.279	.1485	124.1	.0000
9	+.199	.1454	126.0	.0000
10	+.113	.1422	126.6	.0000
11	+.035	.1389	126.7	.0000
12	-.045	.1356	126.8	.0000
13	-.122	.1321	127.7	.0000
14	-.177	.1286	129.6	.0000

Experimental Group No. 14
Autocorrelation Function
Un-augmented pre-Entry raw scores



Lag	Corr.	S.E.	Q	p
1	+.889	.1853	22.99	.0000
2	+.771	.1816	41.01	.0000
3	+.657	.1777	54.69	.0000
4	+.539	.1738	64.29	.0000
5	+.412	.1698	70.19	.0000
6	+.276	.1657	72.95	.0000
7	+.151	.1616	73.83	.0000
8	+.064	.1572	73.99	.0000
9	-.002	.1528	73.99	.0000
10	-.067	.1482	74.19	.0000
11	-.130	.1435	75.02	.0000
12	-.182	.1387	76.74	.0000
13	-.231	.1336	79.72	.0000
14	-.277	.1284	84.38	.0000
15	-.320	.1229	91.17	.0000

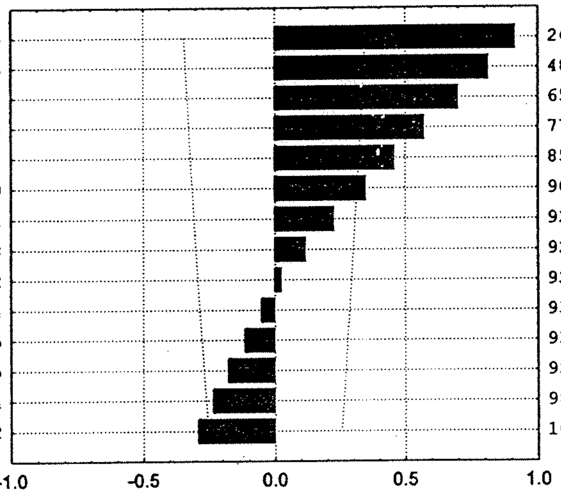
Experimental Group No. 14
Autocorrelation Function
Augmented pre-Entry raw scores



Lag	Corr.	S.E.	Q	p
1	+.887	.1853	22.89	.0000
2	+.767	.1816	40.73	.0000
3	+.654	.1777	54.28	.0000
4	+.539	.1738	63.91	.0000
5	+.421	.1698	70.06	.0000
6	+.282	.1657	72.97	.0000
7	+.157	.1616	73.91	.0000
8	+.067	.1572	74.10	.0000
9	+.001	.1528	74.10	.0000
10	-.066	.1482	74.29	.0000
11	-.130	.1435	75.11	.0000
12	-.183	.1387	76.86	.0000
13	-.235	.1336	79.95	.0000
14	-.281	.1284	84.73	.0000
15	-.322	.1229	91.61	.0000

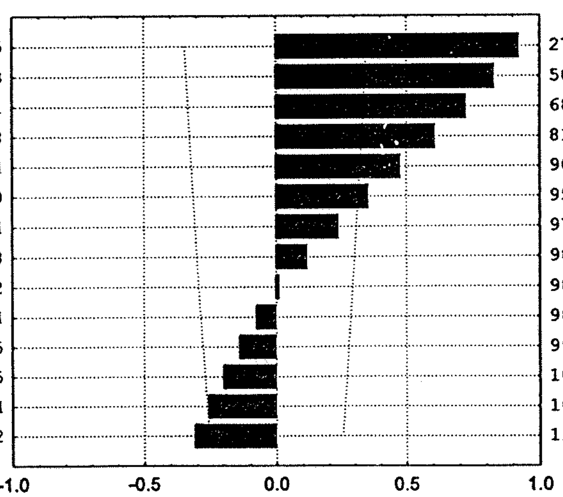
Experimental Group No 15
Autocorrelation Function
Un-augmented pre-Entry raw scores

Lag	Corr.	S.E.	Q	p
1	+.914	.1765	26.80	.0000
2	+.814	.1733	48.84	.0000
3	+.701	.1701	65.82	.0000
4	+.572	.1668	77.58	.0000
5	+.459	.1634	85.46	.0000
6	+.349	.1599	90.23	.0000
7	+.225	.1564	92.30	.0000
8	+.117	.1528	92.88	.0000
9	+.025	.1492	92.91	.0000
10	-.051	.1454	93.04	.0000
11	-.114	.1415	93.69	.0000
12	-.176	.1375	95.33	.0000
13	-.235	.1334	98.44	.0000
14	-.291	.1292	103.5	.0000



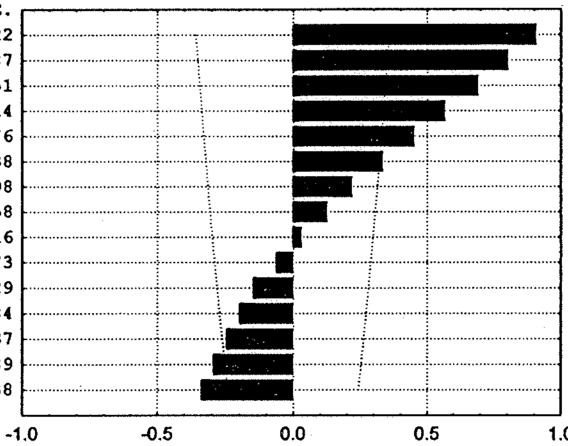
Experimental Group No. 15
Autocorrelation Function
Augmented pre-Entry raw scores

Lag	Corr.	S.E.	Q	p
1	+.922	.1765	27.31	.0000
2	+.830	.1733	50.24	.0000
3	+.725	.1701	68.43	.0000
4	+.610	.1668	81.81	.0000
5	+.477	.1634	90.33	.0000
6	+.354	.1599	95.22	.0000
7	+.238	.1564	97.54	.0000
8	+.117	.1528	98.12	.0000
9	+.011	.1492	98.13	.0000
10	-.075	.1454	98.40	.0000
11	-.139	.1415	99.36	.0000
12	-.199	.1375	101.5	.0000
13	-.256	.1334	105.1	.0000
14	-.308	.1292	110.8	.0000



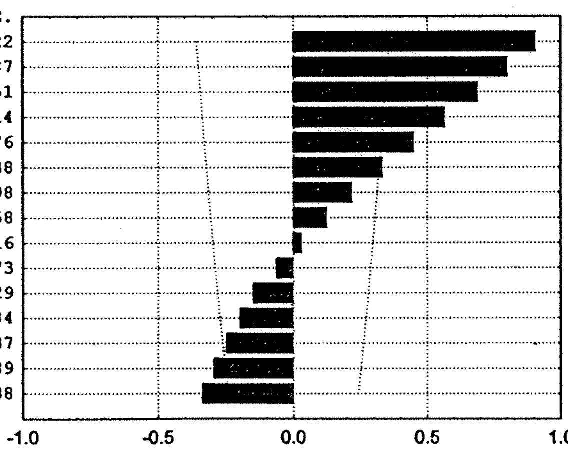
Experimental Group No. 17
Autocorrelation Function
Un-augmented pre-Entry raw score

Lag	Corr.	S.E.	Q	p
1	+.906	.1822	24.75	.0000
2	+.802	.1787	44.91	.0000
3	+.691	.1751	60.49	.0000
4	+.568	.1714	71.47	.0000
5	+.451	.1676	78.71	.0000
6	+.334	.1638	82.87	.0000
7	+.219	.1598	84.75	.0000
8	+.126	.1558	85.41	.0000
9	+.031	.1516	85.45	.0000
10	-.063	.1473	85.64	.0000
11	-.148	.1429	86.71	.0000
12	-.198	.1384	88.75	.0000
13	-.246	.1337	92.14	.0000
14	-.292	.1289	97.29	.0000
15	-.337	.1238	104.7	.0000



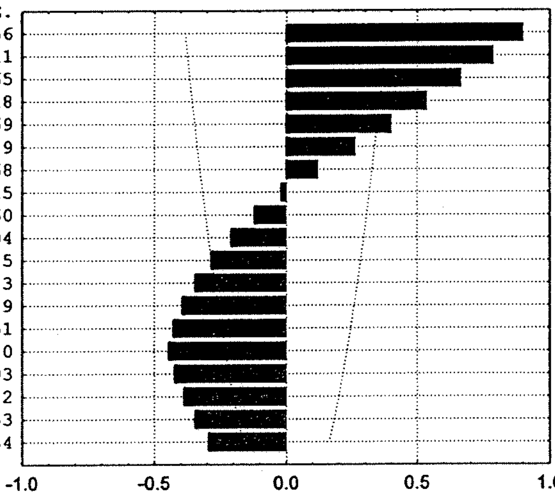
Experimental Group No. 17
Autocorrelation Function
Augmented pre-Entry raw scores

Lag	Corr.	S.E.	Q	p
1	+.906	.1822	24.74	.0000
2	+.802	.1787	44.88	.0000
3	+.691	.1751	60.47	.0000
4	+.568	.1714	71.45	.0000
5	+.451	.1676	78.68	.0000
6	+.335	.1638	82.85	.0000
7	+.220	.1598	84.74	.0000
8	+.126	.1558	85.39	.0000
9	+.032	.1516	85.44	.0000
10	-.063	.1473	85.62	.0000
11	-.148	.1429	86.69	.0000
12	-.197	.1384	88.72	.0000
13	-.247	.1337	92.13	.0000
14	-.293	.1289	97.28	.0000
15	-.336	.1238	104.6	.0000



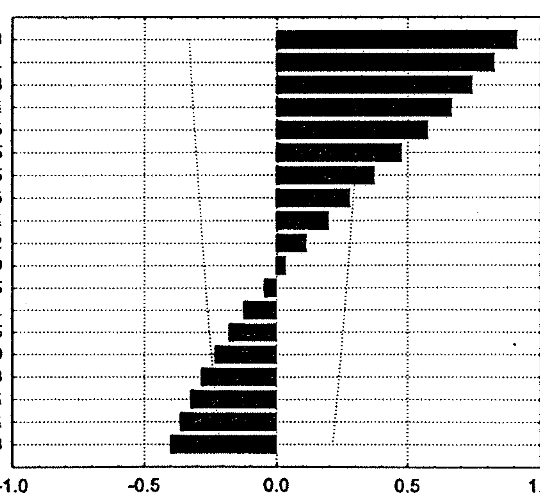
Experimental Group No. 19
Autocorrelation Function
Un-augmented pre-Entry raw scores

Lag	Corr.	S.E.	Q	p
1	+.900	.1956	21.17	.0000
2	+.788	.1911	38.17	.0000
3	+.666	.1865	50.94	.0000
4	+.536	.1818	59.64	.0000
5	+.401	.1769	64.78	.0000
6	+.264	.1719	67.13	.0000
7	+.121	.1668	67.65	.0000
8	-.019	.1615	67.67	.0000
9	-.120	.1560	68.26	.0000
10	-.208	.1504	70.18	.0000
11	-.284	.1445	74.03	.0000
12	-.346	.1383	80.30	.0000
13	-.394	.1319	89.24	.0000
14	-.428	.1251	100.9	.0000
15	-.446	.1180	115.2	.0000
16	-.423	.1103	129.9	.0000
17	-.388	.1022	144.3	.0000
18	-.346	.0933	158.1	.0000
19	-.294	.0834	170.5	.0000



Experimental Group No. 19
Autocorrelation Function
Augmented pre-Entry raw scores

Lag	Corr.	S.E.	Q	p
1	+.909	.1688	29.02	.0000
2	+.826	.1661	53.75	.0000
3	+.742	.1633	74.44	.0000
4	+.665	.1604	91.63	.0000
5	+.576	.1575	105.0	.0000
6	+.477	.1546	114.5	.0000
7	+.374	.1516	120.6	.0000
8	+.279	.1485	124.1	.0000
9	+.199	.1454	126.0	.0000
10	+.113	.1422	126.6	.0000
11	+.035	.1389	126.7	.0000
12	-.045	.1356	126.8	.0000
13	-.122	.1321	127.7	.0000
14	-.177	.1286	129.6	.0000
15	-.230	.1250	132.9	.0000
16	-.281	.1213	138.3	.0000
17	-.323	.1174	145.9	.0000
18	-.362	.1134	156.1	.0000
19	-.400	.1093	169.4	.0000



APPENDIX D

Experimental group word recognition improvement: Successive percentile rankings of individual members from beginning of Grade 1 to end of post-intervention follow-up

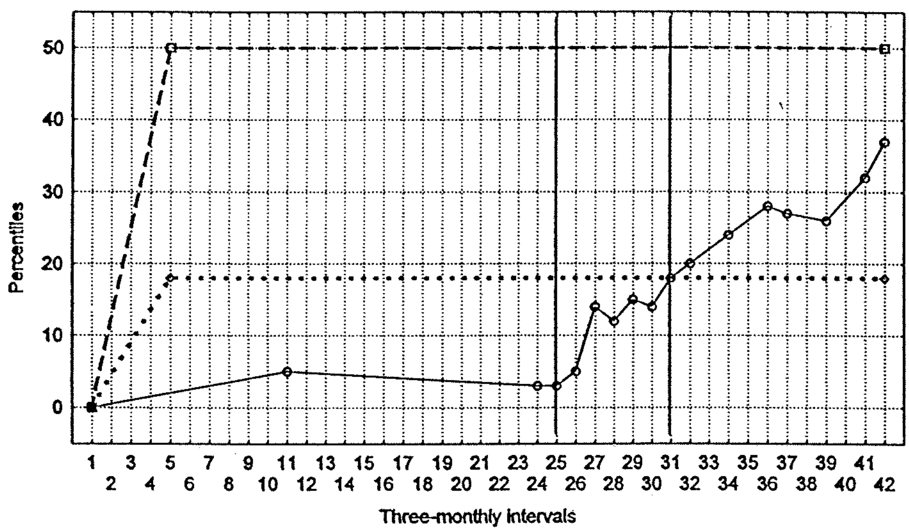
Key:

50th percentile
18th percentile
word recognition performance

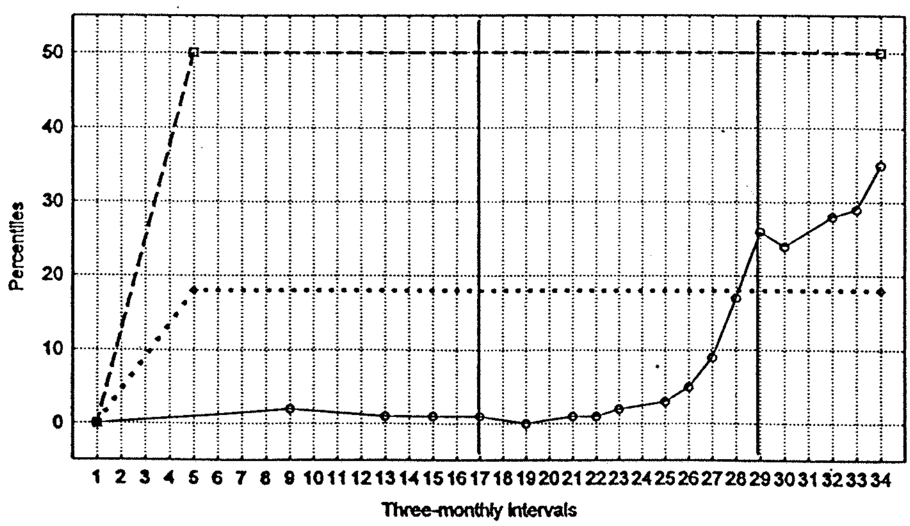
commencement of braille-based input

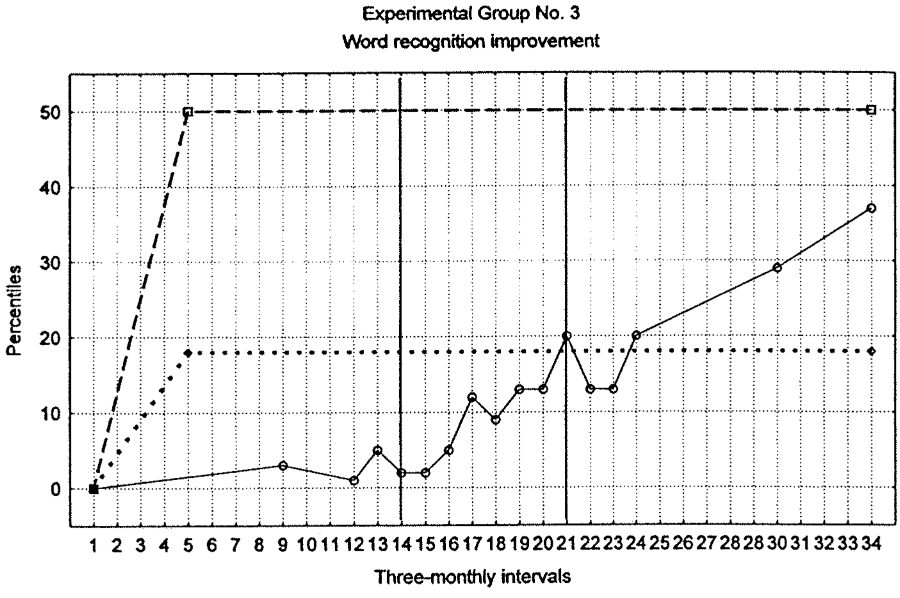
cessation of braille-based input

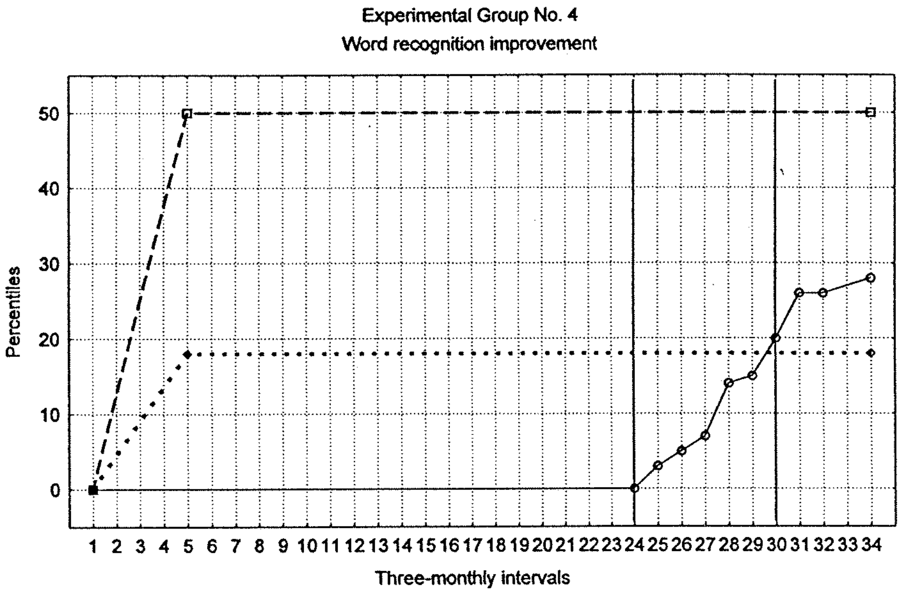
Experimental Group No. 1
Word recognition improvement

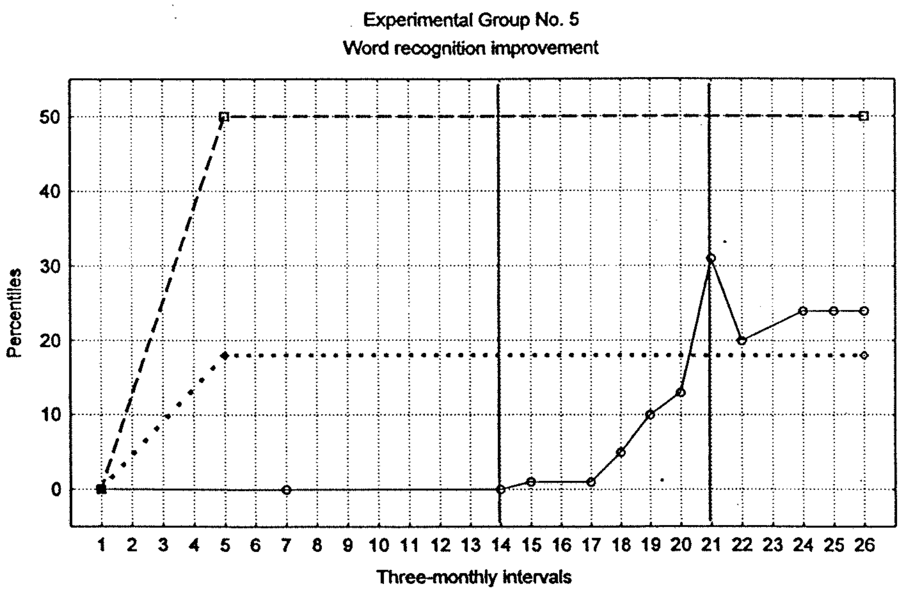


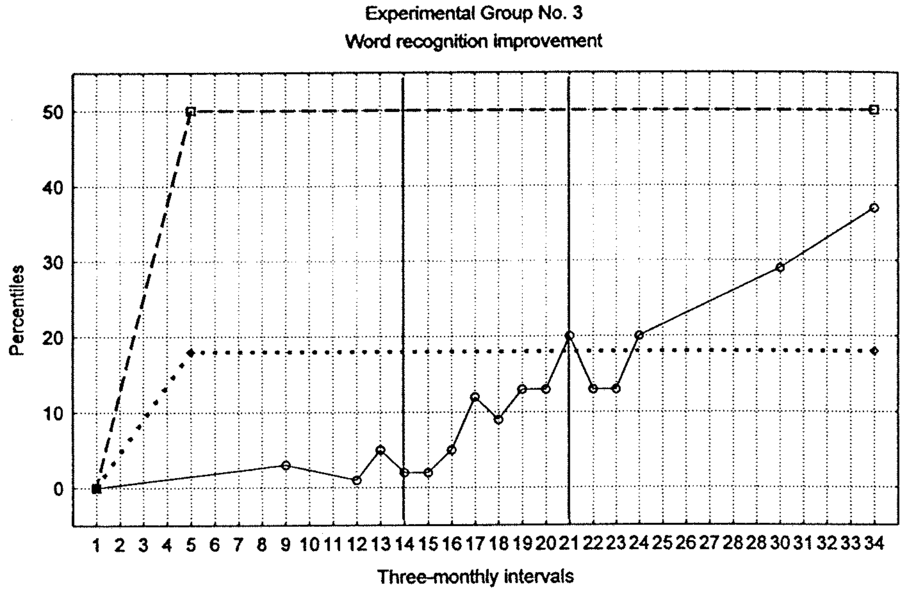
Experimental Group No. 2
Word recognition improvement

