SPEECH PERCEPTUAL ACUITY IN CHILDREN WITH READING DIFFICULTY

Alan James Adlard
University College London
Department of Phonetics and Linguistics.

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1999
To my mother, Elizabeth
and the memory of my father, Leslie.
ABSTRACT

A range of controlled experimental studies has reported comparative weakness in phoneme discrimination and identification in language-impaired (LI) and reading-impaired (SRD) groups of children. The implication was that members of these groups were generally less able to perform reliably on such tests. However, the number of speech contrasts/tokens used has typically been very limited, and it was uncertain to what extent speech perceptual difficulties were linked to the reading status of subjects, or whether all children in SRD groups had comparable difficulties. The main phase of the work reported here was designed to vary the acoustic-phonetic complexity of minimal pairs. Two different synthetic (copy-synthesised) continua for a stop and a fricative contrast were also used, following pilot testing. Non-speech based psychoacoustic tests, and tests of reading and single-item repetition, were employed. Thirteen children having similar reading delays and age, 12 chronological-age and 12 reading-age control children were selected and tested individually. Evidence is reported that a "sub-group" of SRD children performed relatively poorly on several speech-based and repetition tests, whilst the remainder of these children performed within norms. Also, their discrimination performance was particularly weak for consonant contrasts differing in a single feature which was not acoustically-salient. Problems were encountered with nasal and fricative contrasts as well as with stop contrasts. Contrasts of greater acoustic-phonetic complexity provided by consonant clusters were also problematic for these children. The experimental and control groups did not differ on the non-speech discrimination (psychoacoustic) tasks.

Discussion is made of the acoustic cues thought to be related to the range of perceptual "weakness" found, the emergence of the utilisation of such cues in normal perceptual development, and the theoretical importance of phonological knowledge to the development of speech and beginning reading.
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LIST OF ABBREVIATIONS.

CA = chronological age
CCVC = consonant-consonant-vowel-consonant structure
CVC = consonant-vowel-consonant structure
CVCC = consonant-vowel-consonant-consonant structure
dB = decibel
DL = difference limen
Hz = Hertz (number of cycles per second)
ISI = inter-stimulus interval
ITI = inter-trial interval
JND = just noticeable difference
LD = language disabled
LI = language impaired
LN = language normal
ms = milliseconds
RA = reading age
RD = reading disabled
RI = reading impaired
SLI = specific language impaired
SRD = specific reading disabled
TOJ = temporal order judgement
VCV = vowel-consonant-vowel (inter-vocalic consonant) structure
CHAPTER 1.

INTRODUCTION, PREVIOUS STUDIES AND RESEARCH PROPOSALS.

1.1. Introduction.

The reading of alphabetic script is a cognitive skill that normally becomes fluent only after many years of continuous practice. Even so, the final levels of speed and accuracy which individual readers attain as adults vary considerably. Normal reading development must call upon auditory and visual perceptual skills, linguistic knowledge, both short- and long-term memory, written and spoken vocabularies, knowledge of syntactic rules, semantics, phonemic awareness, and knowledge of the various rules governing grapheme-phoneme correspondence. Problems in any one of these areas will have a major impact on the development and maintenance of reading ability.

For some, learning to read fluently and write clearly and accurately present serious long-term difficulties, despite adequate intelligence and abundant learning opportunities (e.g. exposure to print and phonics training). It has been estimated that between 4 and 10% of children will become disabled for reading (decoding) scripts based on the alphabetic principle (Miles and Haslum, 1986; Rutter, 1978; Rutter and Yule, 1975). The exact proportion will depend on the quantitative criteria applied and the community being studied (Greatrex and Drasdo, 1995).

Reading difficulties (and others concerning spelling and writing) can arise in some children as one of a range of problems with language learning, such as expressive and/or cognitive impairments. Reading problems in children can also be "acquired" as a result of brain lesions (Baddeley, Ellis, Miles and Lewis, 1982; Dejerine, 1892; Patterson and Marcel, 1977 and Wernicke, 1885). However, this dissertation does not address the effects of brain trauma on reading development.
There are other children in the school population who typically show highly-specific difficulties with learning to read and spell appropriately for their age, standing out in marked isolation against their normal abilities in other areas of language-learning such as grammar, and in other school subjects. For these children, who will comprise the experimental groups referred to throughout this dissertation, the descriptive term "specific reading difficulties" ("SRD") will be used, alongside those of "reading-disabled" and "reading-impaired" as equivalents.

1.2. Earlier Terminology, and Incidence of Specific Reading Difficulties.

Where, within the reading-score distributions of same-chronological-age reference groups, are those children whose reading skills are inadequate? It has often been remarked that such children "reside" simply in the lowest sector of a distribution based on standard reading tests relating graded reading test performance to norms for a range of chronological ages. The actual numbers of such children in any sample population will clearly depend on the nature of the distribution of the performance measure.

One study that measured both over- and under-achievement in reading was carried out on the Isle of Wight and in London (Yule, Rutter, Berger and Thompson, 1974). It was designed to encompass four age groups (range 9-14 years) in a major city and an area of small towns. A total of over 7,000 children took part. For each age-group, the results (using the Neale Analysis of Reading Ability) showed that the distribution of performance was approximated by a Normal curve except for the extremes of the ranges..."under-achievers were more common than expected on the basis of a normal distribution", and there seemed to be visibly fewer high-achievers than would be needed to fit a Normal curve. Such frequencies of reading impairment seem to argue for a small deviant group whose performance is not merely developmentally "slow" but which has persistent problems with reading.
The widespread use of the term "backward reader" in texts produced in the 1960's tended to imply that all cases of weak reading skills were due to low intelligence (e.g. Lovell, 1967). This term was again used in later experimental work. Differences in outcome between reading backwardness and specific reading retardation were then charted (Yule, 1973). From a large sample of 9-year-olds who each had a reading delay of 33 months compared to the population mean, Rutter and Yule (1975) assumed that it was possible to form sub-groups of children who were estimated to have had a higher or lower IQ. They called those with the higher mean of 102.5 a "specific reading retardation group", and those with a lower mean of 80.0 a "reading backwardness" group. They claimed to show both differences and similarities in other characteristics. The "specific reading retardation" group was reported as containing fewer cases of organic brain damage or neurological abnormalities, whilst the "backwardness" group displayed a variety of motor abnormalities, and showed left/right confusions more frequently. Having formed and labelled their sub-groups only by reference to estimated IQ, there seems to have been a basic confound with the range of language-related difficulties each individual might have suffered. Severe language impairment, for instance including cognitive difficulties, can affect IQ scores (Bishop, 1992). The appropriate attempt at sub-grouping would have been only from within a group of children who were identifiable as "specifically reading impaired".

Perhaps the only distinction in terminology should be that between a "poor" and a "dyslexic" reader. Use of the term "poor" reader would more accurately be reserved to classify someone whose limited reading ability is not markedly weaker than his/her other educational attainments (Fletcher et al., 1992). Therefore, s/he is someone with limited decoding skills who is of somewhat below average intelligence (comprehension or non-verbal), so that reading progress is likely to be broadly in keeping with their general learning ability. In contrast, an individual with "specific reading difficulties" has below average reading and spelling skills despite an average or higher-than-average IQ (often a non-verbal measure).
"Specific reading difficulties" are classified, officially, as a form of developmental learning disorder (Davison and Neale, 1990). It tends to stand in isolation, when compared to a range of other achievements and abilities, and might do so markedly from the age of about 7 or 8 years. There is evidence that IQ is irrelevant to the definition of reading disability, and this issue has been much more closely studied in recent years (Siegel, 1988; Stanovich, 1994).

This dissertation is concerned with the possibility that the development of speech perception might be impaired in children aged between about 9-12 years who present with a significant delay in reading accuracy. Therefore, its focus will be on testing for variability in the performance of groups differing in reading-status on various speech-perceptual and other tasks. It examines only the potential value of performance on phonetic tasks, such as speech discrimination and identification, to understanding the early development of normal reading, and to aspects of childhood dyslexia.

A detailed understanding of the nature of difficulties with phonetic acuity is important in practical terms because of the possibility of promoting the development of remedial techniques which perhaps can be tailored more closely to the particular needs of the individual child. In theoretical terms, an appreciation of developmental difficulties with phoneme recognition is both interesting and important. Provided that a sufficiently wide range of speech contrasts at different levels of complexity are presented, acuity estimates have the potential to reveal more of children's utilisation of acoustic "cues" to speech, and the gradual establishment of stable phonetic categories. Furthermore, the ability to make phonetic judgements might have a key role in the development, in pre-schoolers and first-graders, of what psychologists refer to as "phonemic awareness", and in their ability to adopt (spontaneously or with some explicit training) an analytical approach to reading.

This chapter continues with a summary evaluation of the research which has been undertaken on possible deficits in visual perception, the discrimination of both
non-speech and speech sounds, and the efficiency of short-term memory in either language-impaired (LI) or SRD children. It argues that LI and SRD groups should be studied separately, and that SRD children show consistent evidence of relative difficulty only on tasks involving speech perception. It then goes on to consider whether such difficulties are likely to persist into adulthood, and attempts to relate them to a particular pattern of reading difficulty. The main aim in doing this is to provide a clear theoretical link between the degree of speech perceptual acuity shown by individual children and their accuracy on irregular word and nonword reading. Other theoretical accounts of the way in which speech is perceived and of how reading skills develop will be studied to try to predict a lawful relationship between them. Firstly, however, consideration is made of some of the other types of learning-related difficulties which reading-impaired children are likely to exhibit.