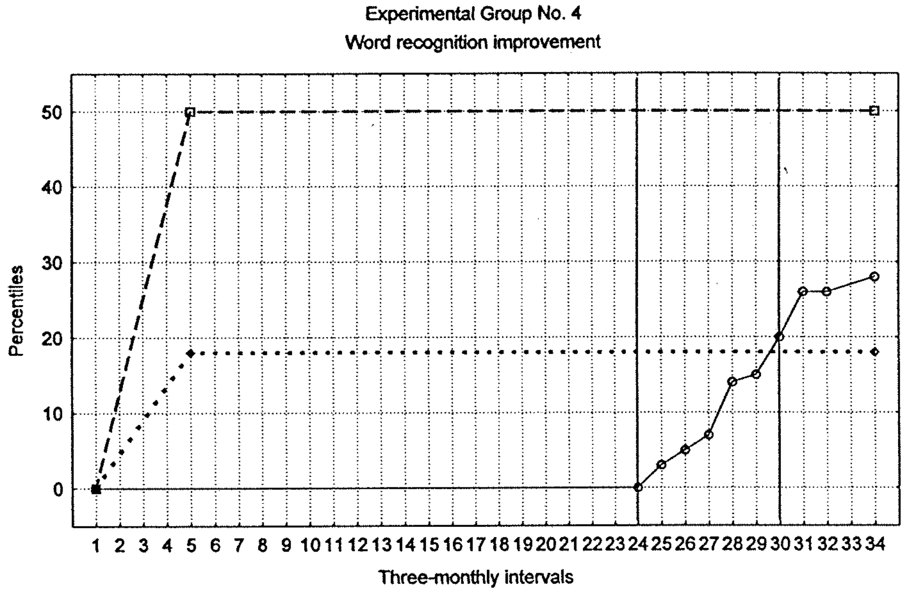


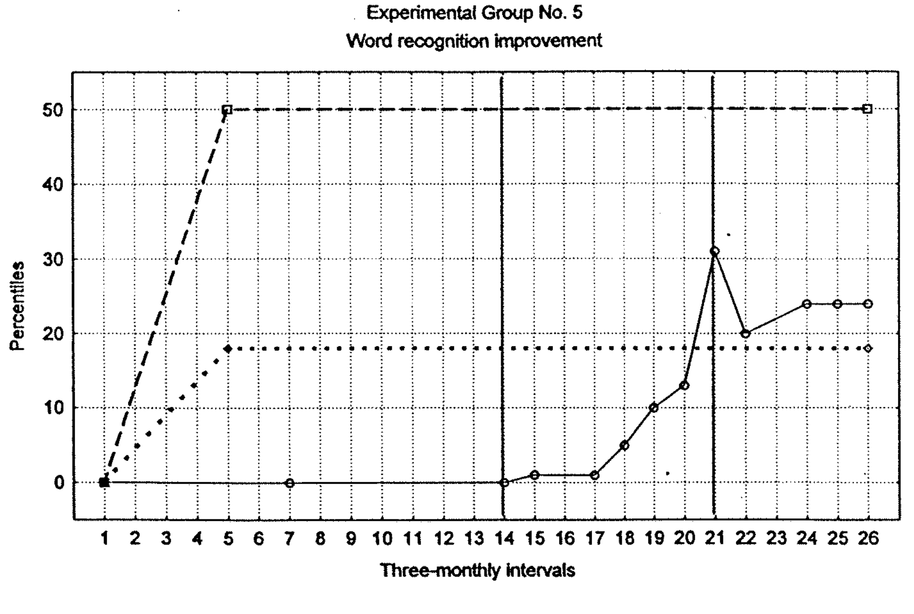

Experimental Group No. 3
Word recognition improvement
Percentiles
0
10
20
30
40
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 28 30 31 32 33 34
Three-monthly intervals

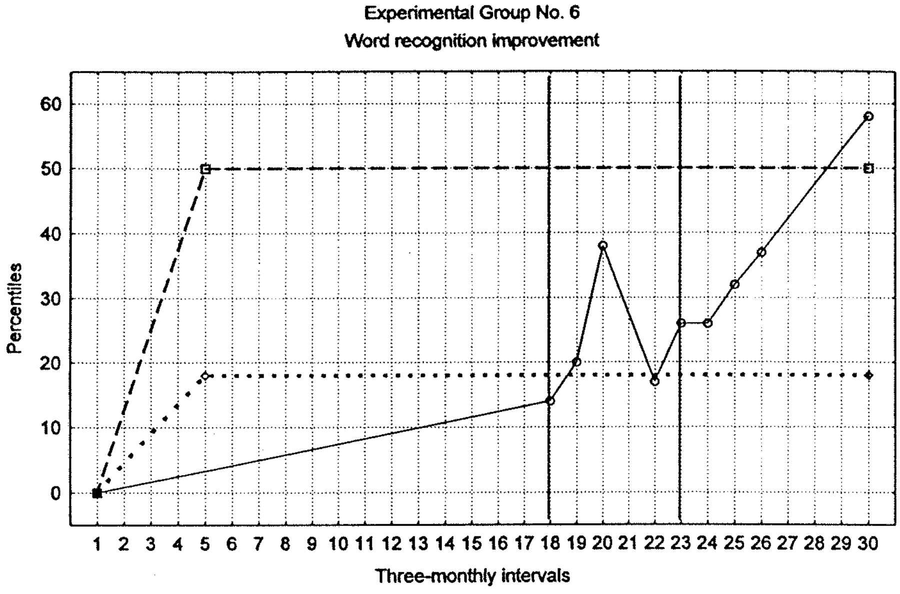

Experimental Group No. 4
Word recognition improvement
Percentiles
0
10
20
30
40
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Three-monthly intervals

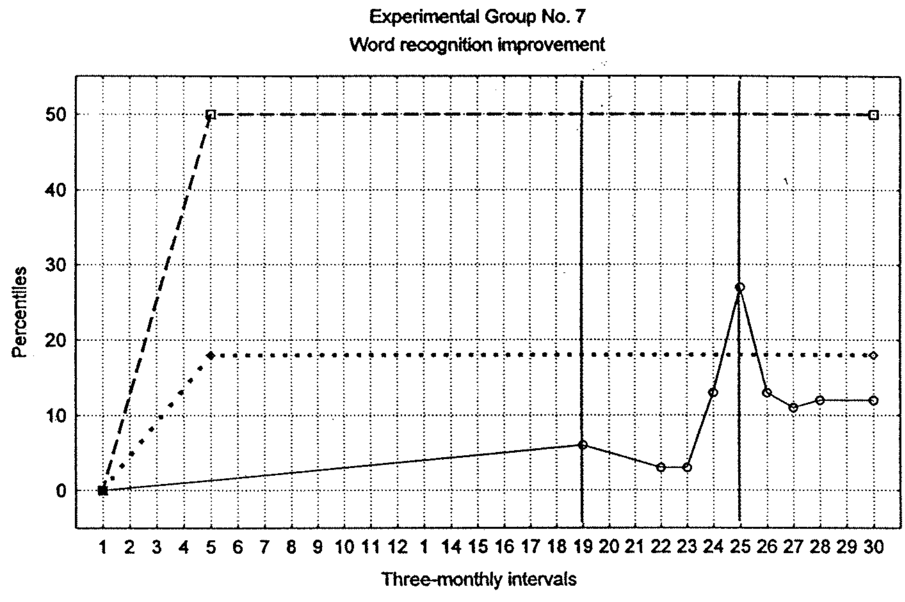

Experimental Group No. 5
Word recognition improvement
Percentiles
0
10
20
30
40
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
Three-monthly intervals

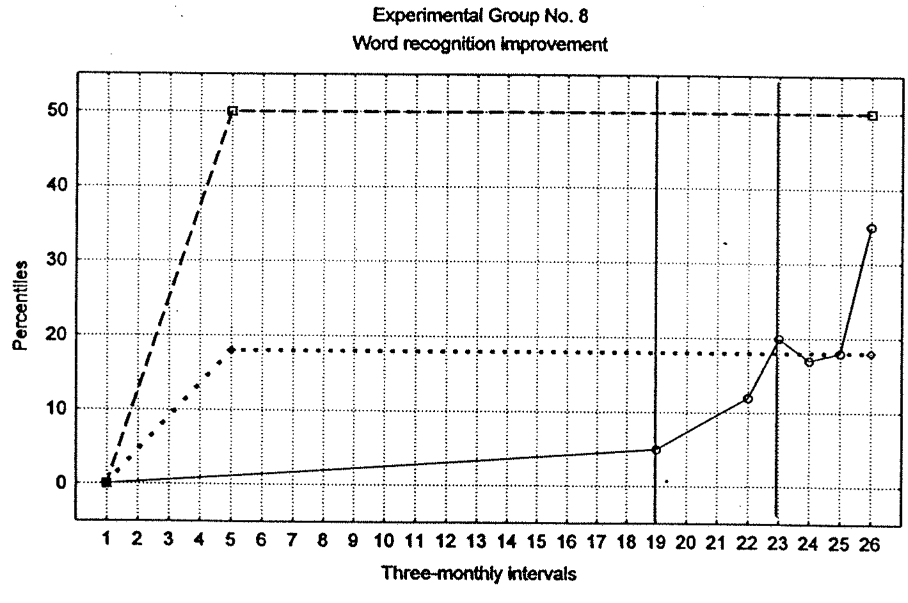

Experimental Group No. 3
Word recognition improvement
Percentiles
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 28 30 31 32 33 34
Three-monthly intervals


Experimental Group No. 4
Word recognition improvement
Percentiles
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Three-monthly intervals

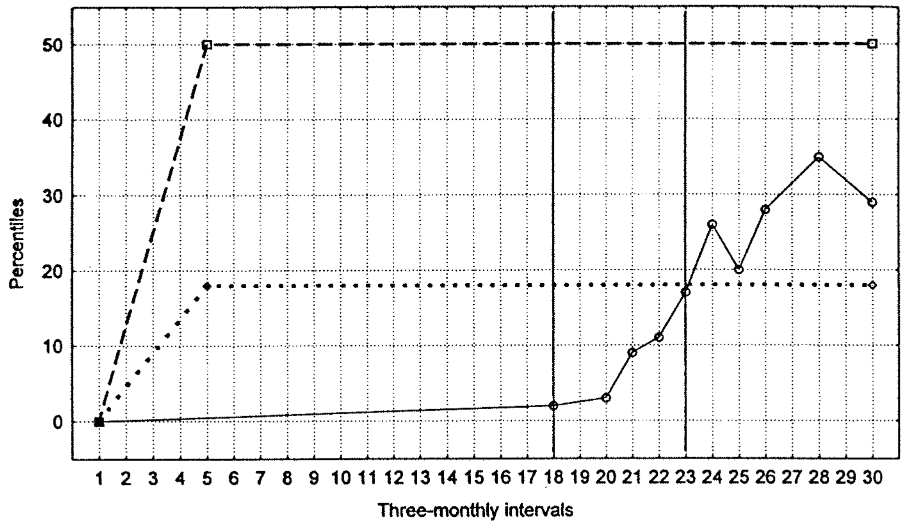

Experimental Group No. 5
Word recognition improvement
Percentiles
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
Three-monthly intervals


Experimental Group No. 6
Word recognition improvement
Percentiles
0
10
20
30
40
50
60
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Three-monthly intervals

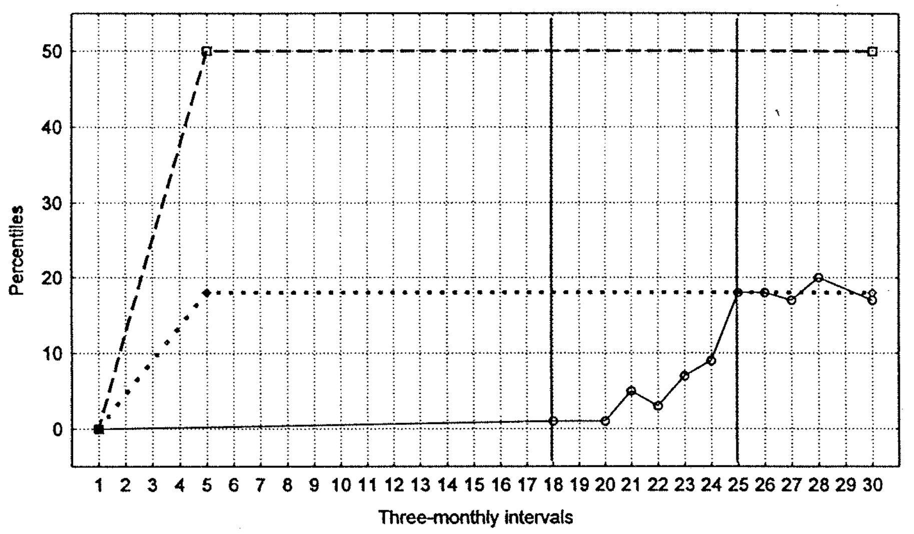

Experimental Group No. 7
Word recognition improvement
Percentiles
0
10
20
30
40
50
1 2 3 4 5 6 7 8 9 10 11 12 1 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Three-monthly intervals


Experimental Group No. 8
Word recognition improvement
Percentiles
0
10
20
30
40
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
Three-monthly intervals

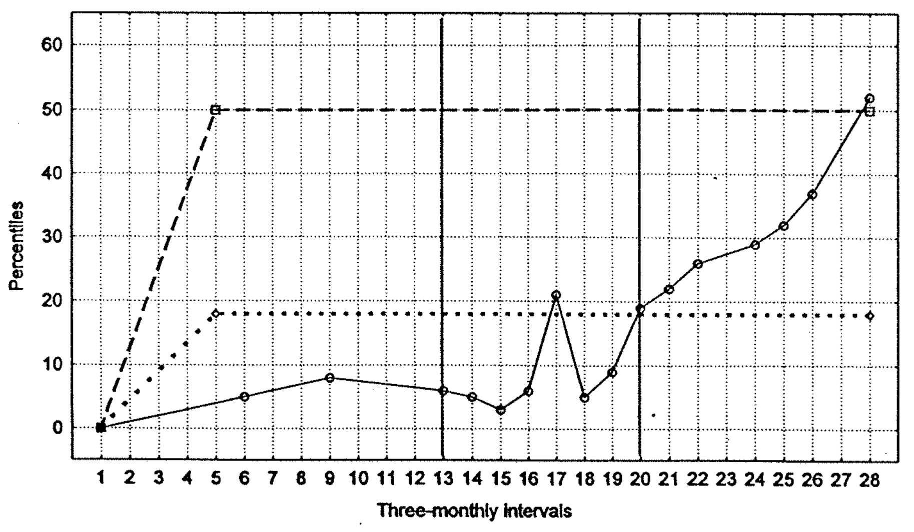
Experimental Group No. 9
Word recognition improvement



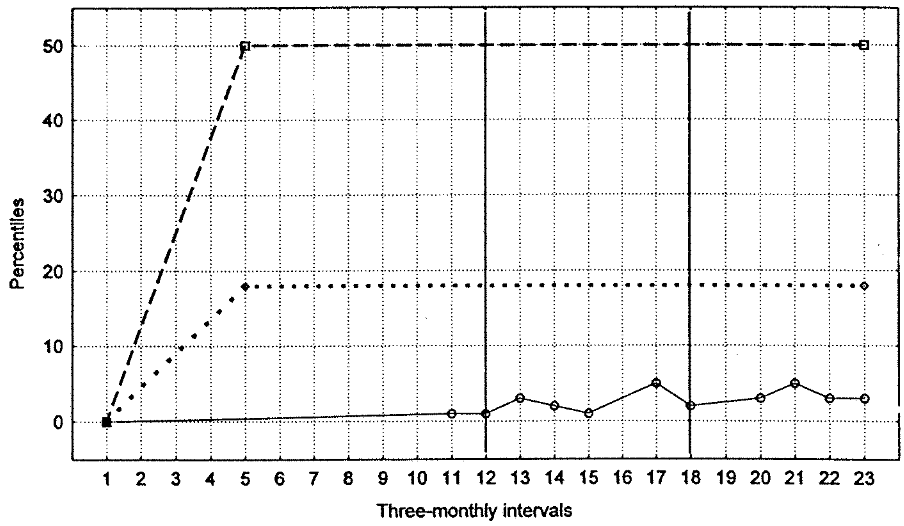
Experimental Group No. 10
Word recognition improvement



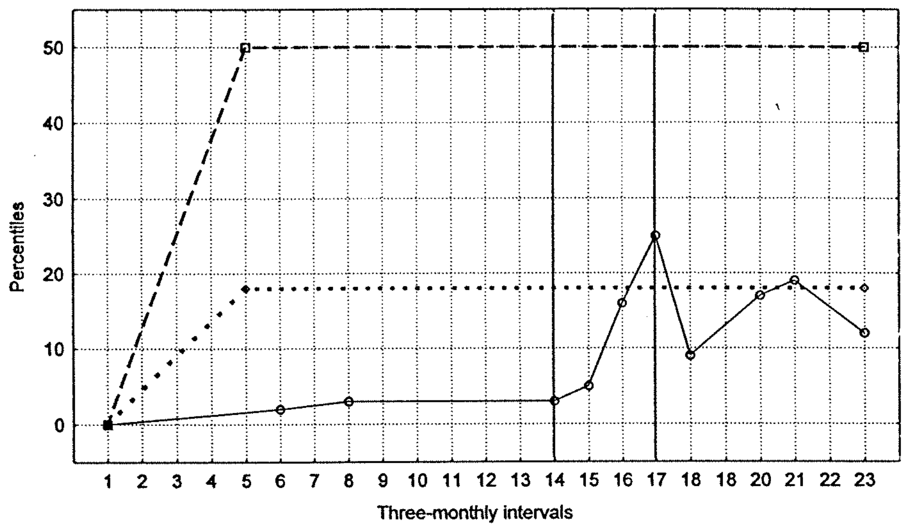
Experimental Group No. 11
Word recognition improvement



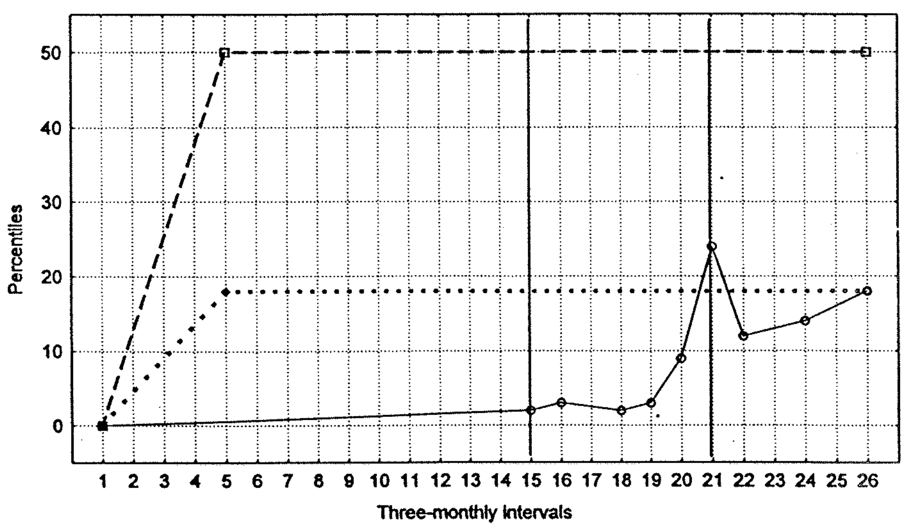
Experimental Group No. 12
Word recognition improvement



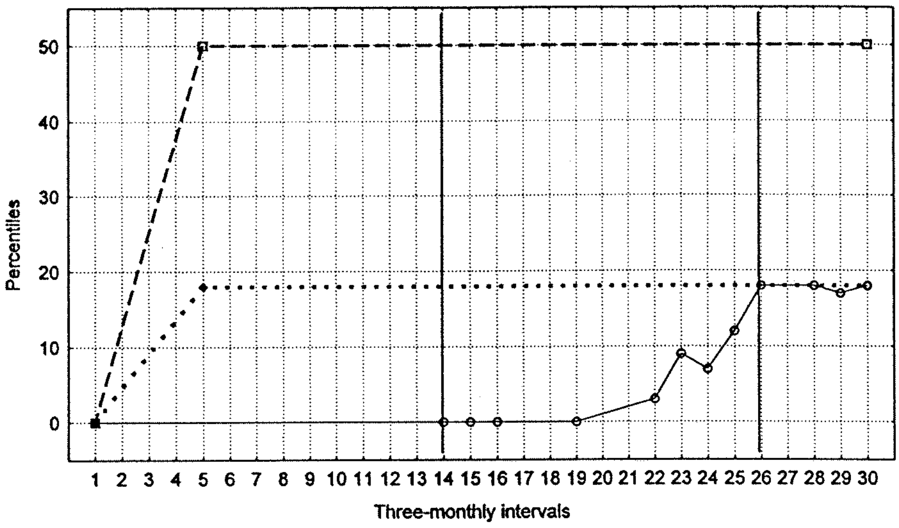
Experimental Group No. 13
Word recognition improvement



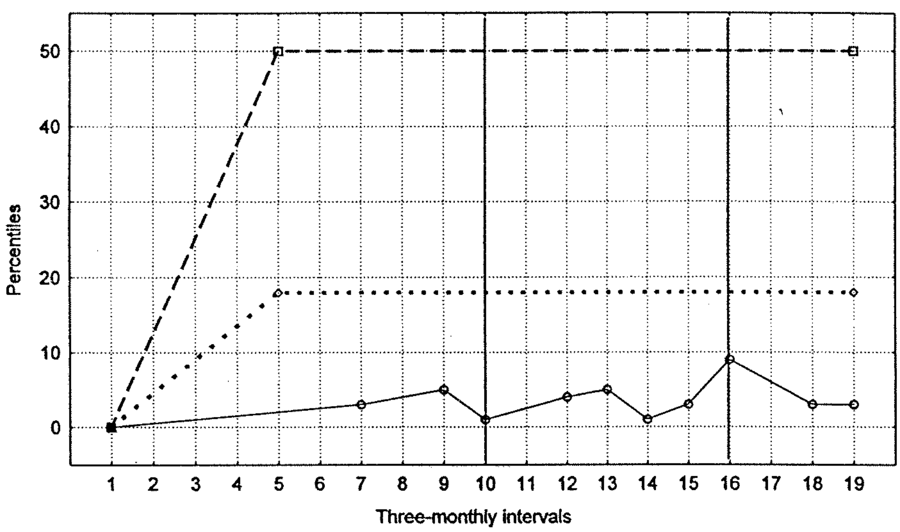
Experimental Group No. 14
Word recognition improvement