1.3. The Performance of Other Tasks by those with Reading Disabilities.

Specifically reading-disabled adults and children, apart from being poor spellers, often have a cramped, uneven style of handwriting (Critchley, 1970). They may be particularly weak at either nonword or irregular-word reading (or both). Some also have problems with other school subjects requiring the learning and manipulation of graphic symbols, such as mathematics and music. Several areas of difficulty with the spoken word have also been documented. Their everyday speech may be entirely normal, but some may be dysfluent in the repetition of multi-syllabic words (e.g. Brady, Poggie and Merlo, 1986). Equally, not all children with expressive difficulties are bad readers (Bishop, 1992). In considering this issue, it should be remembered that no one of these other weaknesses are applicable to all dyslexic individuals. Indeed, some may only apply to a minority of this group. Reports on the performance of only phonological tasks show many instances of experimental-group heterogeneity, as will be discussed later.

There are a number of measures which suggest that weak readers have limited
phonological and/or phonemic "awareness". For instance, they may have difficulty in dividing bi-syllabic words accurately into their component syllables, or apparent problems with segmenting an initial consonant or consonant-cluster (the "onset") of a monosyllable from the "rime" (which comprises all the remaining phonemes). Difficulty here may be part of the reason why many SRD children are perplexed by the "oddity task", in which subjects have to indicate the one word, of three or four given, which doesn't rhyme (Bradley and Bryant, 1979; 1983). Many reading-disabled children appear unable to provide rhyming words in response to spoken words (Bryant, MacLean, Bradley and Crossland, 1990; Goswami and Bryant, 1990). It is clear that reduced phonological awareness is often coincident with inferior decoding skills at the "beginning" stage of reading (e.g. Byrne and Fielding-Barnsley, 1989; Gathercole and Baddeley, 1993; Jorm and Share, 1983; Masterson, Laxon and Stuart, 1992; Seymour and Evans, 1994; Stanovich and Siegel, 1994; Wagner and Torgesen, 1987). Alternatively, there is evidence from a comprehensive training study that the processing units (letter-strings) used in word reading by disabled readers may not necessarily be tied to the onset-rime division (Van Daal, Reitsma and van der Leij, 1994). Problems with word recognition seem to arise from often rather complex effects of sound-spelling regularity. Relatively slow word-recognition speeds then impact on comprehension (see Baron and Strawson, 1976; Denckla and Rudel, 1976; Glushko, 1979; Gough and Hillinger, 1980; Guthrie and Tyler, 1976; Lesgold, Resnick, Roth and Hammond, 1981; Liberman and Shankweiler, 1979; Rack, Hulme, Snowling and Wightman, 1994 and Seidenberg, Waters, Barnes and Tanenhaus, 1984).

Another important deficit of considerable prevalence in the SRD population appears to be that of slower and more error-prone word-finding and object-naming, extending to the naming of familiar objects and of colours (Denckla and Rudel, 1976; Oldfield and Wingfield, 1965; Rudel, Denckla and Broman, 1978). Naming requires the retrieval of precise phonological information from a long-term memory store. In this selection process, Snowling, Van Wagtendonk and Stafford (1988) noted more naming errors by SRD-children following either a
verbal definition or picture-presentation than by same-age controls, even when their spoken vocabularies were of similar size. Tasks of word-retrieval and sentence completion were found to be completed less accurately by SRD children than by CA controls (Snyder and Downey, 1991). These language skills are thought, from the results of a wide range of studies, to be strongly related to adequate reading development. An empirical means of differentiating dyslexic from other learning-disabled boys was suggested by Denckla, Rudel and Broman (1981), who assembled a battery of tests and looked at the performance profiles of a group of boys differing only in respect of their oral reading skill. In summary, the dyslexic boys were reported as being characterised by "slowness, circumlocution, and paraphasic substitutions (dysphasic errors) on confrontation naming tasks". This reveals a deficit in word finding, principally concerning content words (nouns). Word-retrieval when naming familiar objects seems capable of being employed as a powerful marker for reading status within heterogeneous language-disabled groups.

Wagner and Torgesen (1987) reviewed the results of a number of naming tasks presented to dyslexic and same-age control children, and these were characterised in terms of a general deficit in using phonological information for lexical access (Denckla and Rudel, 1976; Stanovich, 1981, 1982 and Vellutino, 1979). The general role of phonological processing was clear because the poorer visual-processing task performance of dyslexics disappeared for those tasks that did not involve either phonological re-coding or overt speech (Legein and Bouma, 1981). When confronted with a reading task, a child with naming difficulties at the letter level will be prone to slowness and inaccuracies of blending, and to errors in the syllabic-structure of the letter-string. Unable to build these larger patterns of sound from even common multi-letter sequences, s/he will, in consequence, tend to be precluded from sounding-out whole words adequately.

Weakness in the naming of letters has implications for naming tasks that involve the selection of whole-word responses. Even if that inventory is complete, and that individual’s receptive phonology is within normal limits in itself, problems of
the dyslexic type might still ensue because of unreliability in the addressing (selection) and output-assembly of that phonology. From longitudinal studies, Mann (1984) and Mann and Liberman (1984) noted that the differences between good- and poor-readers' use of phonemic representation can be related to differences in their phonemic coding abilities even before the children begin to read.

Several different types of information-processing limitation have been put forward as important factors underlying reading failure, as a result of studies of both child and adult SRD- and LI-groups. In attempting to discover these limitations, the assumption has been made that all groups of language impaired children contain those who have reading difficulties and the results of tests on such groups have been claimed to be relevant to dyslexics. However, the relevance of such measures to the abilities of specifically reading-disabled children must be questioned, since by definition they make normal progress in other areas of class work. It is very important to maintain the distinction between the reading abilities of children in LI groups and those who are known to be “SRD”, and an attempt, below, is made to give careful attention to this issue. This will also involve some consideration of auditory and speech-perceptual studies in LI groups. Four key areas of research interest will be considered in this chapter, and will often include adult as well as child studies. These are visual perception, short-term memory (STM), auditory perception, and difficulties concerning aspects of speech perception.

1.4. Possible Areas of Information-Processing Difficulty.

1.4.1. Visual impairments.

Is the mental lexicon (where word-items are stored for matching, or otherwise, with input items) accessed by the use of visual or phonological information in decoding text? There have been several proposals that an underlying cause of reading problems is a deficit in certain fundamental aspects of visual perception.
One of the bases of the argument appears to be that the observed cycles of serial fixation followed by saccadic (ballistic, tracking) movements of the eyes during reading allow problems with "abnormal" visual-persistence of the images to curtail, or at least disrupt, further processing for a proportion of SRD-subjects. A specific example is Badcock and Lovegrove's (1981) proposal that dyslexic children do not read efficiently because of longer-than-normal visual persistence of a previous (print) image, which is related to the spatial frequency of the array. Georgeson and Georgeson (1985) also noted this effect with gratings (periodic stimuli of variable spatial frequency). Lovegrove and his colleagues have also claimed that specific reading disability in children is linked to evidence for abnormal contrast sensitivity functions (Lovegrove, Martin, Bowling, Blackwood, Badcock and Paxton (1982). Other work has emphasised that the visual evoked potentials of dyslexics are delayed (Maddock, Richardson and Stein, 1993), or that they have contrast sensitivity problems (Mason, Cornelissen, Fowler and Stein, 1993). There are disagreements, however, about just how prevalent these defects are within the target population (e.g. Brannan and Williams, 1988), and, as Greatrex and Drasdo (1995) commented...."subjective judgements of contrast sensitivity and other temporal phenomena are notoriously affected by the observer's criterion."

Much of the motivation for this area of research has been in testing the validity of the "magnocellular hypothesis" (e.g. Livingstone, Rosen, Drislane and Galaburda, 1991). This relates to reports that the majority of dyslexic children have a measurable disorder of the fast processing pathway of the visual system. It involves certain retinal ganglion cells and their connections to areas within the occipital and parietal lobes of the brain (see Breitmeyer, 1993; Breitmeyer and Ganz, 1976; Greatrex and Drasdo, 1995 and Lehmkuhle et al., 1993). This is the magnocellular (M) pathway, also referred to as the "transient" pathway, since it involves the larger cells of the lateral geniculate nucleus (LGN) which respond selectively to rapidly-changing visual stimuli (e.g. Zeki and Shipp, 1988; Kaplan, Lee and Shapley, 1991). The "transient" pathway is distinct from the sustained or "parvocellular" pathway, concerned with processing colour and fine detail,
concentrated in the fovea, and involving the smaller LGN cells.

A discrete anatomical deficit such as this is also of considerable interest in terms of understanding the practical implications of observed genetic factors in the etiology of dyslexia (e.g. Rack, 1995). During the execution of a saccade (rapid, linear eye-movements evoked during tracking tasks or in reading text) it is accepted that limited visual processing takes place, possibly due to inhibitory activity. There is a selective depression of motion sensitivity in that perception of rapid displacement of a target is suppressed during saccadic eye-movements, even for target movements as short as 4 degrees of visual angle (Bridgeman et al., 1977). The damping of mechanisms sensitive to movements and transients during saccades acts to preserve visual stability (Burr et al., 1982). There are two major reasons why this suppression is important: to promote stabilisation of the visual environment, and to minimise the possibility that perceived movement during a saccade might interfere with subsequent saccadic programming. These are particularly relevant to physical factors obtaining when reading various texts.