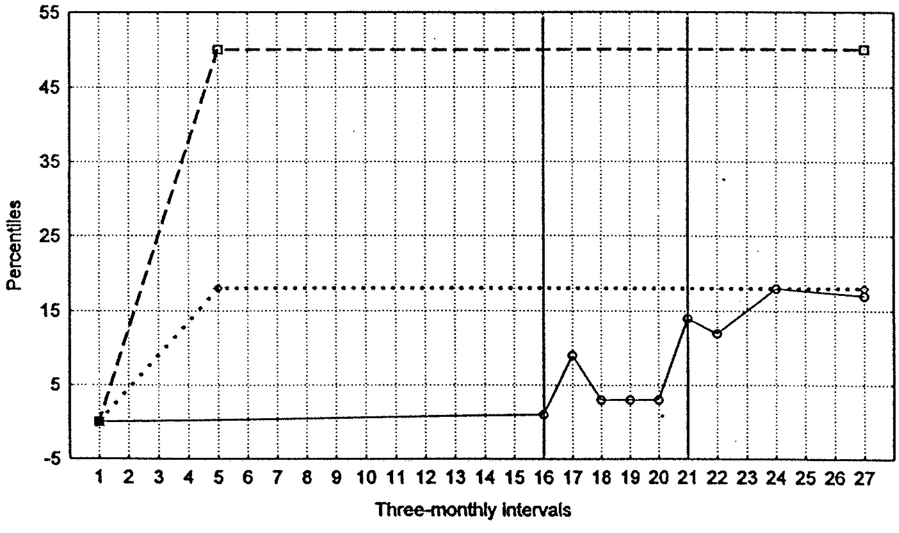
Experimental Group No. 15
Word recognition improvement

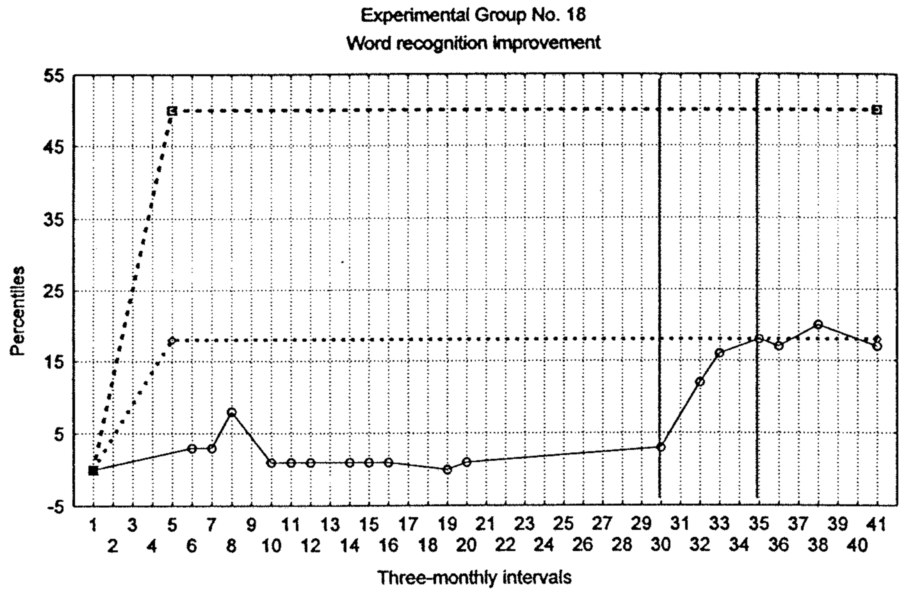


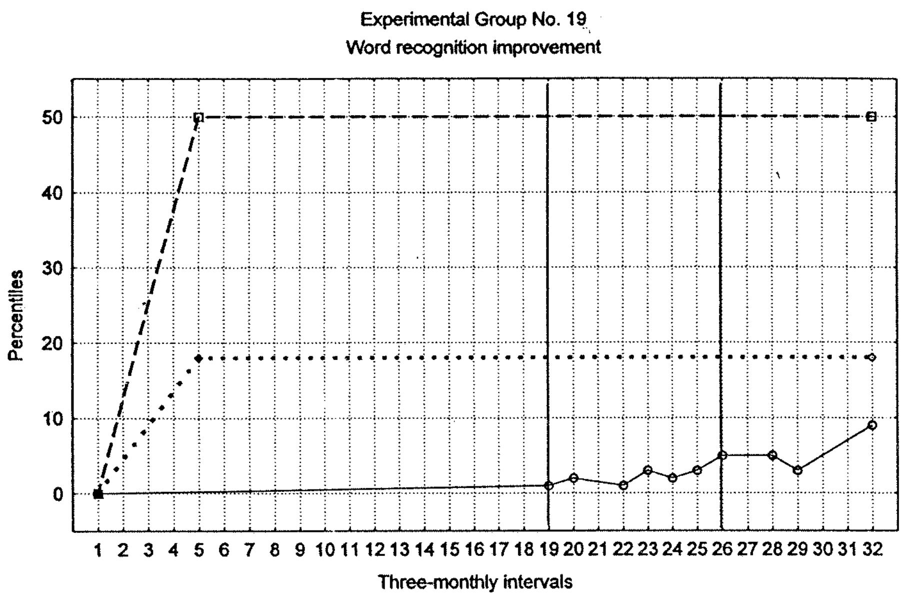
Experimental Group No. 16
Word recognition improvement

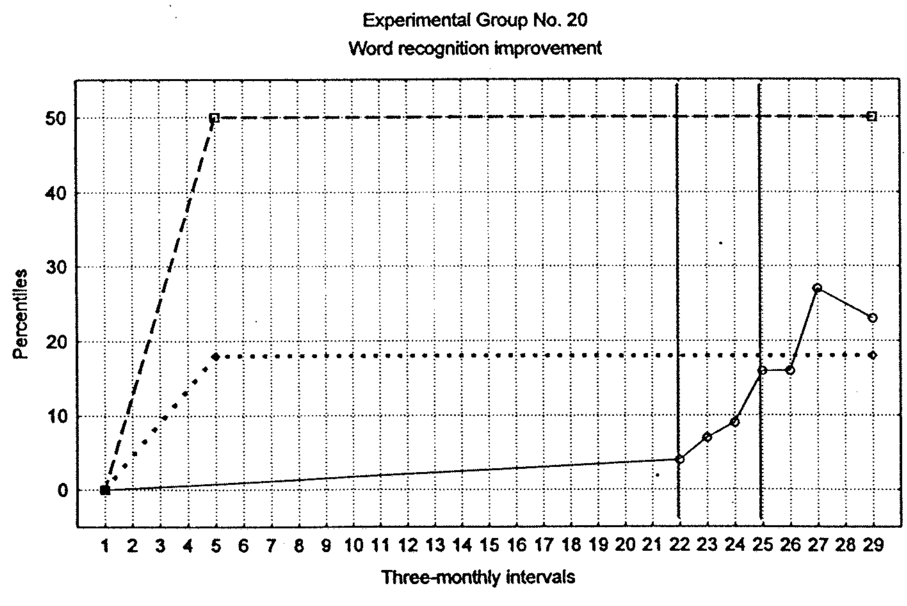


Experimental Group No. 17
Word recognition improvement




Experimental Group No. 18
Word recognition improvement
Percentiles
Three-monthly intervals


Experimental Group No. 19
Word recognition improvement
Percentiles
Three-monthly intervals


Experimental Group No. 20
Word recognition improvement
Percentiles
Three-monthly intervals

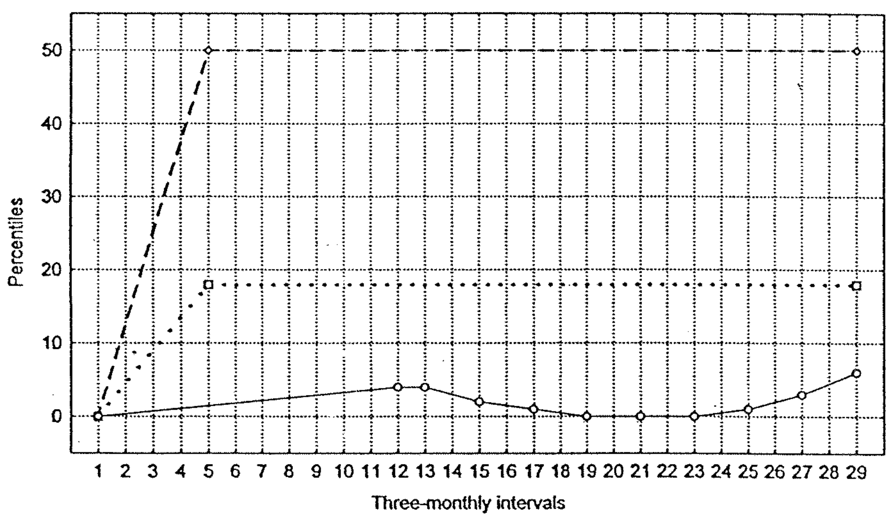
APPENDIX E

Comparison Group Word Recognition Performance: Successive Percentile Rankings of Individual Members from Beginning of Grade 1 to end of Grade 6

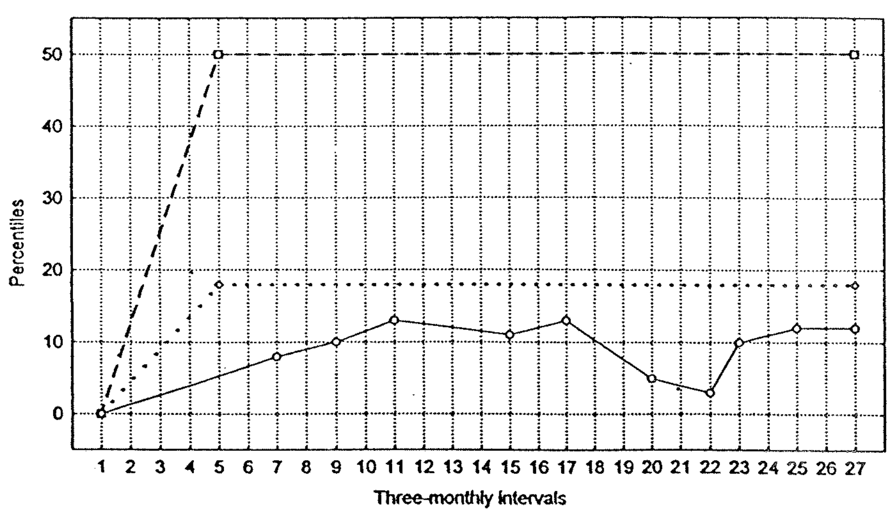
Key:

- 50th percentile
- 18th percentile
- word recognition performance
- average point at which braille-based input commenced with the Experimental group

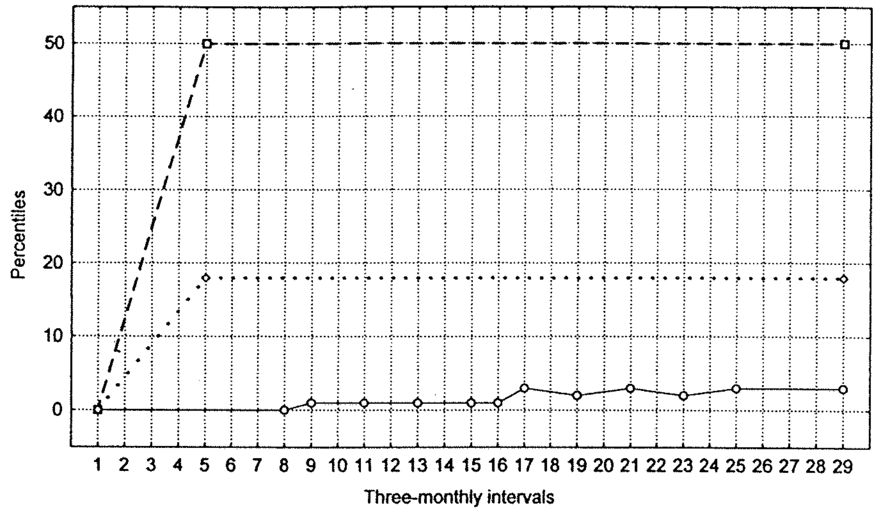
Comparison Group No. 1
Word recognition development



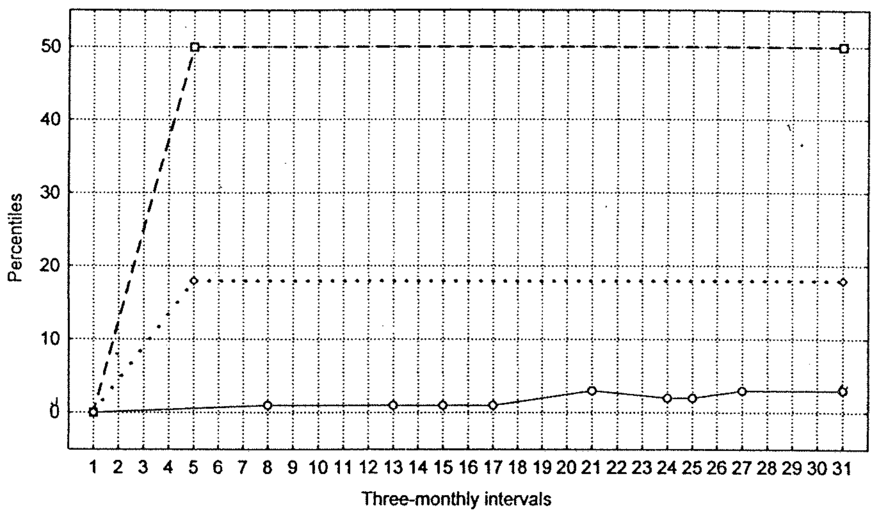
Comparison Group No. 2
Word recognition development



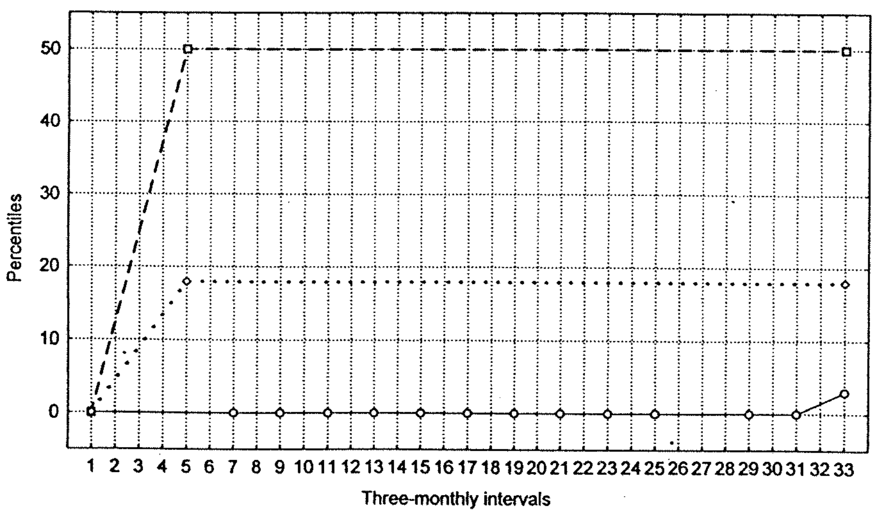
Comparison Group No. 3
Word recognition development

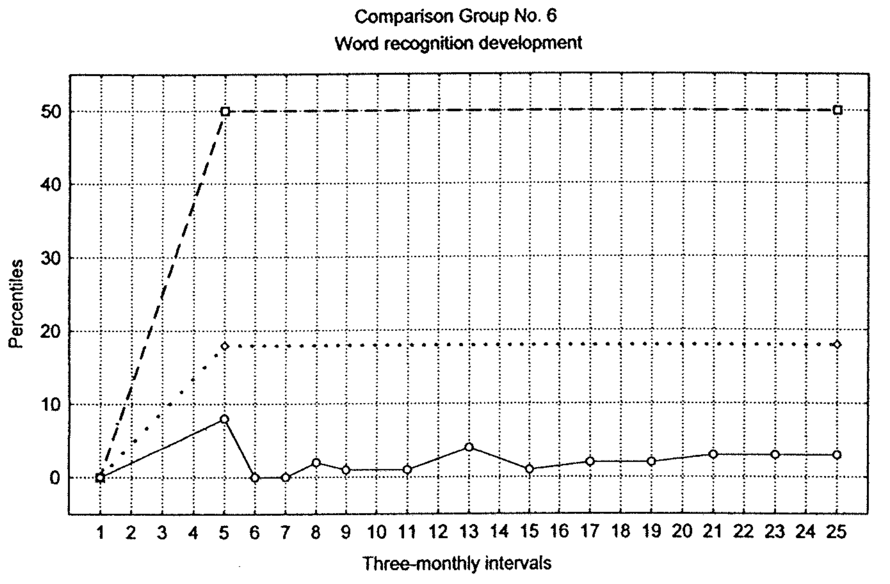


Comparison Group No. 4
Word recognition development

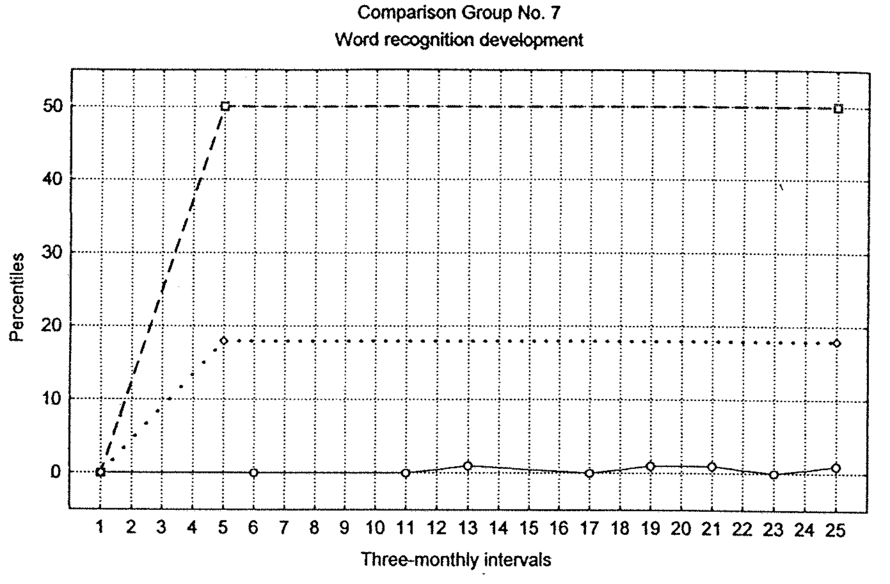


Comparison Group No. 5
Word recognition development

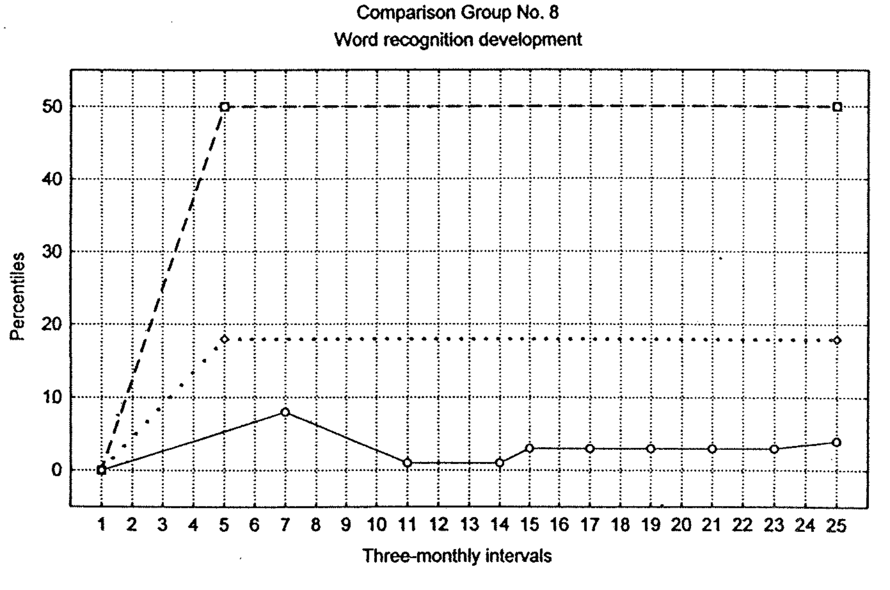




Comparison Group No. 6
Word recognition development
Percentiles
0
10
20
30
40
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Three-monthly intervals

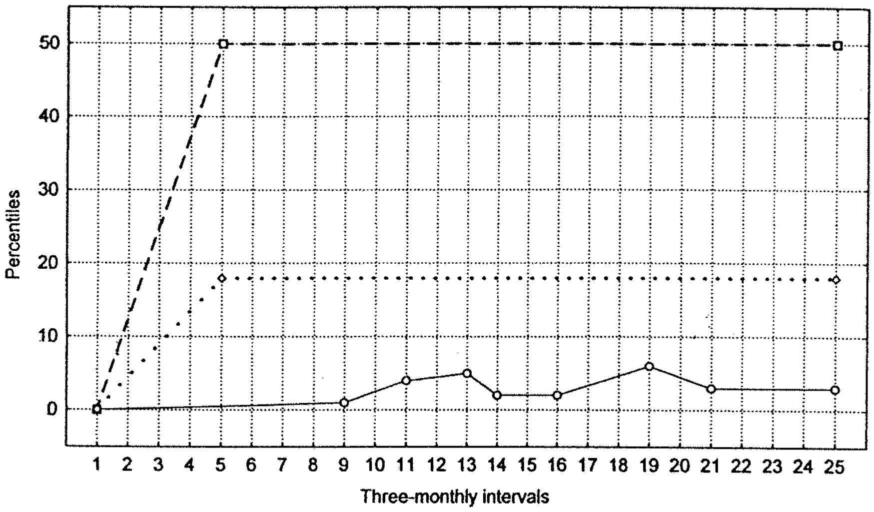


Comparison Group No. 7
Word recognition development
Percentiles
0
10
20
30
40
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Three-monthly intervals