One hypothesis relating to differences in visual persistence is that, if the transient (M) pathway transmits inhibitory impulses with each saccade during reading, then a deficit in that system would cause confusion of successive images through destructive interference. However, this effect only seems applicable to the fluency of rapid (i.e. skilled) reading. It seems less likely to cause significant disruption of learning to recognise individual words and letter-sounds in beginning reading, which are relevant to the first signs of reading-disability (Morais, Cluytens and Alegria, 1984; Morais and Kolinsky, 1994). Furthermore, the reduction in transient-system function in SRD-subjects is reported to be slight, and unlikely to give rise to high levels of blurring of the image (Stein, 1993).

One is also tempted to ask why a transient-system deficit is not also reported by dyslexic subjects in the normal course of visual scanning of object contours? Just why might it be the case that the deficit appears limited to certain levels of
contrast and restricted in spatial frequency? A paper by Victor, Conte, Burton and Nass (1993) reported no difference in the visual evoked potentials (VEPs) of dyslexic and control groups of children. Although there appears to be some physiological and psychophysical evidence that the "transient" and "sustained" systems may inhibit each other (Singer and Bedworth, 1973; Breitmeyer and Ganz, 1976), the case for a temporal deficit in visual processing broad enough to impact significantly on beginning reading remains both fragmented and incoherent.

1.4.2. Normative adult studies of the recall of speech items.

It has been argued widely that language- and reading-impaired children are weak at temporal-order judgement tasks, particularly those requiring the discrimination of sequences of three or more items, because of deficits in short-term memory. Similarly, limitations of phoneme discrimination ability could be due to partial forgetting of phonemic distinctions (trace decay), not the way in which the distinctions are originally represented in sensory perception.

There is a rich literature detailing the differences in short-term memory which distinguish dyslexic from normally-reading subjects. The arguments used to defend the proposed perceptual origins of the "weakness" described earlier, and to question the STM-deficit hypothesis, are given for each study outlined. Since it is also necessary to know under what circumstances the recall of speech items by normal adults shows weakness, a review of some of this work is given first.

In a study concerned with the specification of "distinctive features" by which phonemes are correctly perceived and recalled, Wickelgren (1966) asked some undergraduates to copy down and then recall in serial (original) order blocks of eight C + /a/ syllables. The intrusion of other syllables from the same list of items was much more common than intrusion from outside it, and they tended to come from nearby item-positions (effect of recency). What was also clear was that these "intruding" items tended to have distinctive features in common with
the target consonant, but no precise information was given on phonetic similarities. Consonant-phonemes, at least, are not recalled in an all-or-none manner. He showed that STM appears to use an articulatory or acoustic code for such items, analysing and storing identities on the basis of traces relevant to these codes rather than on the basis of categorisation decisions. If the intrusion and target acoustic-codes are close in a physical sense then decay of the sensory "traces" (for whatever reason) allows less distinction between the respective sets of codes.

The importance to accurate short-term recall of acoustic similarity was also emphasised in a study by Kintsch and Buschke (1969) using lists each containing 16 real words. Using a probe word method, where subjects attempted to respond with the word in the list which followed the probe word, primary memory (indicated by the processing of recent items) was unaffected by the semantic similarity, but diminished by the acoustic similarity, of neighbouring words. The last words on such a list seem therefore to be "stored" mostly in acoustic-phonetic terms. Word-length also affects the structure of short-term memory (Baddeley, Thompson and Buchanan, 1975).

The Wickelgren (1966) and Kintsch and Buschke (1969) studies, dealing with recall up to about 20 seconds after the end of list presentation, have suggested that because acoustically-coded speech items are confusable under certain circumstances, this form of coding is unstable, perhaps decaying at a fixed rate. An acoustic-phonetic trace from a good exemplar of a word- or syllable-item is capable of containing a large amount of stimulus-detail (Miller, 1977, 1994). It has been noted that non-identical "same" judgements are typically slower (with perhaps a more thorough perceptual analysis) than identical "same" judgements, at least where the discrimination of tokens within a phoneme-boundary of a synthetic /b/ - /p/ continuum are concerned (Pisoni and Tash, 1974). They also found that "different" judgements were faster the greater the acoustic difference between the paired CV's.
If the inter-stimulus interval between the to-be-compared items is increased (delayed comparison) then discrimination accuracy decreases (Pisoni, 1973). The confusions found are explainable, however, in terms of processing-time. The nature of the speech-perceptual process, including categorisation and storage, would need some critical time, even in adults, for completion and can be affected by task-demands.

A construction of this type, to account for the apparent fixed-rate decay of "raw" information, was suggested by Crowder and Morton (1969) to be a "pre-categorical acoustic store" (PAS). They proposed that the acoustic-phonetic information is raw (pre-categorical) in the sense that, at the point of decision-making, it had ..."not yet made contact with the subject's overlearned linguistic repertoire". However, the vulnerability to making certain "close" errors in recall did, by contrast, infer the opportunity to complete a critical amount of processing in order to account for the adequate storage and recall of dis-similar items.