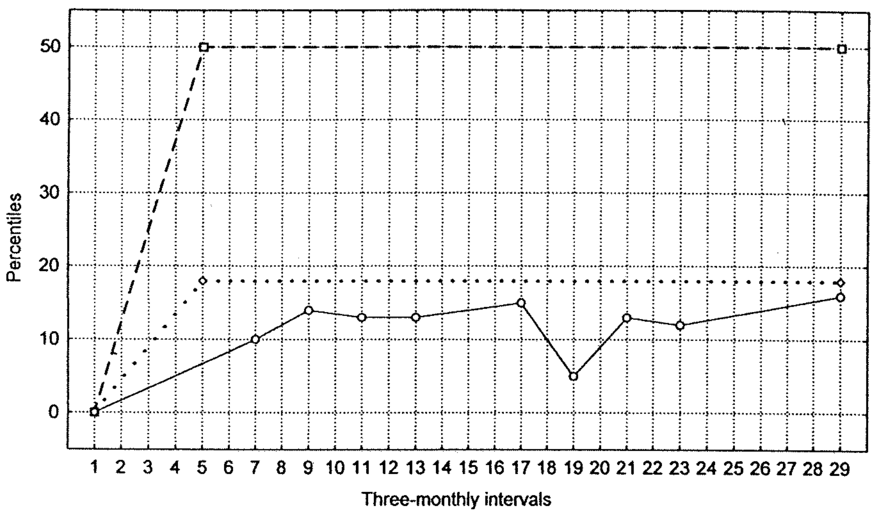


Comparison Group No. 8
Word recognition development
Percentiles
0
10
20
30
40
50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Three-monthly intervals

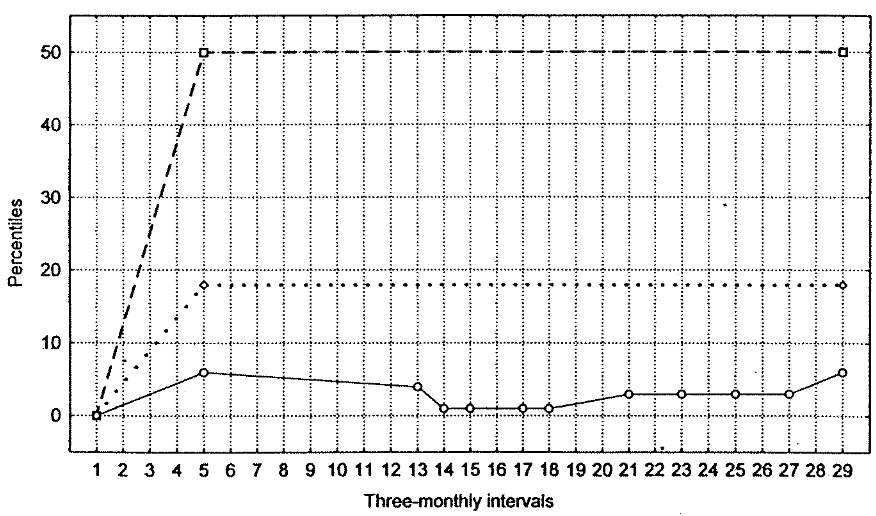
Comparison Group No. 9
Word recognition development



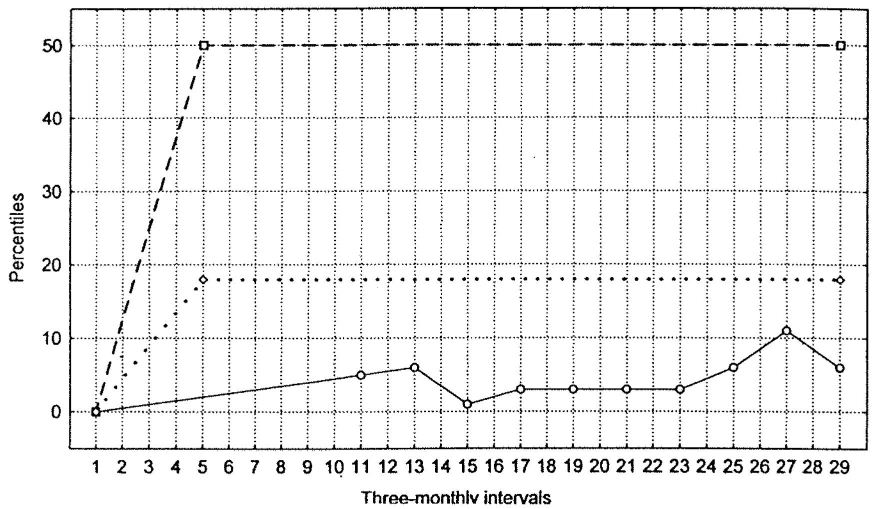
Comparison Group No. 10
Word recognition development



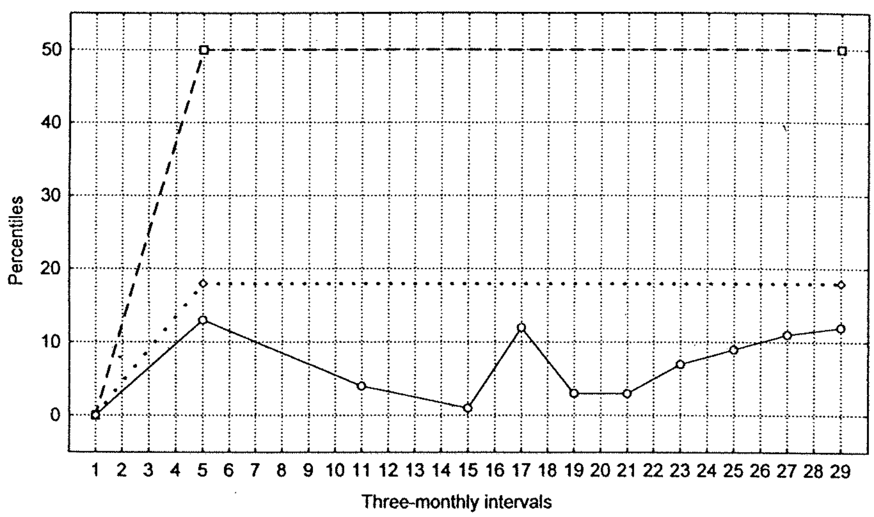
Comparison Group No. 11
Word recognition development



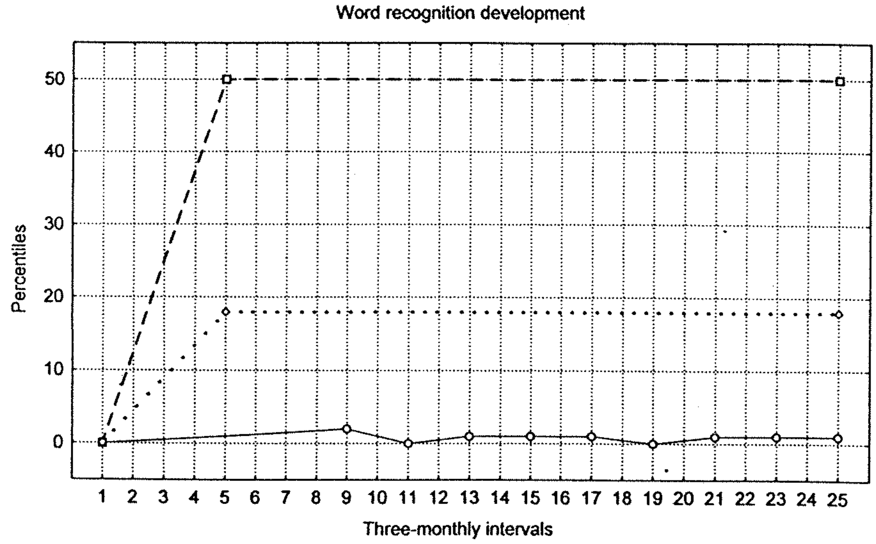
Comparison Group No. 12
Word recognition development



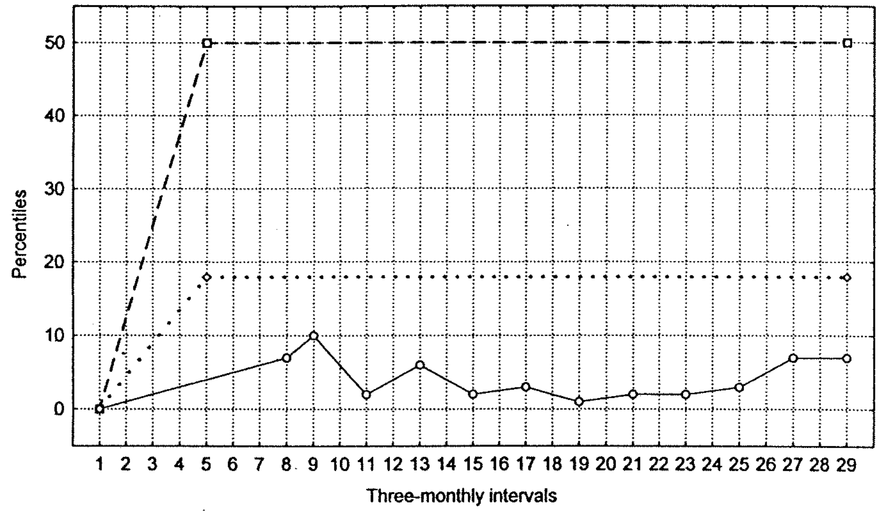
Comparison Group No. 13
Word recognition development



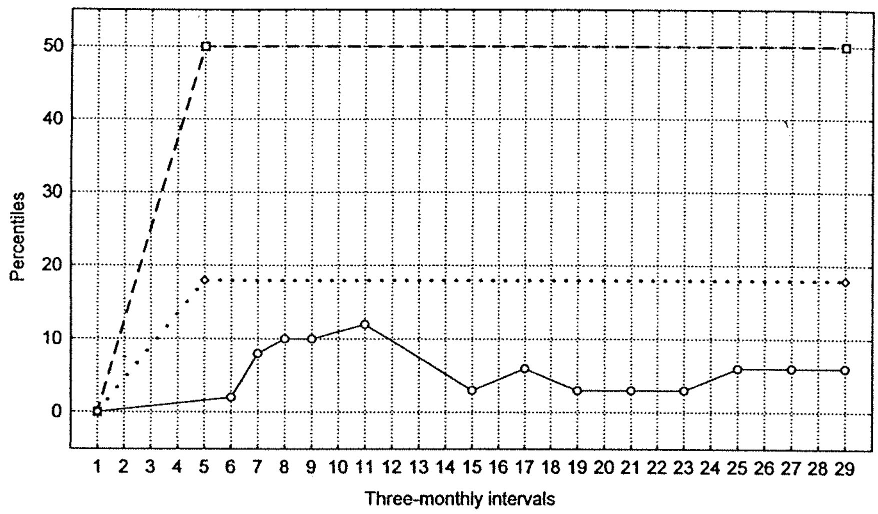
Comparison Group No. 14
Word recognition development



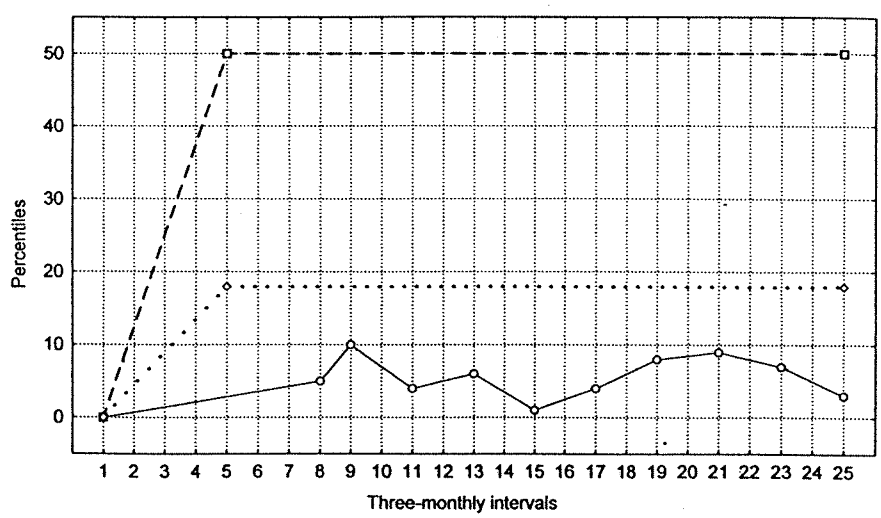
Comparison Group No. 15
Word recognition development

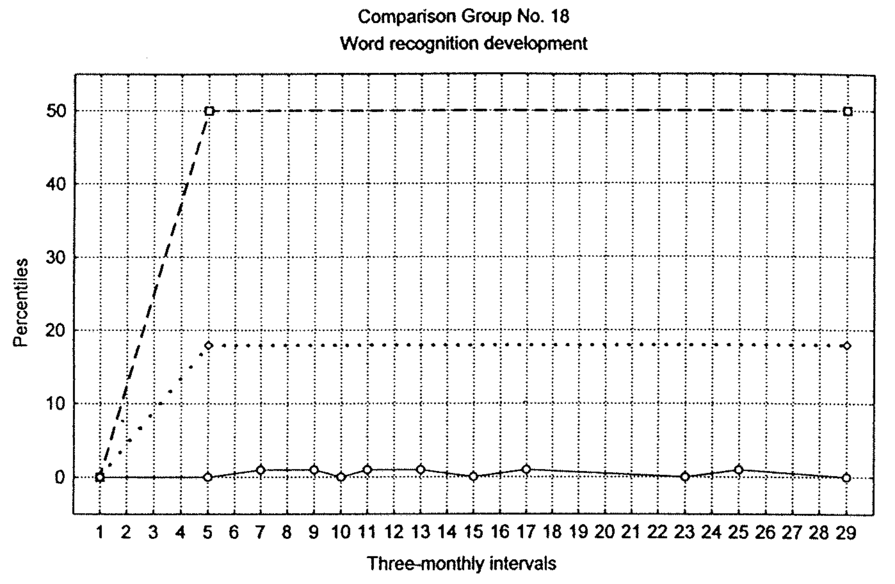


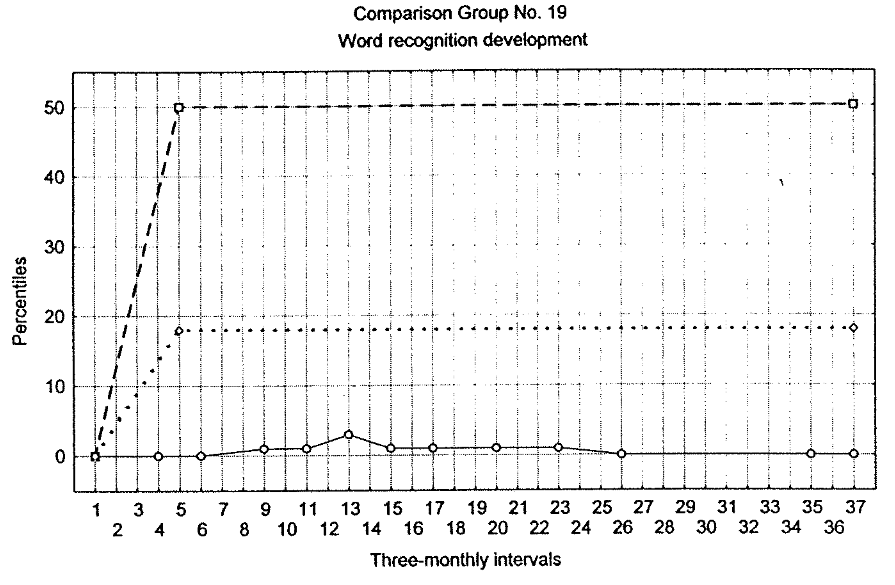
Comparison Group No. 16
Word recognition development

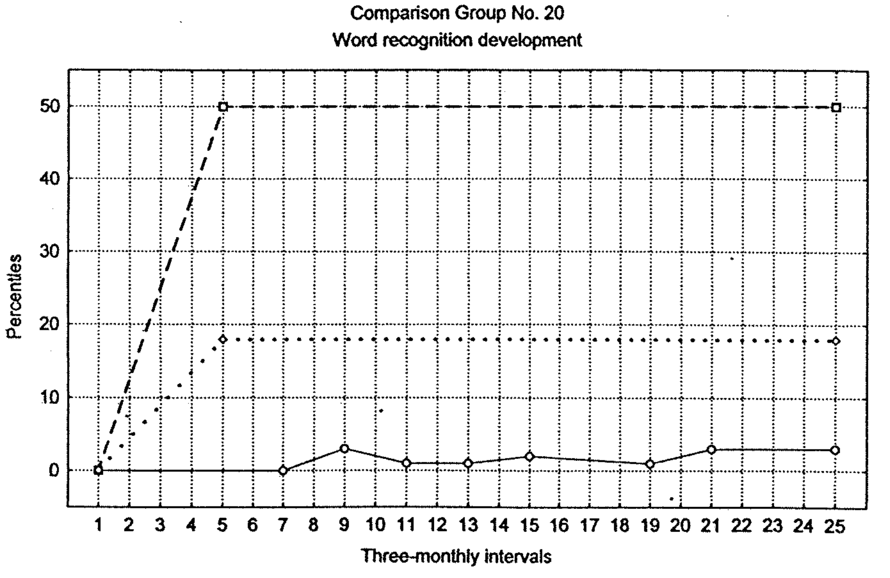


Comparison Group No. 17
Word recognition development




Comparison Group No. 18
Word recognition development
Percentiles
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
Three-monthly intervals


Comparison Group No. 19
Word recognition development
Percentiles
50
40
30
20
10
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
Three-monthly intervals


Comparison Group No. 20
Word recognition development
Percentiles
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Three-monthly intervals

APPENDIX F

Experimental Group Raw Data Plots

Key:

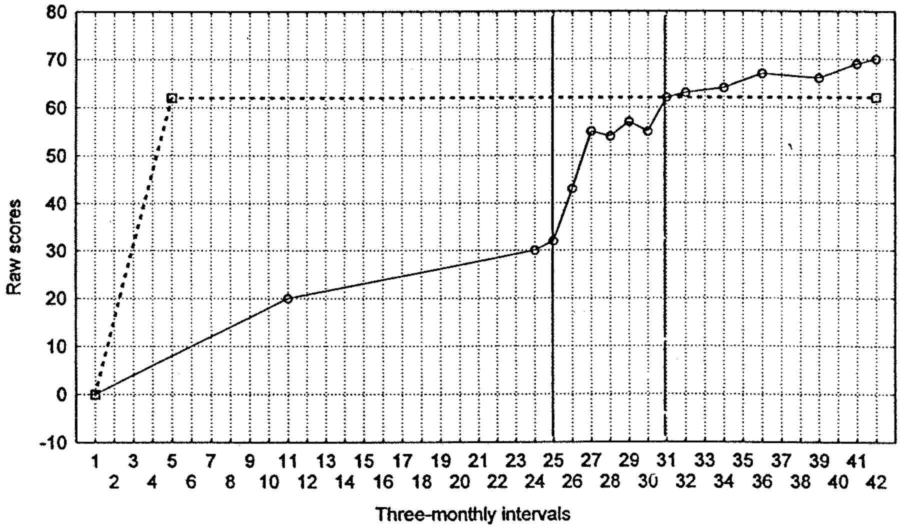
50th percentile

word recognition performance

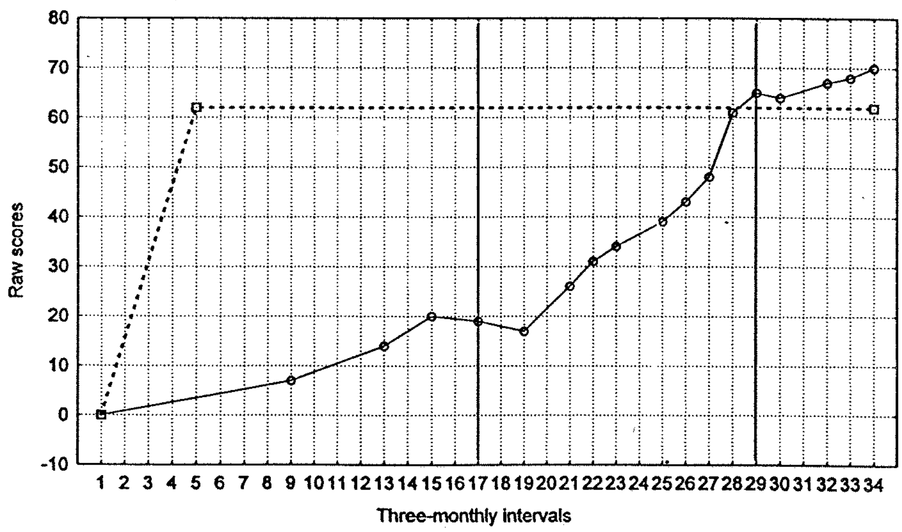
commencement of braille-based input

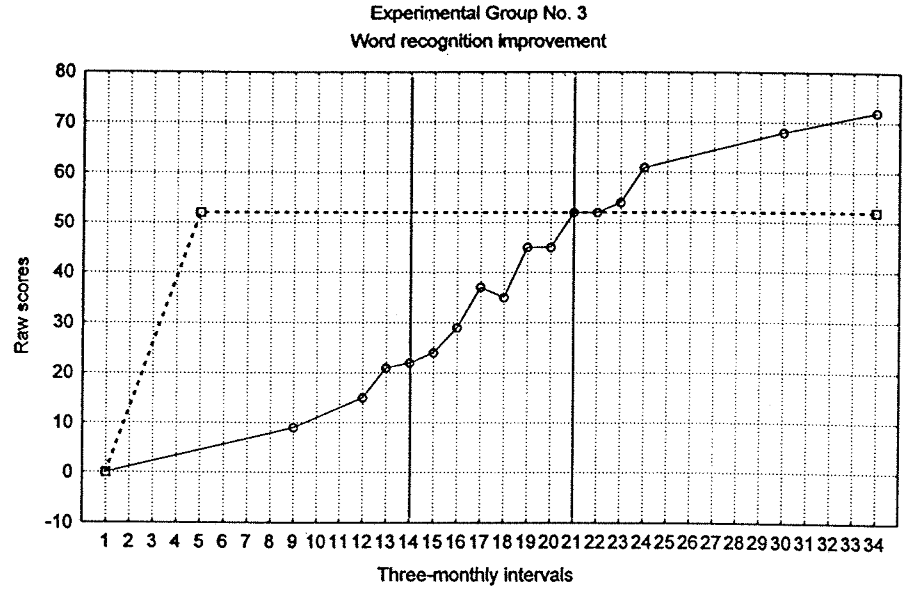
cessation of braille-based input

Experimental Group No. 1
Word recognition improvement

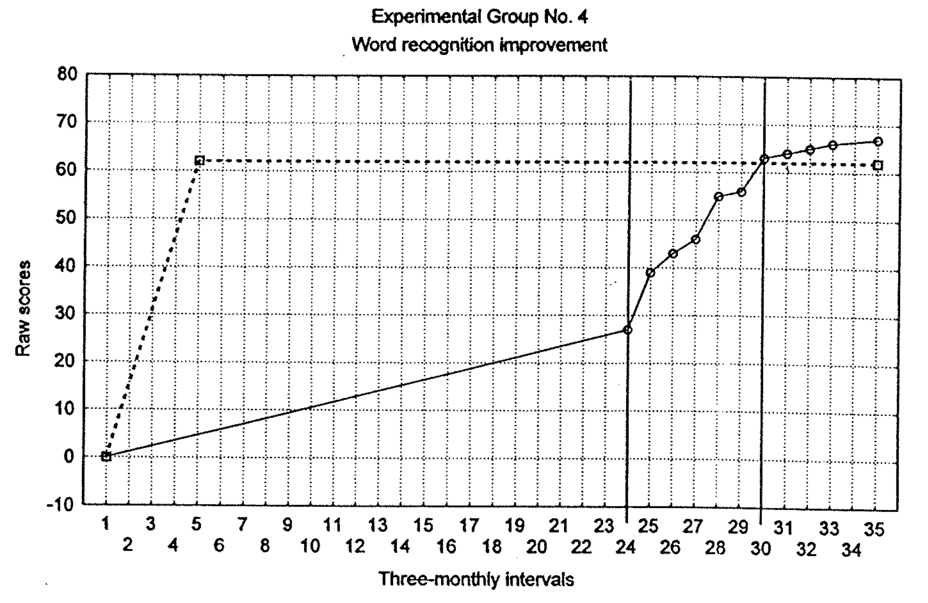


Experimental Group No. 2
Word recognition improvement

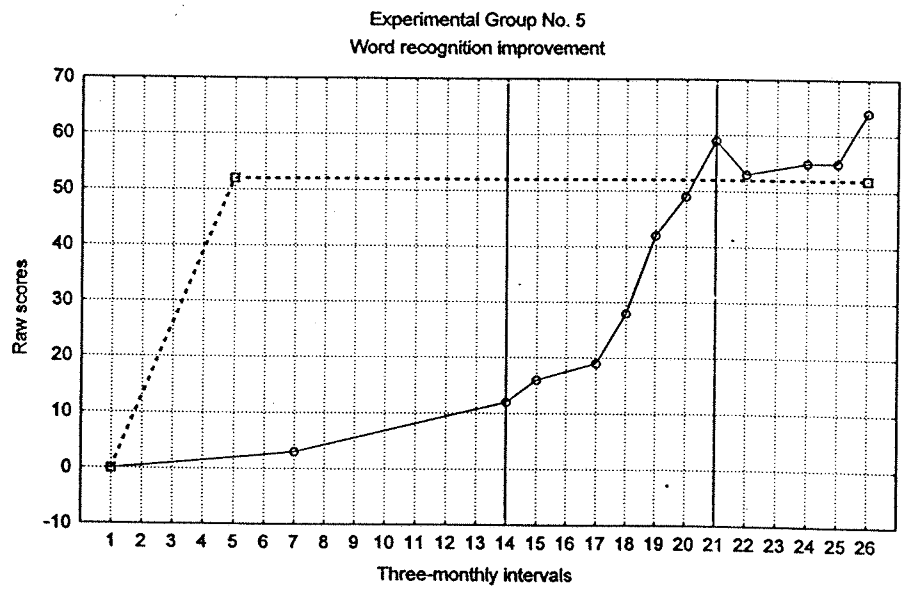




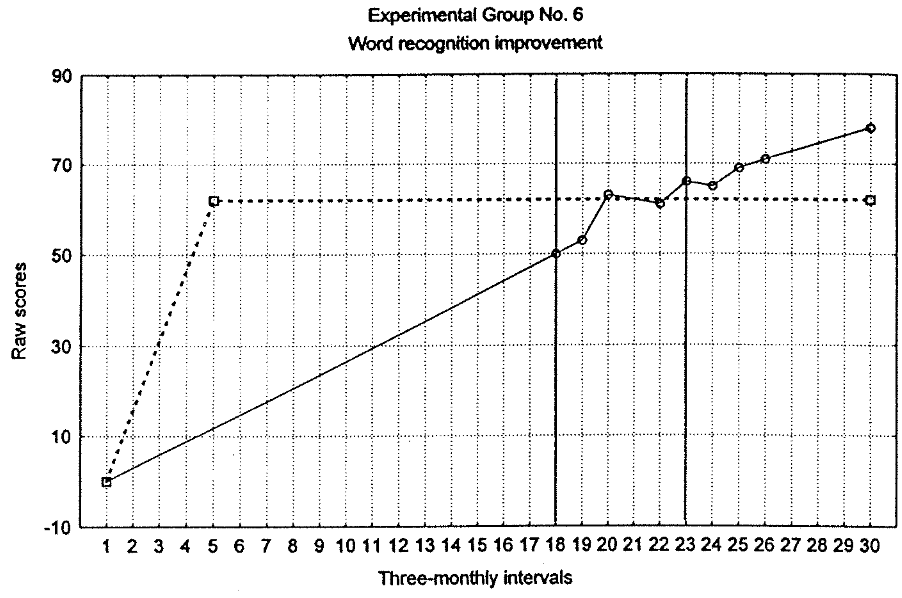
Experimental Group No. 3
Word recognition improvement
Raw scores
Three-monthly intervals

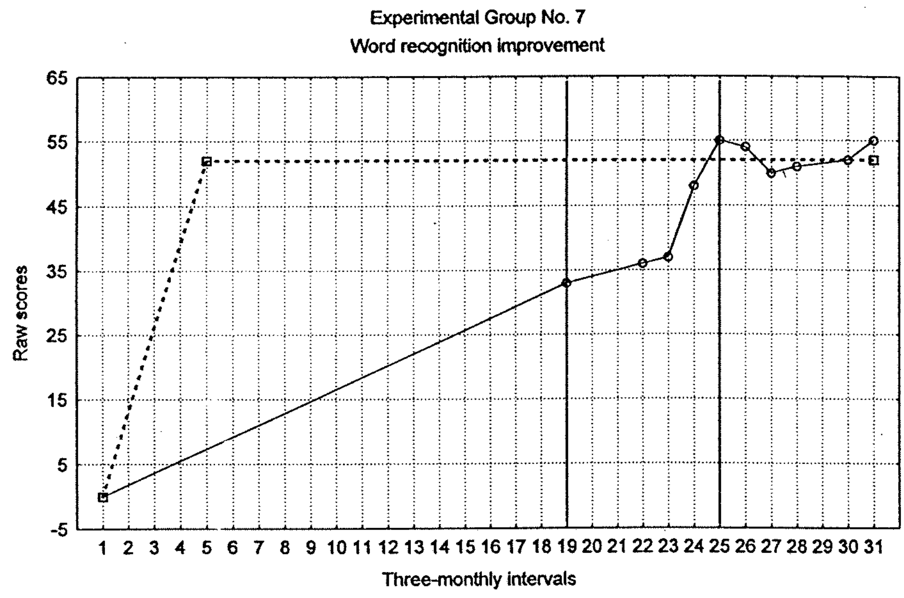


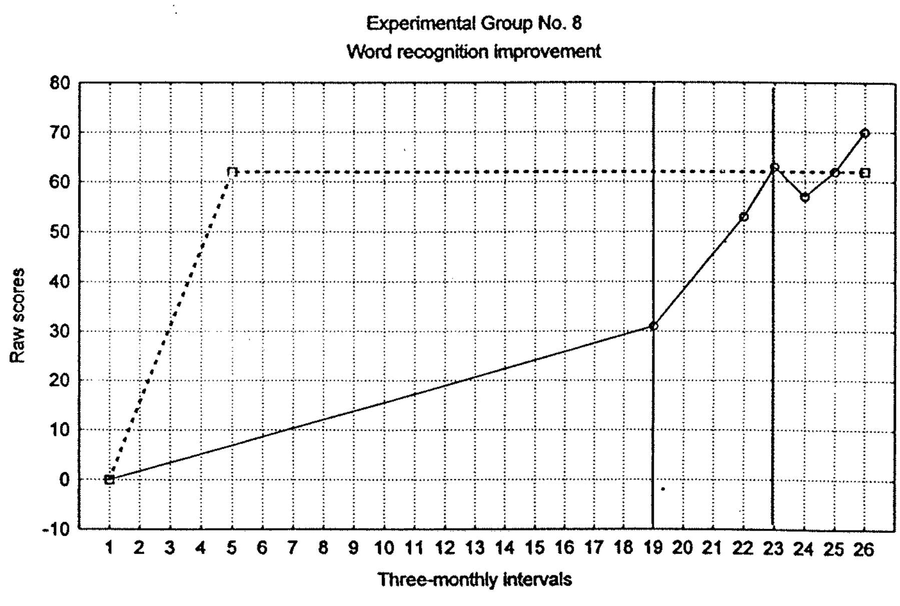
Experimental Group No. 4
Word recognition improvement
Raw scores
Three-monthly intervals

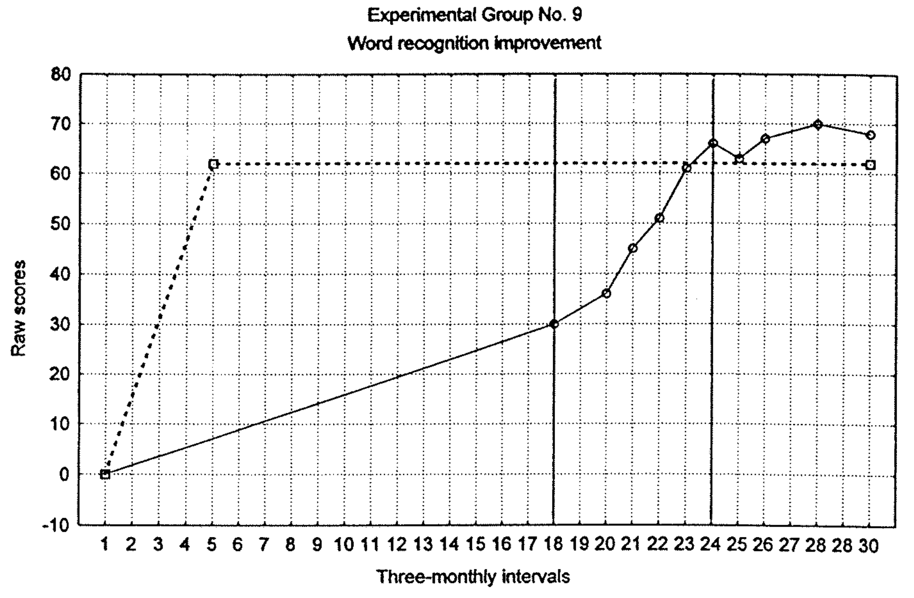


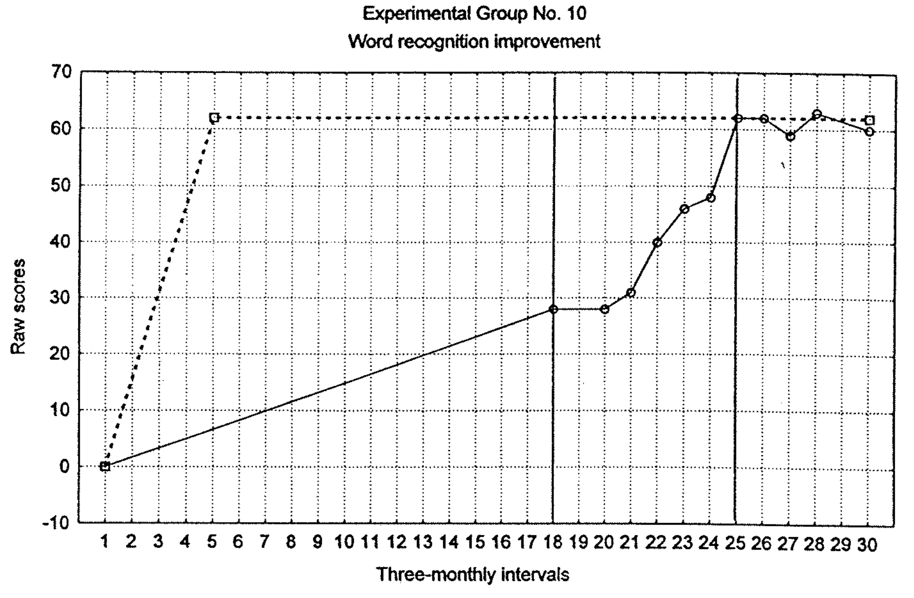
Experimental Group No. 5
Word recognition improvement
Raw scores
Three-monthly intervals

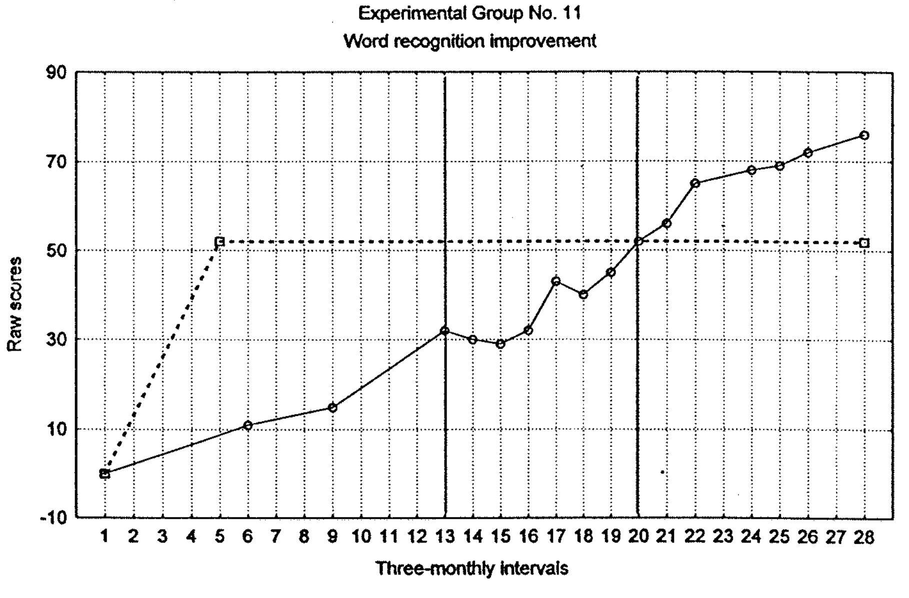

Experimental Group No. 6
Word recognition improvement
Raw scores
Three-monthly intervals

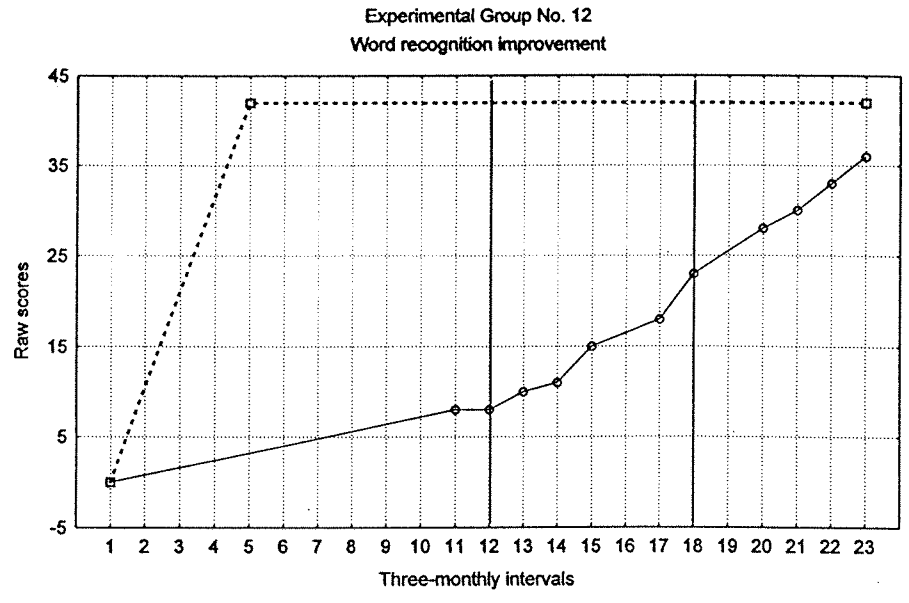

Experimental Group No. 7
Word recognition improvement
Raw scores
Three-monthly intervals

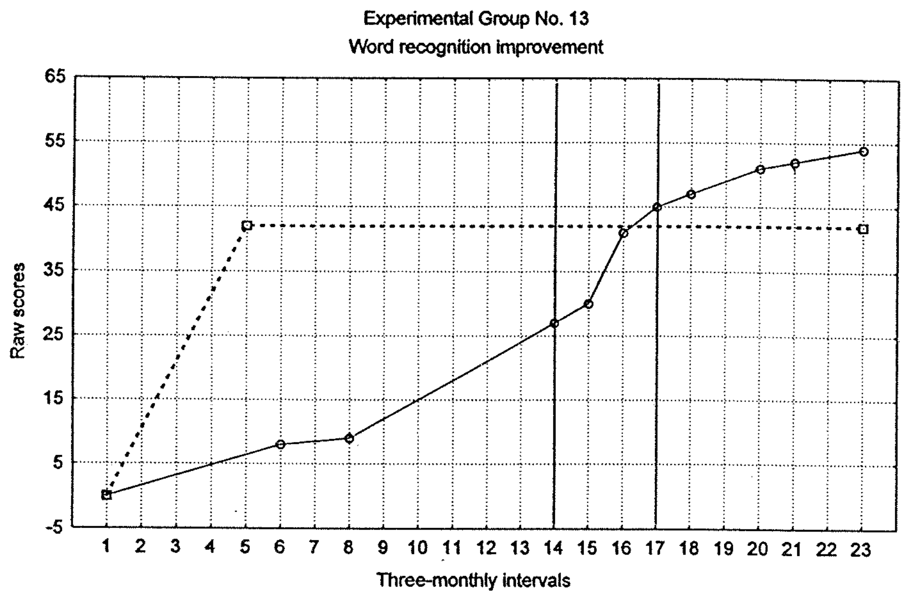

Experimental Group No. 8
Word recognition improvement
Raw scores
Three-monthly intervals

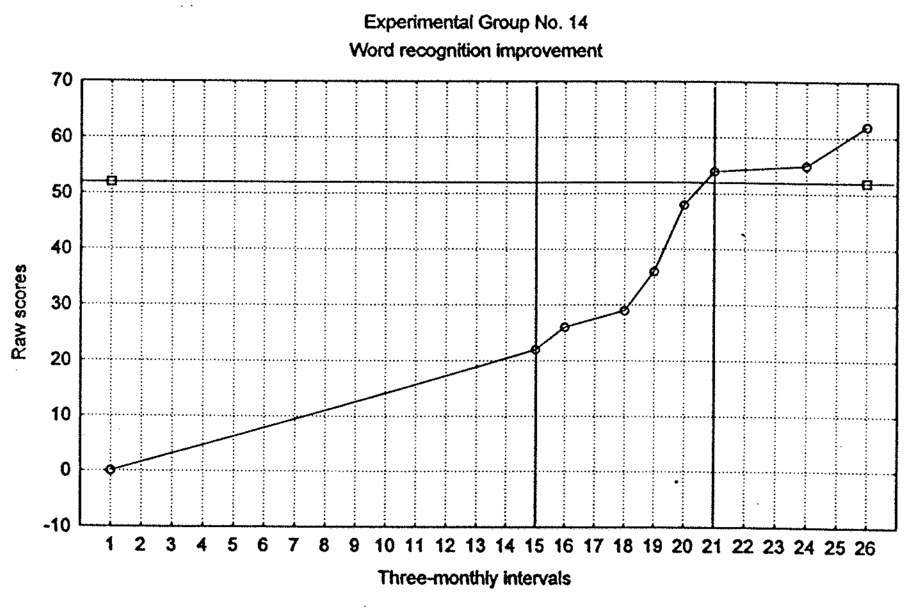

Experimental Group No. 9
Word recognition improvement
Raw scores
Three-monthly intervals

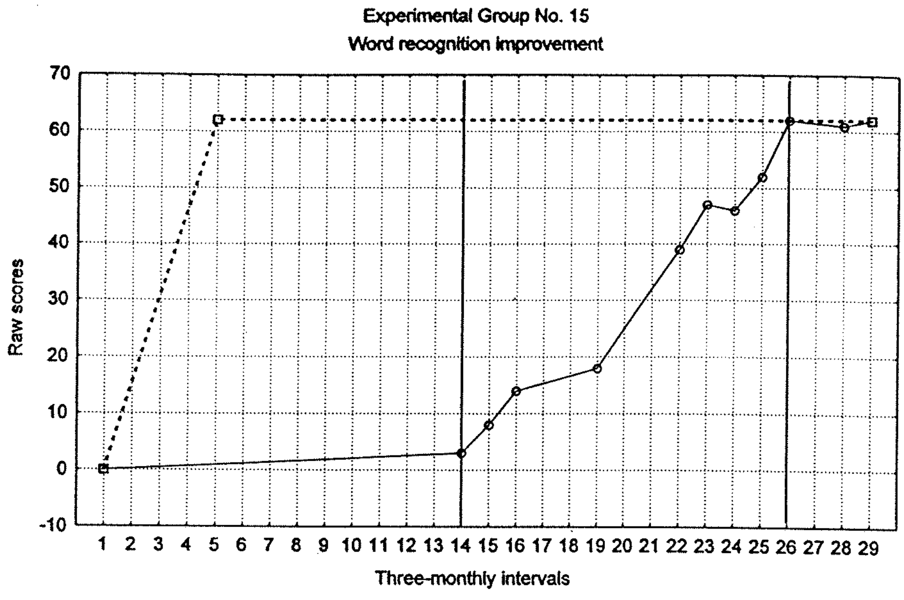

Experimental Group No. 10
Word recognition improvement
Raw scores
Three-monthly intervals