The main point seems to be that a direct or "raw" store of acoustic-phonetic information is available whilst an identification decision is being made, but that this information is purely sensory and not extendable in time by rehearsal before some classification decision has been made. At the point of decision, this critical amount of processing, in order to accurately "code" the stimulation into a more durable form, appears not always to have been completed. Crowder and Morton proposed that other properties of the PAS were that it could be overwritten by masking stimuli, that it decayed spontaneously over time, was not modified by visual stimulation (i.e. no cross-modal interference) nor by silent rehearsal, and is distinguishable in storage from the instructions for articulatory assembly.

It is important to establish at this point whether, normally, all classes of speech material are likely to be equally affected by STM storage problems. Two normative studies, again using undergraduate subjects, suggested they were not,
in line with the essence of Wickelgren's findings. Pisoni (1973) compared the discrimination both within and between categories, for various inter-stimulus intervals, of synthetic tokens of the vowels /i/ and /i/, and selected stop consonants /b/, /d/ and /p/. He found generally better within-category discrimination for vowels than for stop consonants, and concluded that this was primarily due to "the differential availability within auditory STM of the acoustic cues which distinguish these two classes of speech sound." Presumably information on such factors as differences in stop release-bursts, VOT values, F1 transition-onsets, and the transition extents of the second and third formant frequencies decays rather more rapidly from the sensory store than that associated with steady-state portions of utterances. *Within-category* acoustic information for the "same-different" discrimination of sequentially-presented syllable-initial stop consonants differing in place-of-articulation was estimated to be available if the second stimulus was presented within about 400 ms of the first (Howell and Darwin, 1977). This effect, of detecting very "fine-grained" differences in formant transition paths, is apparently related to a right-ear advantage. Pisoni's (1973) estimate was that the "differential availability of auditory STM" in favour of the vowels chosen appeared, nevertheless, to rapidly reduce as the ISI increased beyond 250 ms. This occurred to the extent that vowel discrimination accuracy, both within and between categories, began to decrease at a faster rate than for stop consonants.

Experiments by Darwin and Baddeley (1974) also suggested that representations of the auditory input in an acoustic store quite rapidly become degraded. Using a seven-item reading task and an eight-item listening task followed by written recall, they stressed that the acoustic similarity of either vowels or consonants will grossly affect recall accuracy. The probability of making an error increased with serial position for all stimulus-sets, particularly when a verbal, rather than a tone suffix was used. After some decay has taken place the respective "traces" may retain substantial information for a number of acoustically different items, such as /i/, /æ/ and /u/ or /g/, /ʃ/ and /m/, but much less for acoustically similar ones, such as /i/, /e/ and /æ/ and /b/, /d/ and /g/. Apart from these factors,
rehearsal efficiency and recall accuracy could have been independently affected by the number of items presented for serial recall and by presentation-rate. It is arguable that another method involving shorter item-strings (using the same stimulus-sets) and longer delays before recall (without the opportunity for covert rehearsal) would have been a clearer measure of decay effects in an acoustic-phonetic "store".

1.4.2. (a). **Normative studies of the recall of speech-items in children.**

Studies of the short-term memory of language-normal children have considered other factors which might limit their performance, and which might be largely age-dependent. More familiar, whole word measures of short-term memory capacity and accuracy also show effects at the phonological level. For LN children of different ages, there are differences in the types of errors made in deciding whether a word, given immediately after a just-presented list of unrelated words, had or had not occurred in that list.

Felzen and Anisfeld (1970) employed semantically related and phonemically related words in testing 8 and 11 year-olds. When the test-words shared features in either dimension with a previously-heard word, subjects experienced difficulty in deciding whether the word was "new" or "old", but the effects varied with subject-age. The errors made by the younger children were predominantly related to whether the test-word rhymed with one member of the list (e.g. "lamp" /læmp/, "camp" /kæmp/). Those made by the older children showed mostly a semantic relationship, (e.g. "crook" and "thief"). Such confusions underline the importance of sensitivity to rhyme (or "same" judgements at the phonological level) in the development of normal phonemic awareness, which may continue to be the predominant mode of word-analysis for several years after entering school.

Acoustic-phonetic cues seem to be contained within (represented by) an acoustic store, at least part of which rapidly and spontaneously decays. Experiments
have suggested that, in order to make an accurate identification of a particular phone or (synthetic) syllable, the information contained within the store must be extracted and appropriately-sequenced within less than about one second. It is probable that all the acoustic information in the store must be used unselectively and immediately. If a categorisation attempt is not made within this time frame it seems that identification, and perhaps discrimination, will be uncertain and error-prone.