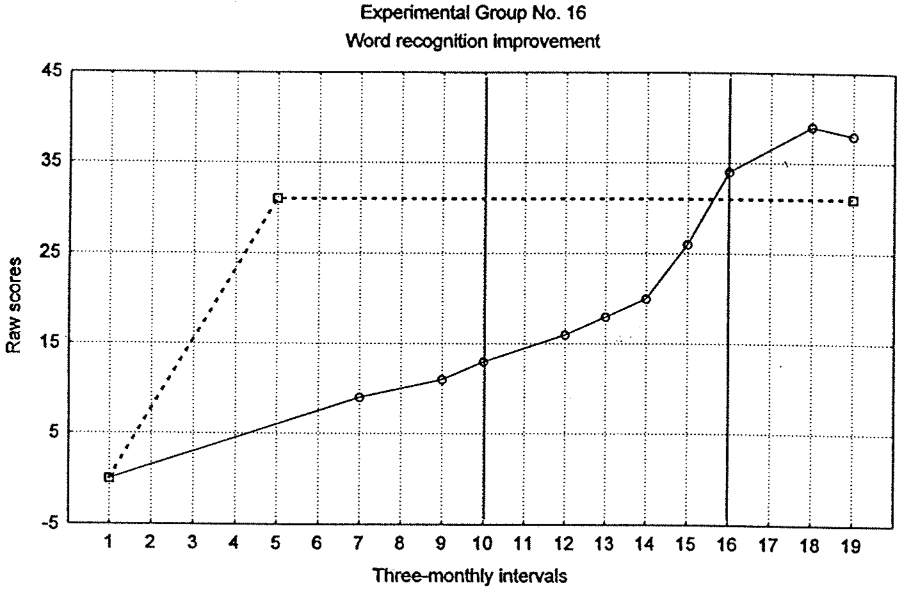

Experimental Group No. 11
Word recognition improvement
Raw scores
Three-monthly intervals

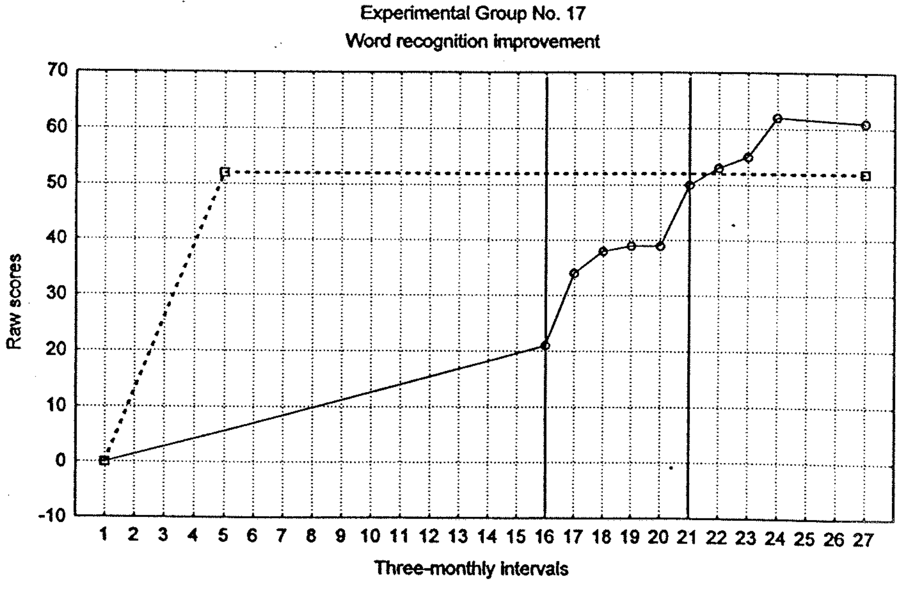

Experimental Group No. 12
Word recognition improvement
Raw scores
45
35
25
15
5
-5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Three-monthly intervals

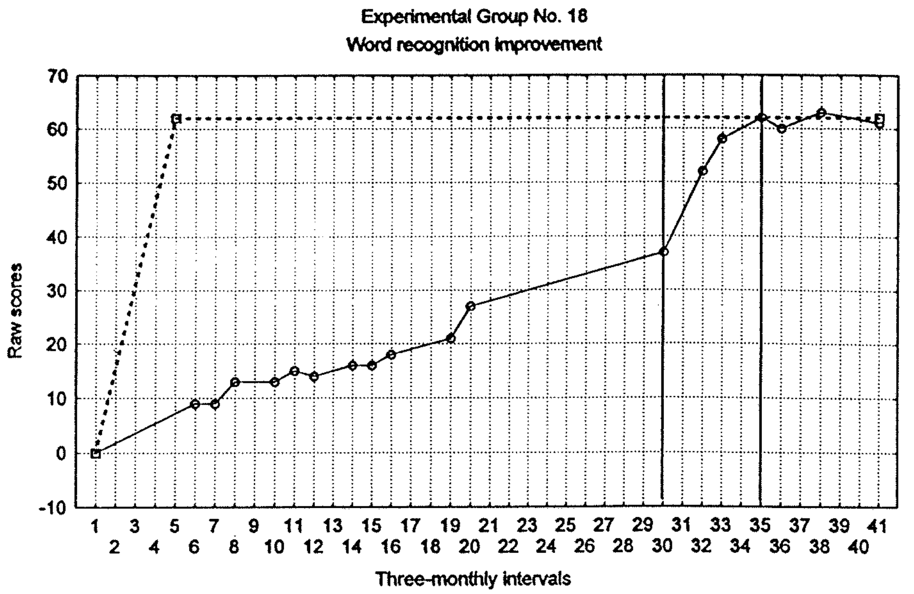

Experimental Group No. 13
Word recognition improvement
Raw scores
65
55
45
35
25
15
5
-5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Three-monthly intervals

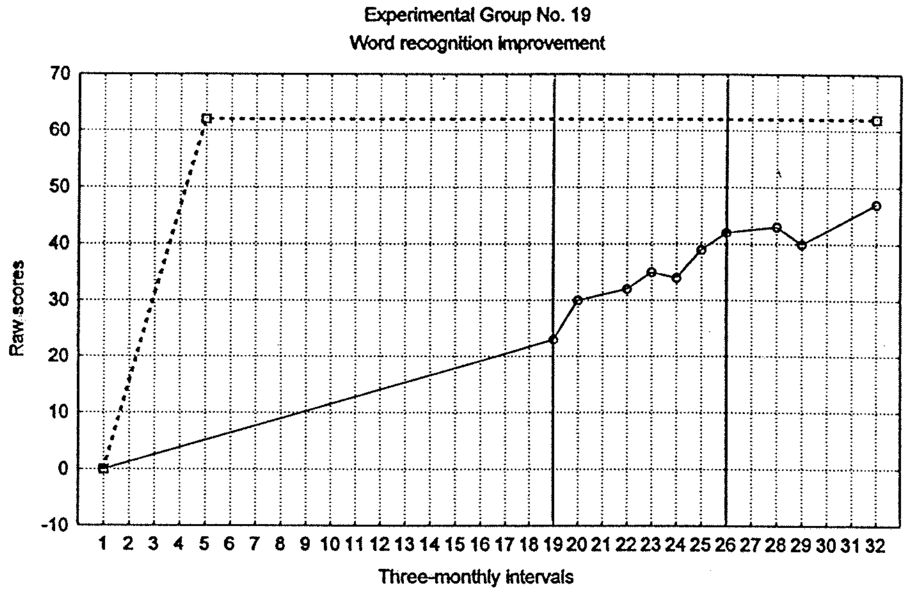

Experimental Group No. 14
Word recognition improvement
Raw scores
70
60
50
40
30
20
10
0
-10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
Three-monthly intervals

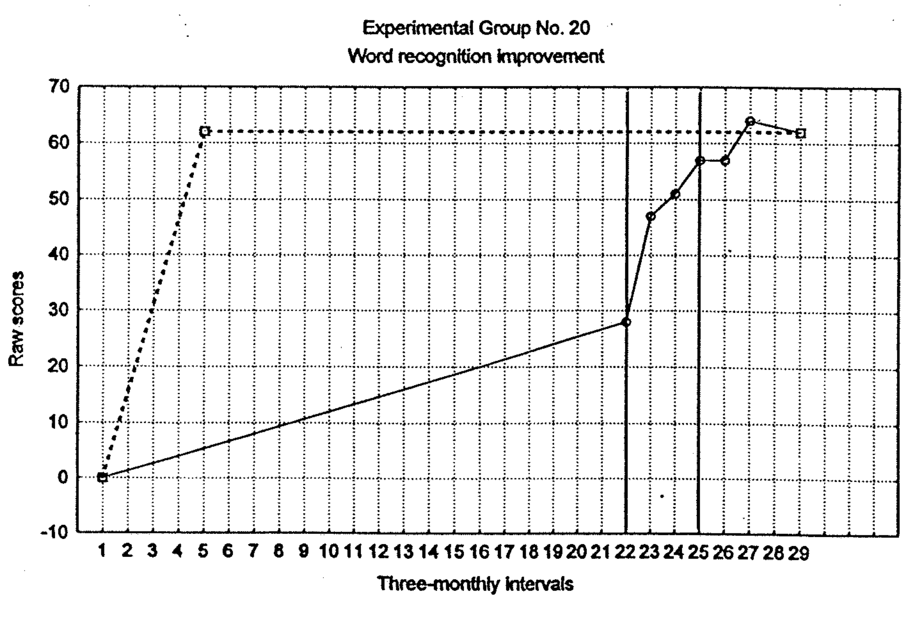

Experimental Group No. 15
Word recognition improvement
Raw scores
70
60
50
40
30
20
10
0
-10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
Three-monthly intervals


Experimental Group No. 16
Word recognition improvement
Raw scores
45
35
25
15
5
-5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Three-monthly intervals


Experimental Group No. 17
Word recognition improvement
Raw scores
70
60
50
40
30
20
10
0
-10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
Three-monthly intervals

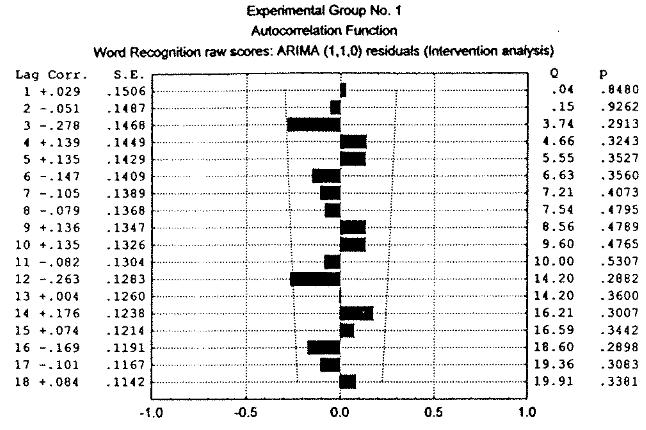

Experimental Group No. 18
Word recognition improvement
Raw scores
70
60
50
40
30
20
10
0
-10
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Three-monthly intervals


Experimental Group No. 19
Word recognition improvement
Raw scores
70
60
50
40
30
20
10
0
-10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Three-monthly intervals

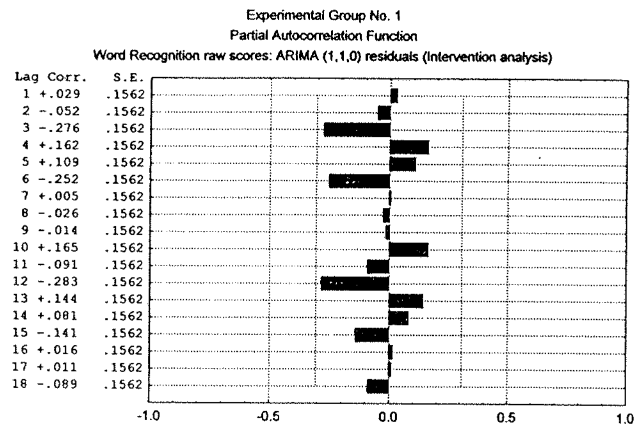

Experimental Group No. 20
Word recognition improvement
Raw scores
70
60
50
40
30
20
10
0
-10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
Three-monthly intervals

APPENDIX G

Diagnostic Criteria for Interrupted Time Series Analysis

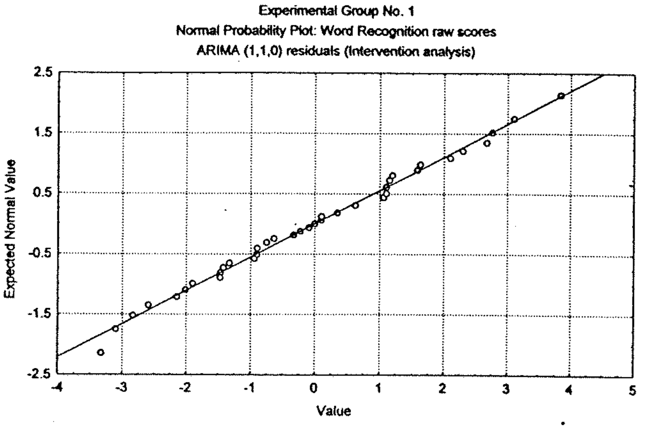


Lag	Corr.	S.E.	Q	p
1	+.029	.1506	.04	.8480
2	-.051	.1487	.15	.9262
3	-.278	.1468	3.74	.2913
4	+.139	.1449	4.66	.3243
5	+.135	.1429	5.55	.3527
6	-.147	.1409	6.63	.3560
7	-.105	.1389	7.21	.4073
8	-.079	.1368	7.54	.4795
9	+.136	.1347	8.56	.4789
10	+.135	.1326	9.60	.4765
11	-.082	.1304	10.00	.5307
12	-.263	.1283	14.20	.2882
13	+.004	.1260	14.20	.3600
14	+.176	.1238	16.21	.3007
15	+.074	.1214	16.59	.3442
16	-.169	.1191	18.60	.2898
17	-.101	.1167	19.36	.3083
18	+.084	.1142	19.91	.3381



Lag	Corr.	S.E.
1	+.029	.1562
2	-.052	.1562
3	-.276	.1562
4	+.162	.1562
5	+.109	.1562
6	-.252	.1562
7	+.005	.1562
8	-.026	.1562
9	-.014	.1562
10	+.165	.1562
11	-.091	.1562
12	-.283	.1562
13	+.144	.1562
14	+.081	.1562
15	-.141	.1562
16	+.016	.1562
17	+.011	.1562
18	-.089	.1562

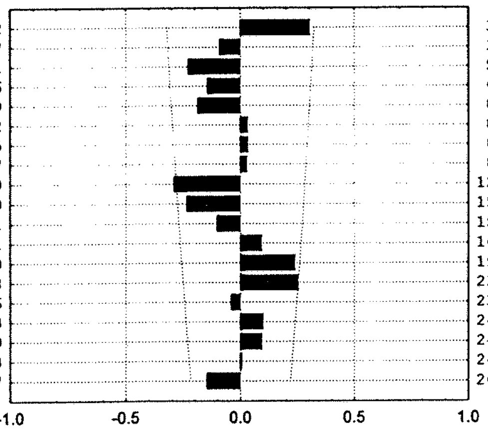
No serial dependency. Residuals follow a white noise process.



Shapiro-Wilks' W test = .9862; p < .9101. Normally distributed residuals.

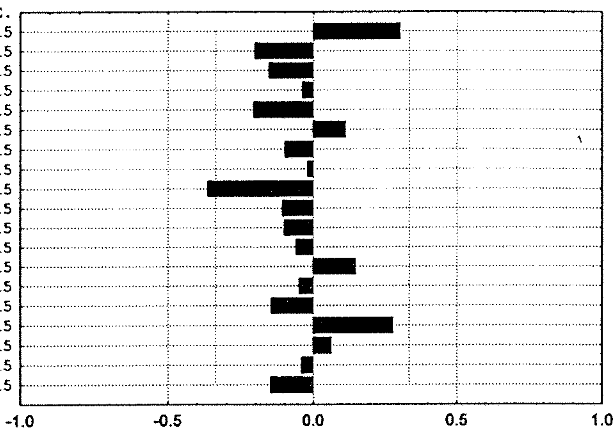
Experimental Group No. 2
Autocorrelation Function
Word recognition raw scores: ARIMA (1,0,0) residuals (Intervention analysis)

Lag	Corr.	S.E.	Q	p
1	+.304	.1642	3.43	.0639
2	-.090	.1617	3.74	.1540
3	-.227	.1591	5.78	.1226
4	-.142	.1566	6.61	.1582
5	-.186	.1539	8.06	.1528
6	+.032	.1512	8.11	.2302
7	+.033	.1485	8.16	.3189
8	+.028	.1457	8.20	.4146
9	-.290	.1429	12.31	.1965
10	-.234	.1400	15.11	.1282
11	-.102	.1371	15.66	.1543
12	+.092	.1341	16.13	.1853
13	+.238	.1310	19.44	.1100
14	+.253	.1278	23.35	.0549
15	-.040	.1246	23.45	.0750
16	+.099	.1213	24.11	.0871
17	+.094	.1179	24.74	.1007
18	+.005	.1143	24.75	.1322
19	-.145	.1107	26.47	.1178



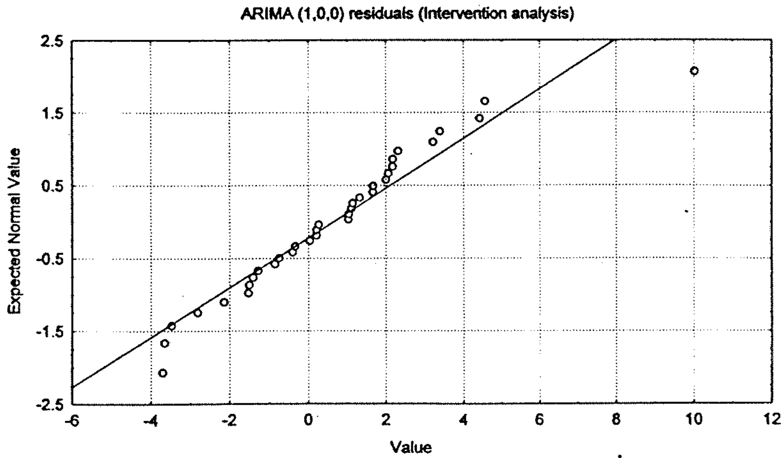
Experimental Group No. 2
Partial Autocorrelation Function
Word recognition raw scores: ARIMA (1,0,0) residuals (Intervention analysis)

Lag	Corr.	S.E.
1	+.304	.1715
2	-.201	.1715
3	-.153	.1715
4	-.038	.1715
5	-.205	.1715
6	+.114	.1715
7	-.098	.1715
8	-.019	.1715
9	-.363	.1715
10	-.106	.1715
11	-.100	.1715
12	-.059	.1715
13	+.150	.1715
14	-.049	.1715
15	-.145	.1715
16	+.280	.1715
17	+.064	.1715
18	-.040	.1715
19	-.148	.1715



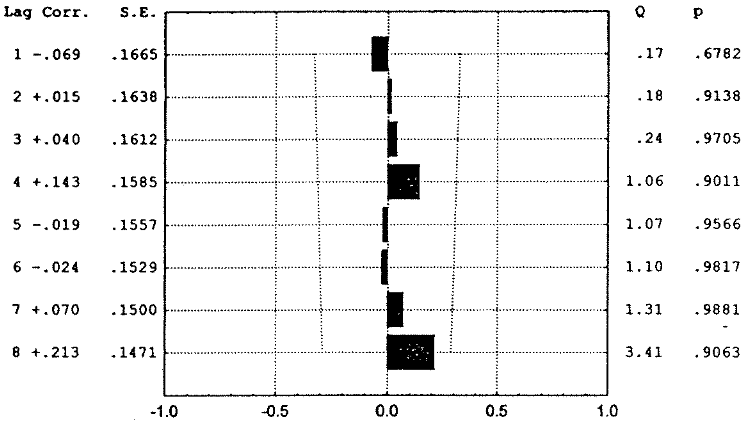
No serial dependency. Residuals follow a white noise process.

Experimental Group No. 2
Normal Probability Plot: Word Recognition raw scores
ARIMA (1,0,0) residuals (Intervention analysis)

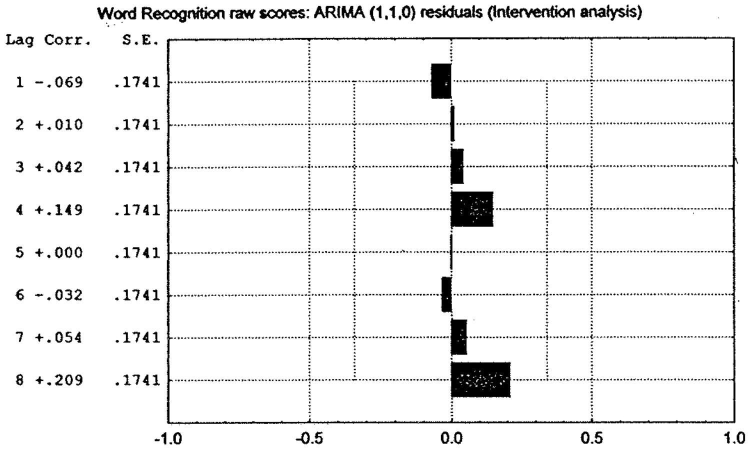


Shapiro-Wilks' W test = .9305; p <.0324 . Residuals not normally distributed.

Experimental Group No. 3
Autocorrelation Function
Word Recognition raw scores: ARIMA (1,1,0) residuals (Intervention analysis)

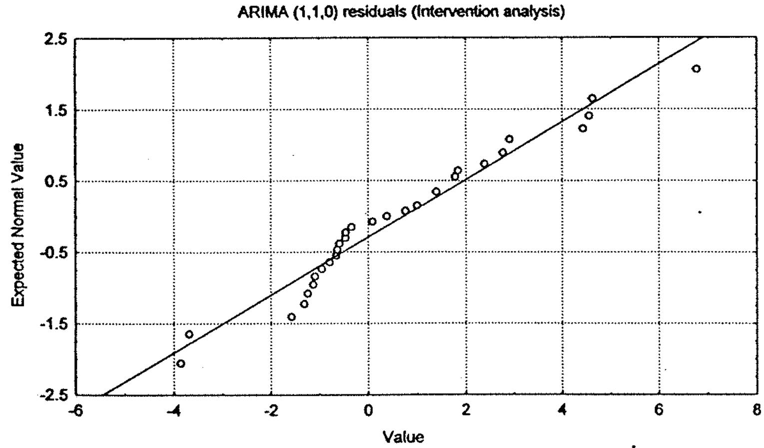


Experimental Group No. 3
Partial Autocorrelation Function
Word Recognition raw scores: ARIMA (1,1,0) residuals (Intervention analysis)



No serial dependency. Residuals follow a white noise process.

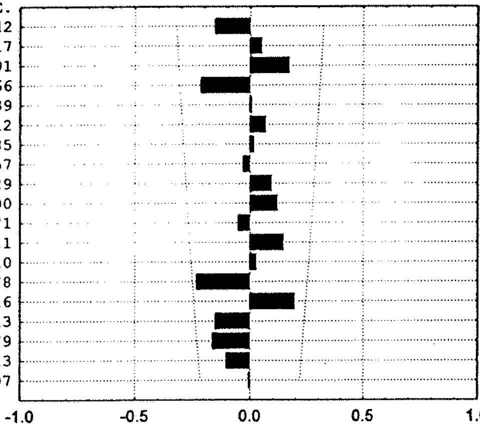
Experimental Group No. 3
Normal Probability Plot: Word Recognition raw scores
ARIMA (1,1,0) residuals (Intervention analysis)



Shapiro-Wilks' W test = .9615; p < .2853. Normally distributed residuals.

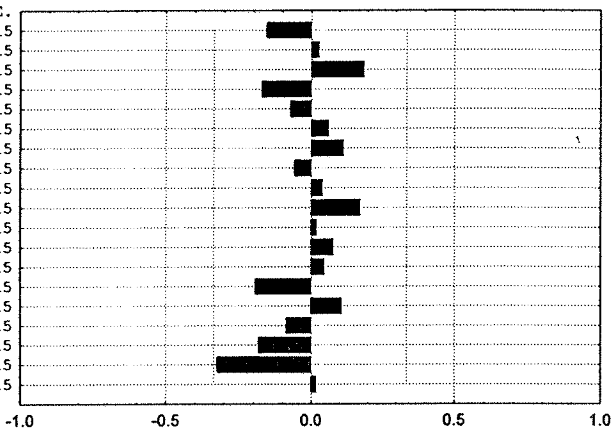
Experimental Group No. 4
Autocorrelation Function
Word Recognition raw scores: ARIMA (1,1,0) residuals (Intervention analysis)

Lag	Corr.	S.E.	Q	p
1	-.154	.1642	.88	.3484
2	+.051	.1617	.98	.6132
3	+.171	.1591	2.13	.5460
4	-.214	.1566	3.99	.4073
5	+.006	.1539	3.99	.5505
6	+.069	.1512	4.20	.6496
7	+.017	.1485	4.21	.7548
8	-.030	.1457	4.26	.8334
9	+.095	.1429	4.69	.8602
10	+.120	.1400	5.43	.8610
11	-.052	.1371	5.57	.9006
12	+.148	.1341	6.78	.8718
13	+.028	.1310	6.83	.9108
14	-.233	.1278	10.15	.7513
15	+.196	.1246	12.63	.6310
16	-.152	.1213	14.19	.5846
17	-.163	.1179	16.11	.5159
18	-.103	.1143	16.92	.5283
19	-.005	.1107	16.93	.5948



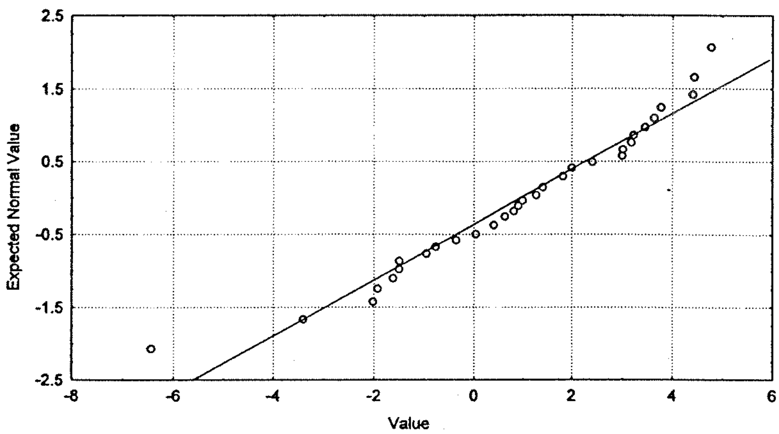
Experimental Group No. 4
Partial Autocorrelation Function
Word Recognition raw scores: ARIMA (1,1,0) residuals (Intervention analysis)

Lag	Corr.	S.E.
1	-.154	.1715
2	+.028	.1715
3	+.187	.1715
4	-.171	.1715
5	-.072	.1715
6	+.062	.1715
7	+.114	.1715
8	-.058	.1715
9	+.041	.1715
10	+.174	.1715
11	+.019	.1715
12	+.079	.1715
13	+.047	.1715
14	-.193	.1715
15	+.108	.1715
16	-.086	.1715
17	-.182	.1715
18	-.324	.1715
19	+.018	.1715

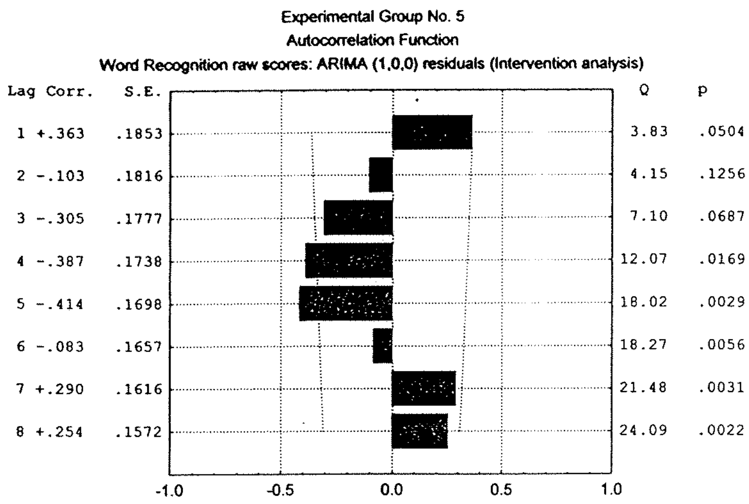


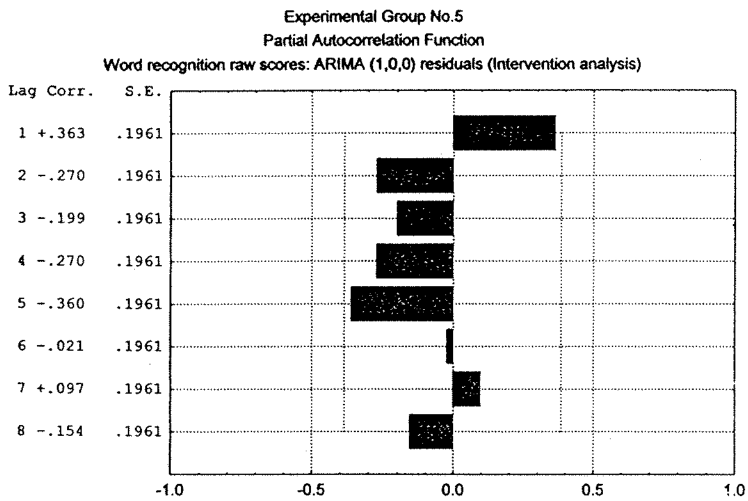
No serial dependency. Residuals follow a white noise process.

Experimental Group No. 4
Normal Propability Plot: Word Recognition raw scores
ARIMA (1,1,0) residuals (Intervention analysis)

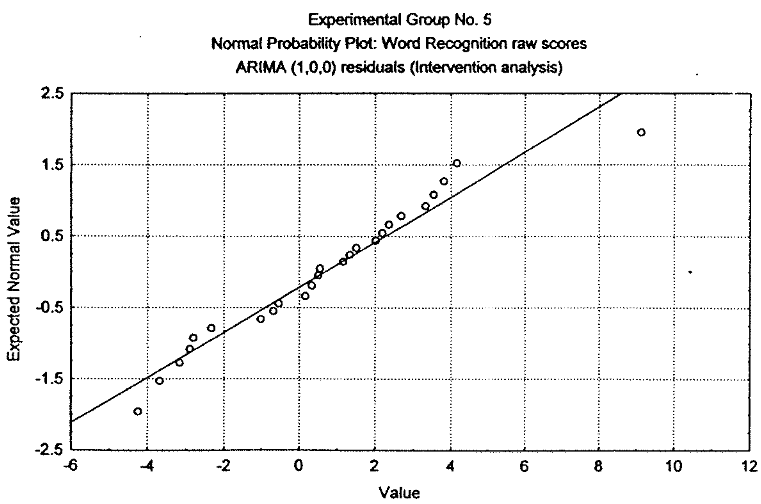


Shapiro-Wilks' W test = .9559; $p < .1844$. Normally distributed residuals.

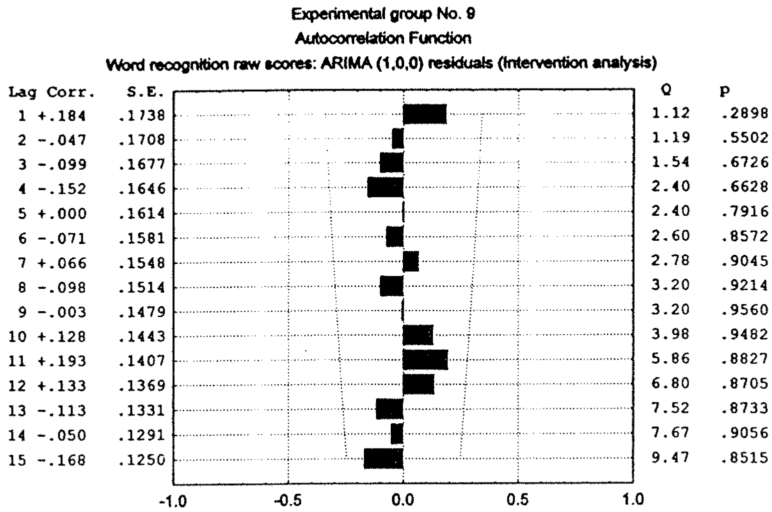


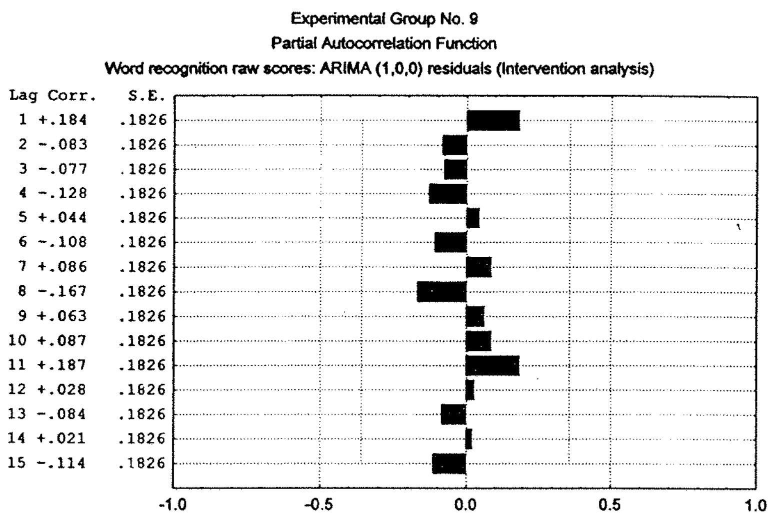


No serial dependency. Residuals follow a white noise process.

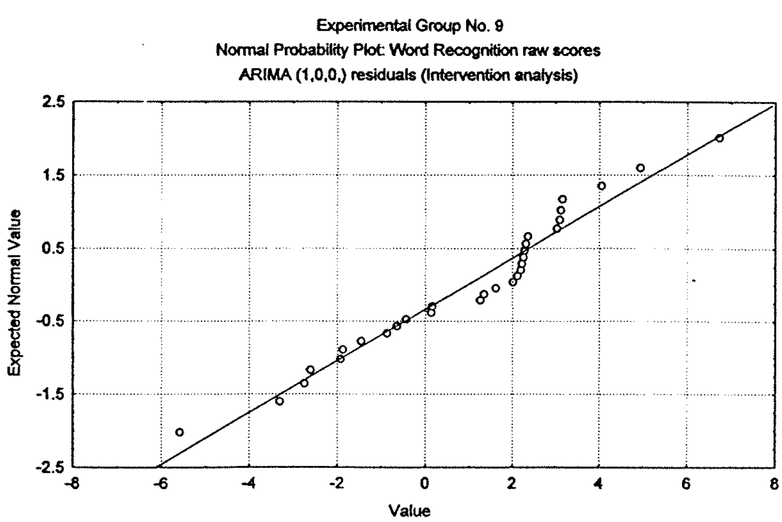


Shapiro-Wilks' W test = .9547; p < .2975. Normally distributed residuals.





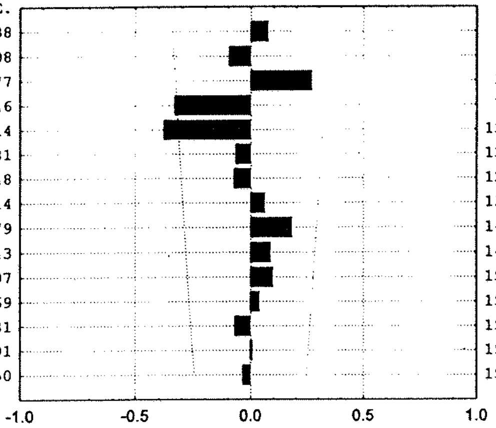
No serial dependency. Residuals follow a white noise process.



Shapiro-Wilks' W test = .9672; p < .4668. Normally distributed residuals.

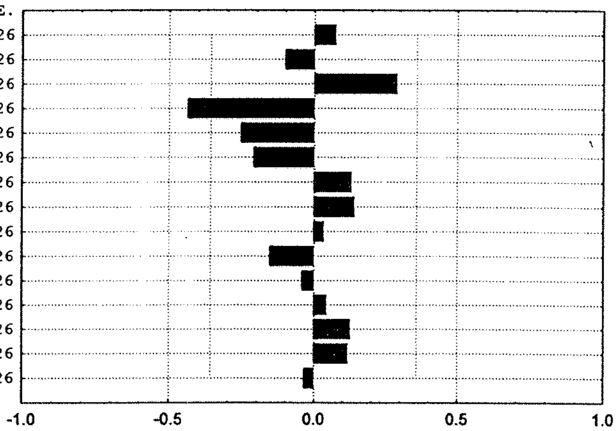
Experimental Group No. 10
Autocorrelation Function
Word Recognition raw scores: ARIMA (1,0,0) residuals (Intervention analysis)

Lag	Corr.	S.E.	Q	p
1	+.075	.1738	.18	.6671
2	-.094	.1708	.49	.7823
3	+.269	.1677	3.06	.3828
4	-.330	.1646	7.09	.1313
5	-.376	.1614	12.51	.0285
6	-.065	.1581	12.68	.0485
7	-.073	.1548	12.90	.0747
8	+.062	.1514	13.06	.1097
9	+.182	.1479	14.57	.1035
10	+.088	.1443	14.94	.1341
11	+.098	.1407	15.43	.1638
12	+.039	.1369	15.51	.2149
13	-.068	.1331	15.77	.2617
14	+.006	.1291	15.77	.3274
15	-.033	.1250	15.85	.3924



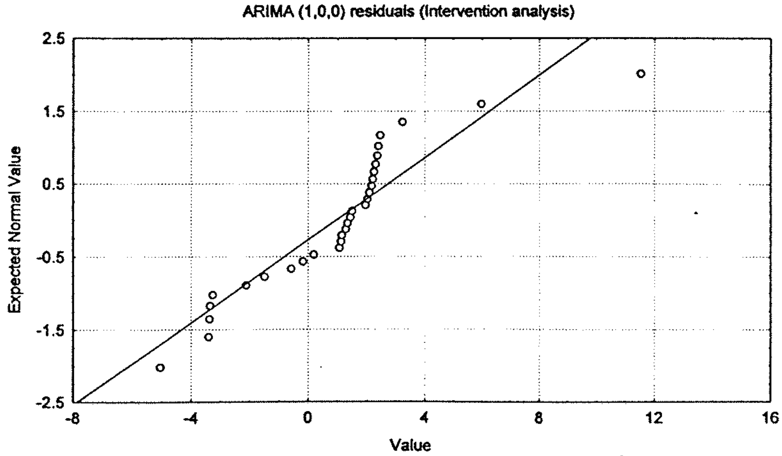
Experimental Group No. 10
Partial Autocorrelation Function
Word Recognition raw scores: ARIMA (1,0,0) residuals (Intervention analysis)

Lag	Corr.	S.E.
1	+.075	.1826
2	-.101	.1826
3	+.289	.1826
4	-.436	.1826
5	-.253	.1826
6	-.210	.1826
7	+.130	.1826
8	+.140	.1826
9	+.034	.1826
10	-.153	.1826
11	-.041	.1826
12	+.045	.1826
13	+.127	.1826
14	+.118	.1826
15	-.034	.1826



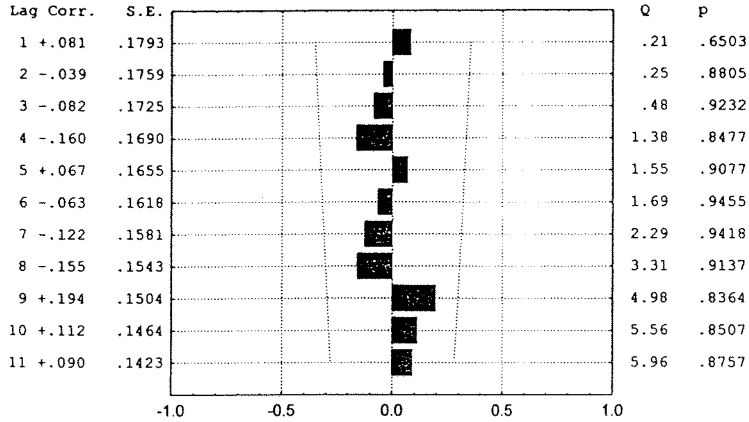
No serial dependency. Residuals follow a white noise process.

Experimental Group No. 10
Normal Probability Plot: Word Recognition raw scores
ARIMA (1,0,0) residuals (Intervention analysis)

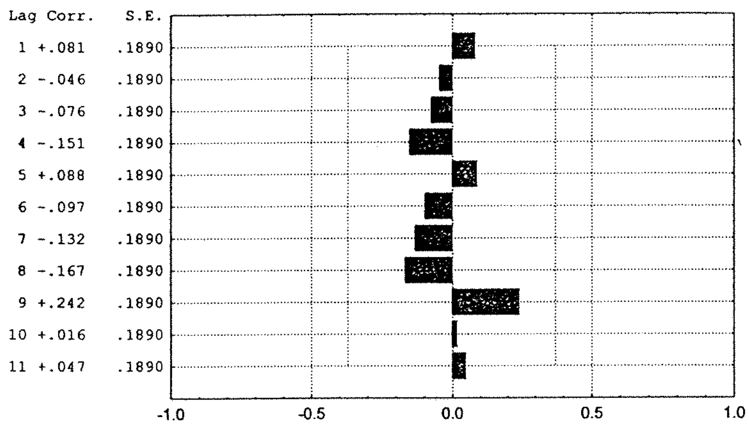


Shapiro-Wilks' W test = .8751; $p < .0022$. Residuals not normally distributed.

Experimental Group No. 11
Autocorrelation Function
Word Recognition raw scores: ARIMA (1,0,0) residuals (Intervention analysis)

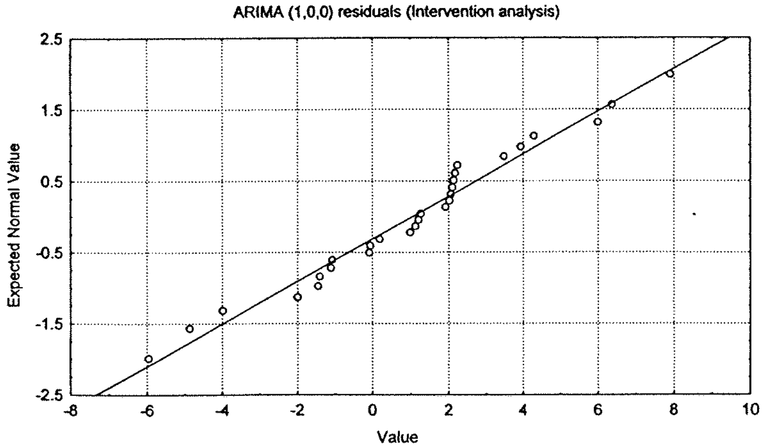


Experimental Group No. 11
Partial Autocorrelation Function
Word Recognition raw scores: ARIMA (1,0,0) residuals (Intervention analysis)

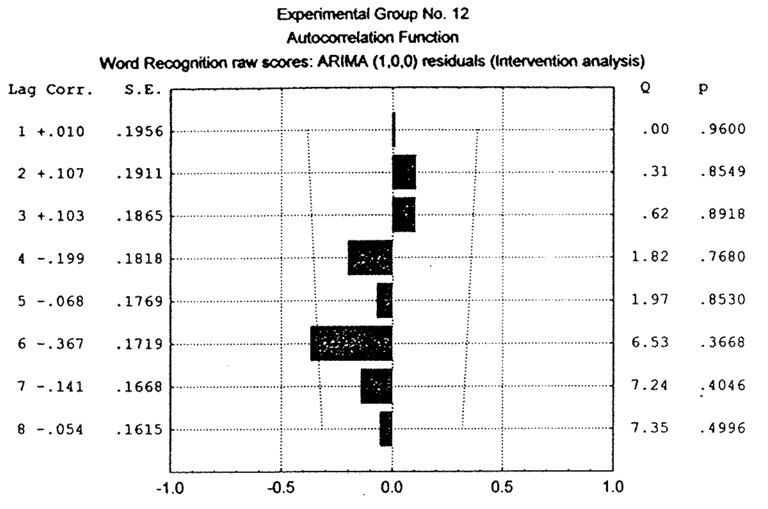


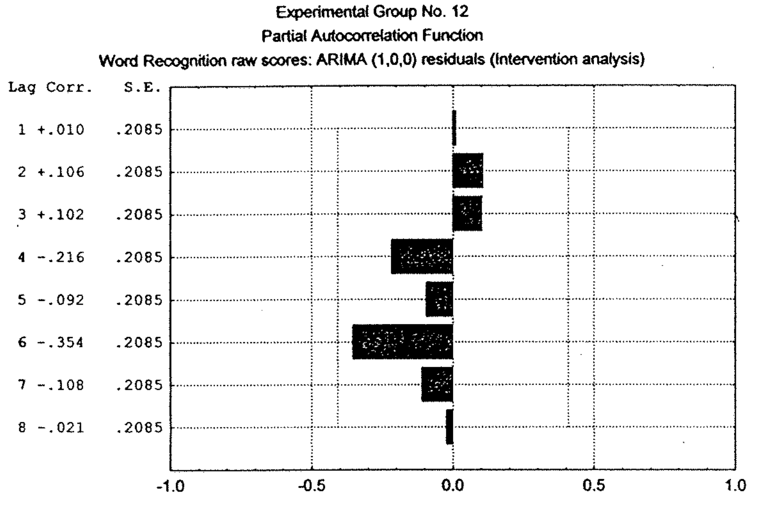
No serial dependency. Residuals follow a white noise process.