What must also be true is that if the acoustic detail is unreliably registered as a pattern of "cues" distributed over time, then phoneme classification (identification) will be unreliable. Discrimination problems generally begin with pairs which share phonemic features and are also acoustically very similar. When sensory perception is insufficiently accurate to enable the consistent identification of phonemes or the discrimination of acoustically-similar items, a response-delay will naturally ensue, giving an opportunity for spontaneous trace decay in acoustic STM to further degrade the subjective sound-image(s).

1.4.2.(b). Serial-recall in reading-impaired children.

Digit sequences.

Memory deficits for reading-disabled children have been reported for the serial recall of digits (e.g. Sipe and Engle, 1986). A control group of good readers of the same age was used (about 10 years), and both prefix and suffix conditions were employed. Interestingly, the recall of the reading-impaired children was within normal limits without a suffix item, so that short-term memory itself was not impaired in the experimental children. Also, the use of a prefix disrupted recall of the earliest items to a similar extent for both groups.

Reading groups differed only in the accuracy of their recall of the final items in the suffix condition. Again, short-term memory differences need not be implicated since the reading-impaired children may have had greater difficulty
in overcoming the distraction of a suffix item, given the amount of processing they were perhaps still trying to complete. Younger children may also have been disproportionately distracted by the addition of any "shadowing" task, typically involving the contralateral ear, during presentation of the list. Sipe and Engle's poor readers showed significantly worse recall of digits for all recall-delay periods between 1 and 16 seconds, but .... “their less consistent, weaker, less durable phonetic coding” could itself have been responsible for this result. Poor phonetic coding of the suffix item itself might cause additional confusion for these children.

In a test of digit span where digits were presented auditorally in noise to normal and reading-disabled groups of 11 year-olds, the SRD-group was less accurate for repeated sequences but were performed similarly to normals on a spatial analogue of digit sequences: the Corsi Blocks task (Gould and Glencross, 1990). Consequently, they were described as having a deficit in verbal serial organisation for auditorally-presented material. The same digit-sequence deficit might have been demonstrated even without background noise, as has been demonstrated for the recall of words by Brady, Shankweiler and Mann (1983). The serial-ordering deficits which Corkin reported for reading-impaired children included pointing-sequences using Knox cubes, and digit span (Corkin, 1974).

Torgesen and Houck (1980) estimated that the proportion of variance in performance accounted for by "working (short-term) memory" between good and poor readers on ordered-recall for the digit-span test is about 10 %, whilst that accounted for by differences in phonological awareness abilities is around 40-70 %. Stanovich, Nathan and Zolman (1988) noted a modest relationship between memory, articulation speed and reading development but added that studies have shown that tests of memory span are poor predictors of reading ability (Curtis, 1980; Daneman and Carpenter, 1980). Certainly, both the Gould and Glencross (1990) and Sipe and Engle (1986) findings of inferior recall of digit-sequence in SRD's suggest a problem with efficient coding of spoken items which preserves order-information, particularly when a suffix item is presented.
Brady, Shankweiler and Mann (1983) found that children who were reading-disabled tended to have problems with the recall of both common and infrequent words presented in a background of noise. They recognised the probability that SRD-children and adults..."have a general problem with the use of a phonetic code however the material is presented". They tended to have poorer recognition scores as well as recall accuracy, and to be significantly less affected by rhyme and phonemic similarity than were normally-reading subjects. Phoneme-transposition errors occurred in orderly ways, retaining the same position in a syllable or preserving consonant-clusters, for instance, just as did the errors of good readers. The poor readers simply made more transposition-errors. Errors were more frequent with stops than with fricatives, but seemed to be related to the acoustic characteristics of those segments. This last general point had been noted by Wickelgren (1966) for intrusion errors in CV lists recalled by undergraduate subjects (see above). Subsequently, Brady, Mann and Schmidt (1987) found similarities of error-type on recall, for groups of 7-8 year-olds who were either good readers or reading-impaired, on 4-item lists of CV syllables (such as /sa/, /za/, /ga/ and /ka/). Even in quiet listening conditions, the phoneme-similarity aspect was significantly stronger for poor readers. As had been found in numerous other studies for the discrimination of consonants sharing certain features, the effect did not generalise to vowel errors, for which no group differences emerged. Incomplete codings could then be attributable to certain consonant pairs in SRD-children.

These children's errors of speech discrimination could be explained if the representation of the first item is masked, or undergoes destructive (retroactive) interference by presentation of the second item. The other possibility is that the second item is not processed adequately as a result of proactive interference arising from the presence of at least part of the trace of the first item. However, interference from such sources (assumed to be destructive) would generally be
understood to be a sensory-perceptual factor, not one of short-term memory. A stronger version of any STM trace-decay hypothesis would perhaps be needed to account for the observed experimental-group differences in speech identification consistency, where the perceptual decision-process can begin immediately after presentation. The corresponding trace would need to be so unstable that it could not always be used to inform the correct response-choice, but would then be logically and practically indistinguishable from the contents of a "pre-categorical" store. A unifying hypothesis could be that, whatever the precise reasons for their relatively inefficient processing of verbal material in these tasks, incomplete coding(s) could delay the operation of normal (covert) rehearsal routines, which may be one of the essential procedures in the establishment and recall of an "order-of-presentation."