Experimental Group No. 11
Normal Probability Plot: Word Recognition raw scores
ARIMA (1,0,0) residuals (Intervention analysis)

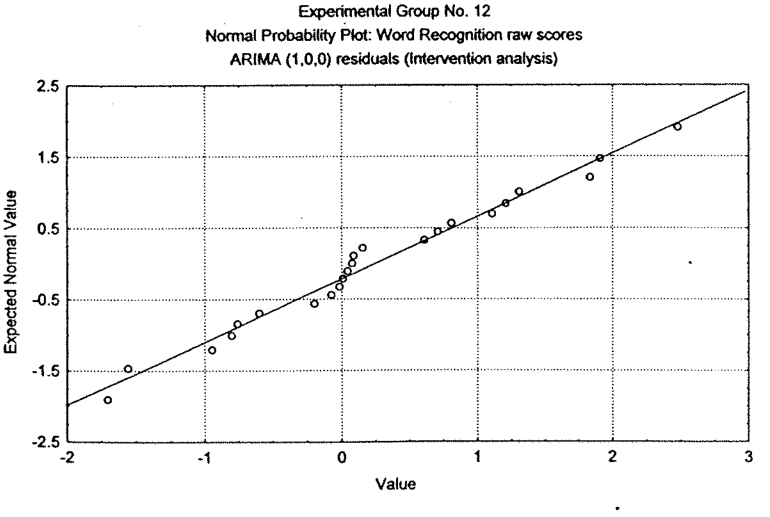


Shapiro-Wilks' W test = .9757; p < .7387. Normally distributed residuals.



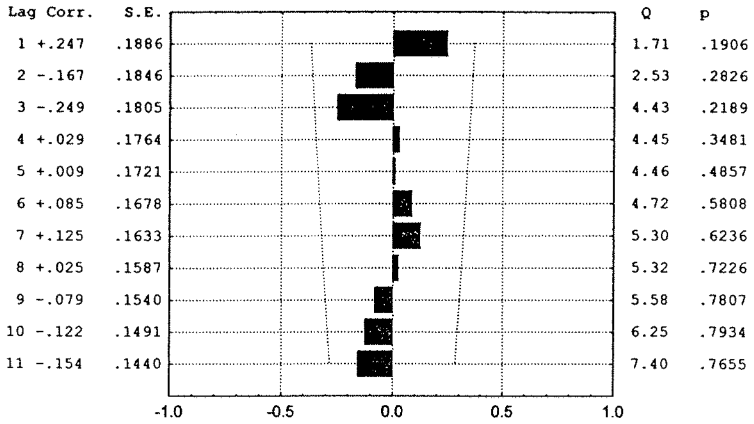


No serial dependency. Residuals follow a white noise process.

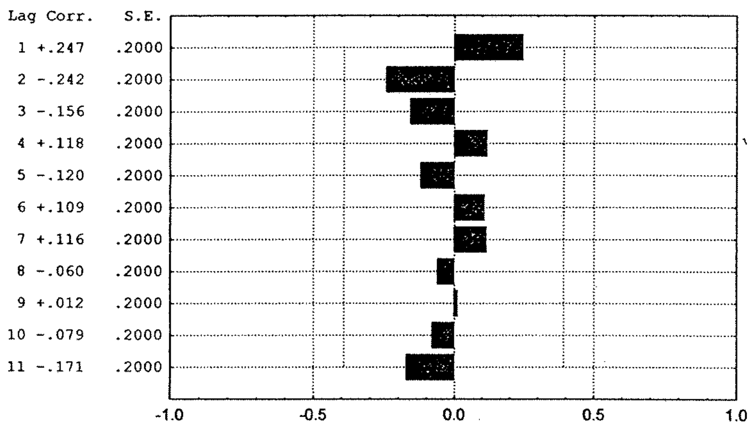


Shapiro-Wilks' W test = .9553; p < .8551. Normally distributed residuals.

Experimental Group No. 13
Autocorrelation Function
Word Recognition raw scores: ARIMA (1,0,0,) residuals (Intervention analysis)

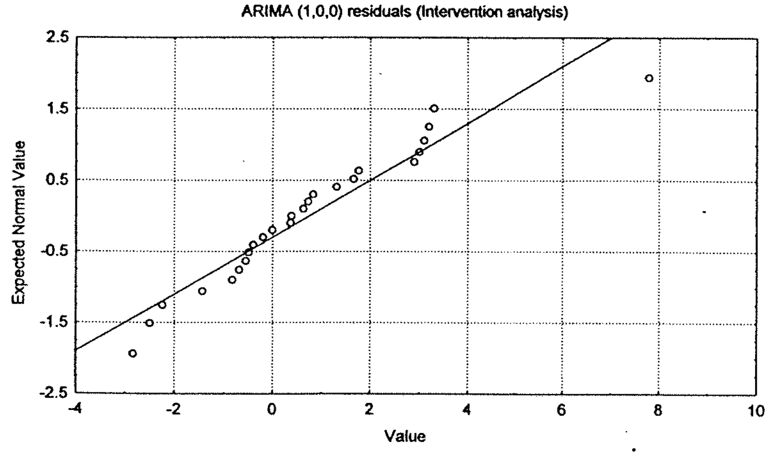


Experimental Group No. 13
Partial Autocorrelation Function
Word Recognition raw scores: ARIMA (1,0,0) residuals (Intervention analysis)



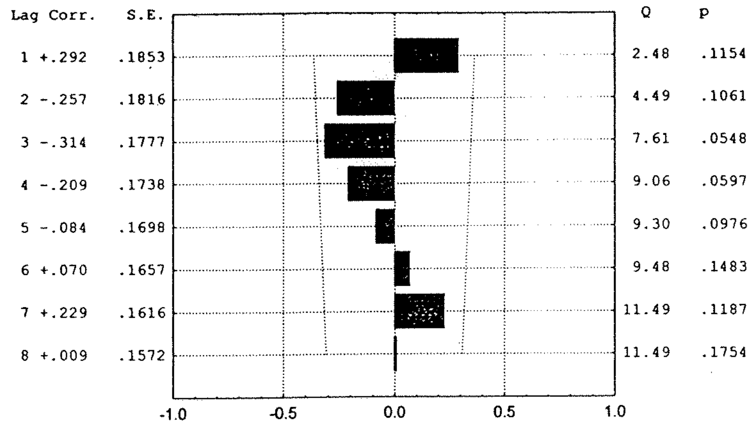
No serial dependency. Residuals follow a white noise process.

Experimental Group No. 13
Normal probability Plot: Word Recognition raw scores
ARIMA (1,0,0) residuals (Intervention analysis)

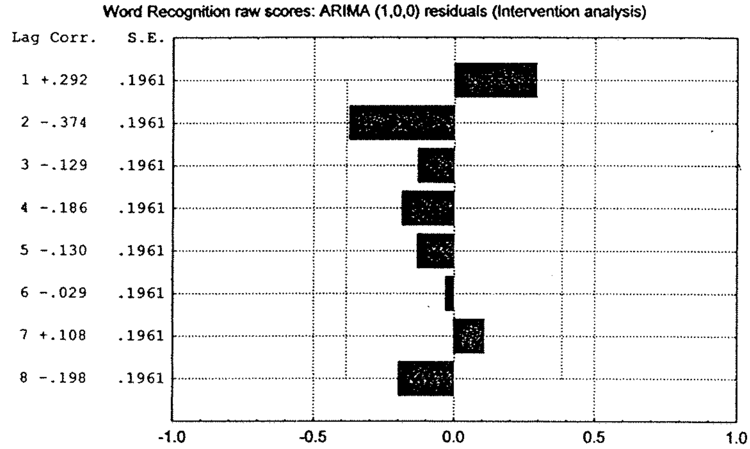


Shapiro-Wilks' W test = .9270; p < .0741. Normally distributed residuals.

Experimental Group No. 14
Autocorrelation Function
Word Recognition raw score: ARIMA (1,0,0) residuals (Intervention analysis)

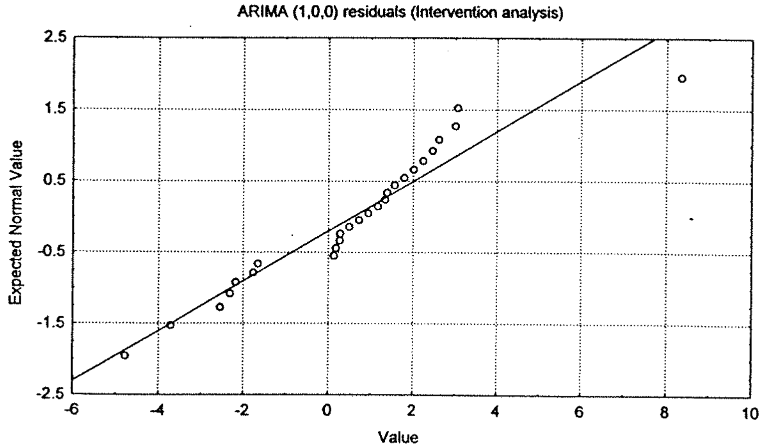


Experimental Group No. 14
Partial Autocorrelation Function
Word Recognition raw scores: ARIMA (1,0,0) residuals (Intervention analysis)



No serial dependency. Residuals follow a white noise process.

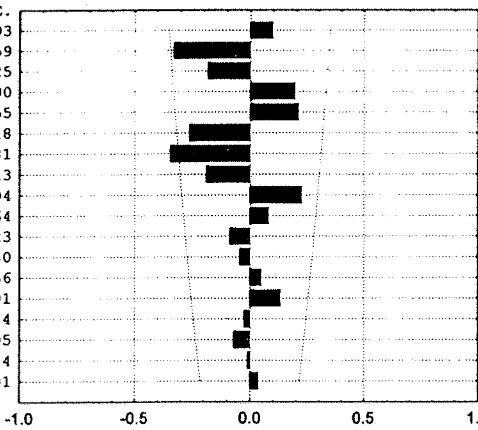
Experimental Group No. 14
Normal Probability Plot: Word Recognition raw scores
ARIMA (1,0,0) residuals (Intervention analysis)



Shapiro-Wilks' W test = .9338; p < .0956. Normally distributed residuals.

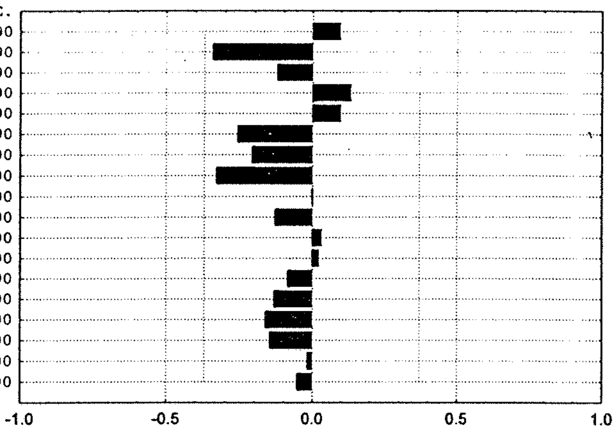
Experimental Group No. 15
Autocorrelation Function
Word Recognition raw scores: ARIMA (1,1,0) residuals (Intervention analysis)

Lag	Corr.	S.E.	Q	p
1	+.096	.1793	.29	.5930
2	-.329	.1759	3.79	.1506
3	-.182	.1725	4.90	.1795
4	+.195	.1690	6.23	.1828
5	+.212	.1655	7.86	.1640
6	-.261	.1618	10.45	.1068
7	-.344	.1581	15.18	.0338
8	-.189	.1543	16.67	.0338
9	+.226	.1504	18.92	.0259
10	+.081	.1464	19.22	.0376
11	-.087	.1423	19.59	.0513
12	-.043	.1380	19.69	.0732
13	+.049	.1336	19.83	.0997
14	+.133	.1291	20.89	.1046
15	-.024	.1244	20.93	.1392
16	-.069	.1195	21.27	.1686
17	-.009	.1144	21.27	.2145
18	+.037	.1091	21.39	.2605



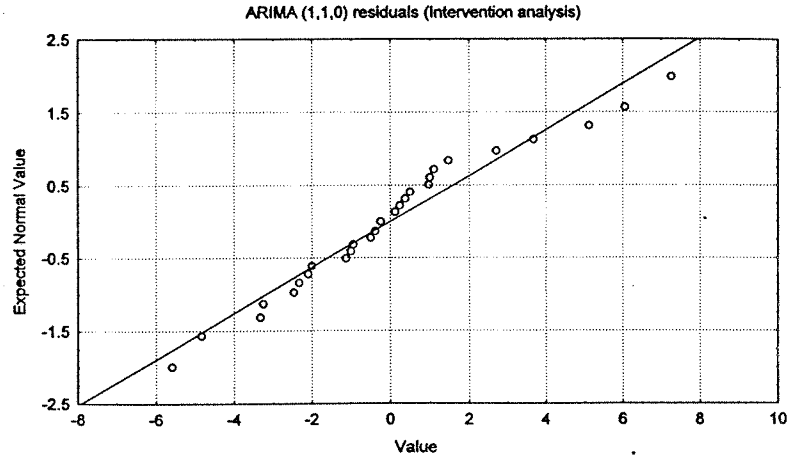
Experimental Group No. 15
Partial Autocorrelation Function
Word Recognition raw scores: ARIMA (1,1,0) residuals (Intervention analysis)

Lag	Corr.	S.E.
1	+.096	.1890
2	-.342	.1890
3	-.122	.1890
4	+.134	.1890
5	+.098	.1890
6	-.257	.1890
7	-.208	.1890
8	-.328	.1890
9	+.001	.1890
10	-.129	.1890
11	+.033	.1890
12	+.024	.1890
13	-.085	.1890
14	-.133	.1890
15	-.162	.1890
16	-.147	.1890
17	-.016	.1890
18	-.053	.1890



No serial dependency. Residuals follow a white noise process.

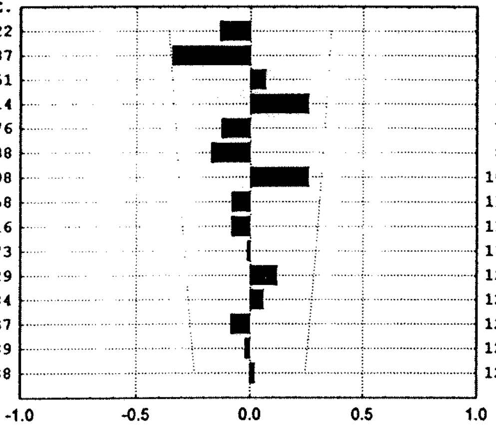
Experimental Group No. 15
Normal Probability Plot: Word Recognition raw scores
ARIMA (1,1,0) residuals (Intervention analysis)



Shapiro-Wilks' W test = .9349; $p < .0665$. Normally distributed residuals.

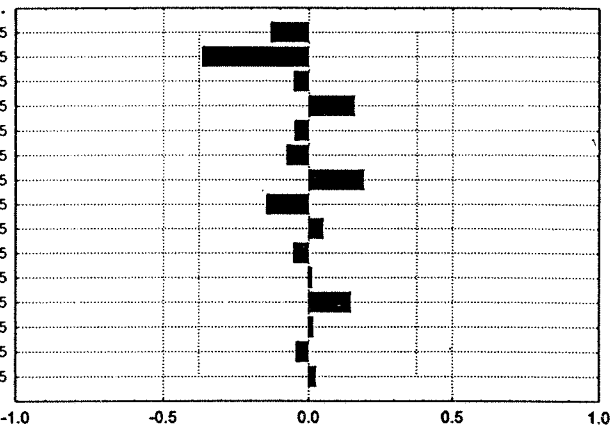
Experimental Group No. 17
Autocorrelation Function
Word recognition raw score: ARIMA (1,0,0) residuals (intervention analysis)

Lag	Corr.	S.E.	Q	p
1	-.131	.1822	.52	.4706
2	-.341	.1787	4.17	.1243
3	+.066	.1751	4.31	.2297
4	+.258	.1714	6.58	.1600
5	-.124	.1676	7.12	.2116
6	-.169	.1638	8.19	.2245
7	+.258	.1598	10.79	.1481
8	-.079	.1558	11.05	.1989
9	-.081	.1516	11.33	.2535
10	-.011	.1473	11.34	.3317
11	+.119	.1429	12.03	.3614
12	+.058	.1384	12.20	.4296
13	-.082	.1337	12.58	.4810
14	-.020	.1289	12.60	.5582
15	+.020	.1238	12.63	.6310



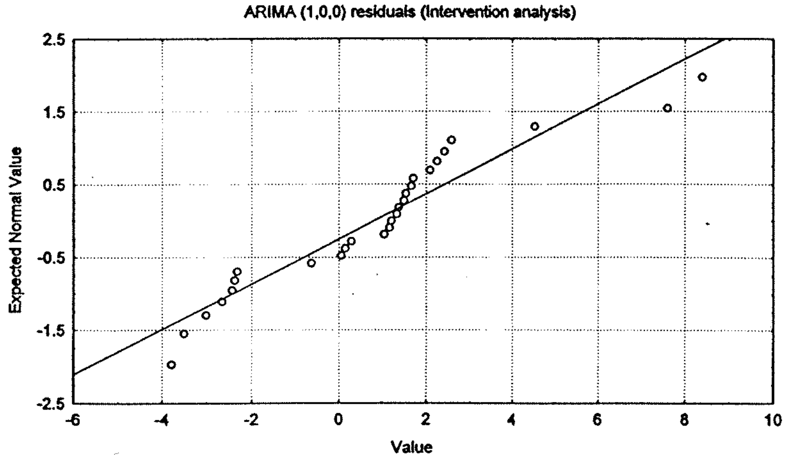
Experimental Group No. 17
Partial Autocorrelation Function
Word recognition raw score: ARIMA (1,0,0) residuals (intervention analysis)

Lag	Corr.	S.E.
1	-.131	.1925
2	-.365	.1925
3	-.051	.1925
4	+.161	.1925
5	-.048	.1925
6	-.076	.1925
7	+.193	.1925
8	-.146	.1925
9	+.052	.1925
10	-.051	.1925
11	+.012	.1925
12	+.148	.1925
13	+.017	.1925
14	-.043	.1925
15	+.026	.1925

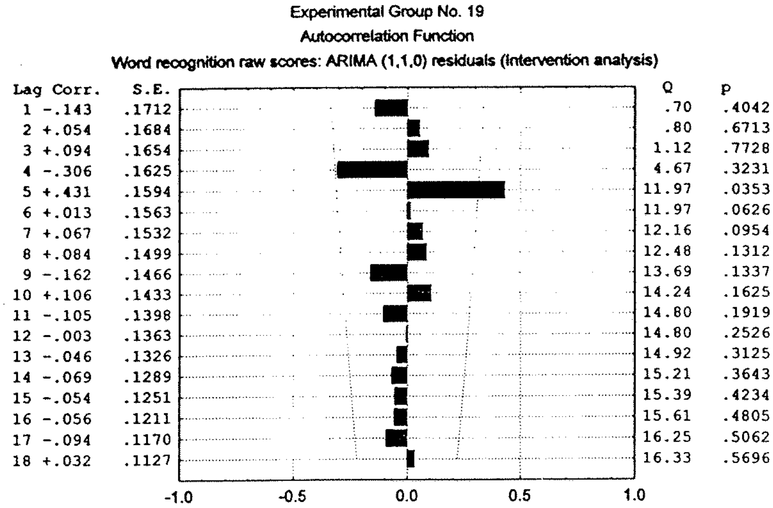


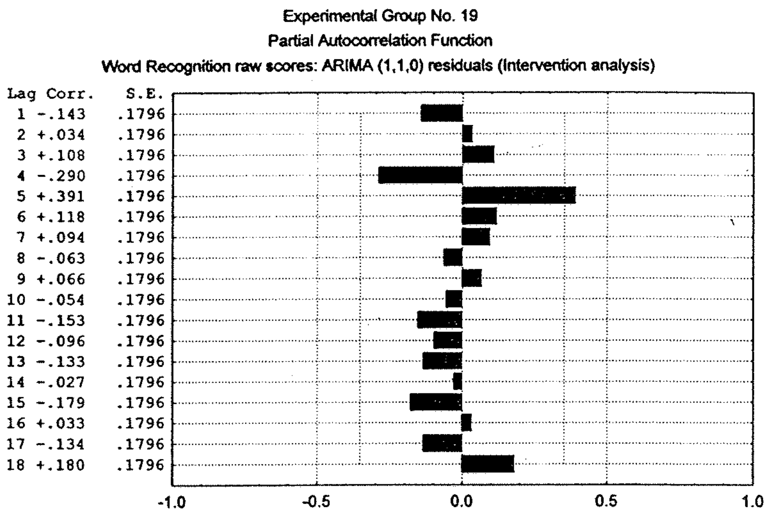
No serial dependency. Residuals follow a white noise process.

Experimental Group No. 17
Normal Probability Plot: Word recognition raw scores
ARIMA (1,0,0) residuals (Intervention analysis)

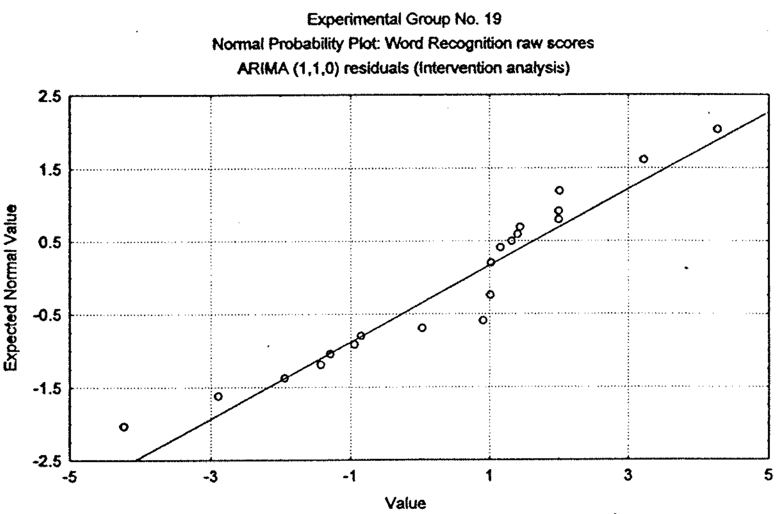


Shapiro-Wilks' W test = 9152; p < . 0304. Residuals not normally distributed.





No serial dependency. Residuals follow a white noise process.



Shapiro-Wilks' W test = .8846; p < .0030. Residuals not normally distributed.