1.4.2.(c). The recall of speech-items in "language-impaired" children.

Studies of memory capacity in language-impaired children do not always state the reading-status of their experimental subjects; it seems that they are frequently too young to be reliably assessed on reading-age (accuracy). The severity of the auditory memory problems evident in some, at least, of the work on young children suggests that they are likely to have significant problems with learning to read beyond a very elementary level. Behind their auditory memory limitations seems to lie evidence of perceptual dysfunction.

Pre-school children aged 3-4 years were studied by Masland and Case (1968) because they had a spoken vocabulary of only three or four words, despite having normal hearing, no mental retardation and having suffered no physical or emotional trauma. Repeating a sequence of digits presented at the rate of 1 per second is very difficult for them, usually achieving just a 2- or 3-item sequence. There is evidence that rates of verbal rehearsal are slower in SRD children (Torgesen and Goldman, 1977). The speech of some of these children was said to..."use an accurate syllable-pattern carried by vowels and unadorned by consonant details." This might suggest that they could process voicing and
stress variations but not the briefer, acoustically more complex phonemes. Locke (1969) compared 6-year-olds with low and average auditory memory-spans (AMS), and found that the children with poor AMS were worse at imitating novel (non-English) phones. These children also seemed to have weaker oral stereognosis (i.e. continuous awareness of changes in the size and shape of the oral cavity, and configuration of the articulators) which could, in itself, account for the result. Their "auditory memory store" status could again be due to limitations of speech perceptual acuity, but this was not directly tested.

Similar findings for the recall of lists, each comprising 6 digits plus a suffix item, were reported by Gillam, Cowan and Day (1995). When free recall was allowed, the LI children performed much better than for ordered (serial) recall. The information remains in storage so memory itself seems little affected, but the sequencing requirement does cause difficulties for them. Gillam et al. proposed that..."slowed interpretative processes may cause (the LI children) to over-rely on acoustic-phonetic information in the memory trace, thus more susceptible to interference by the "trace" of the suffix item". For Gathercole and Baddeley (1989) language-impaired children may.... "have difficulty with storing phonological features in STM - perhaps tied to the rate at which they "code" trace information".

Again, these studies seem to assume that acoustic-phonetic information is adequately read-into auditory STM, and that trace decay follows from subsequent problems with handling or "coding" the information. A far more explicit and parsimonious explanation would be that the acoustic-phonetic representations of at least some of the "language-impaired" children, as well as those who are specifically "reading-disabled", are not always reliable, and thus become primarily responsible for their (selective) recall errors. The effects of recency may be enhanced for these subjects because of interference arising from relatively inefficient attempts to code preceding items, which are further affected by the presence of subsequent items, including verbal suffixes.
1.4.2.(d). Conclusions on the studies of STM / categorisation.

The conclusions from this necessarily selective review of the issue of STM in speech-based experiments using a variety of different subject-groups are that:

(1). There is no unequivocal experimental evidence for the poorer recall of certain test materials by SRD- and language-impaired children being due specifically to dysfunction of a short-term memory store. A frank dysfunction of short-term acoustic memory, such as more-rapid trace decay, would be indiscriminate at least as to the consonantal nature of its speech-content, and generalise to complex non-speech stimuli.

(2). There is no empirical evidence that the decay of acoustic-phonetic "pre-categorical" traces is significantly faster in language- or reading-disabled subjects than it is in language-normal children or adults. The trend of experimental findings seems to be that trace-decay is spontaneous and begins, for all subjects, several hundred milliseconds following the end of stimulus-presentation. There is most confusion with consonant phonemes which are acoustically and phonetically similar.

(3). Poorer list recall, whether for words or digits, in some SRD-children is highly likely to be evoked by categorisation difficulties through limited representation of one or more acoustic-phonetic cues and/or slower phoneme selection for output phonology, which the presence of some trace-decay will exacerbate.

(4). Apparent errors of order (particularly involving consonant transposition) arise primarily from the perceptually confusing effects, for at least some SRD children, of the featural similarity of phonemes. Necessarily longer decision times would interact with the demands of time-pressure, particularly for rapidly presented TOJ tasks, where the ISI is much shorter than 1 s. The basis for this is
an appreciation of the concept of pre-categorical acoustic storage (PAS).

(5). Poorer recall of digit-strings or tonal sequences by SRD subjects could be regarded as relating to a different order of coding difficulty than that relevant to the discrimination of speech stimuli or speech-relevant complex tones. SRD subjects have been shown to have frequent problems of rehearsal-speed (Torgesen and Goldman, 1977) and efficient recall in confrontation-naming tasks (Denckla and Rudel, 1976; Snyder and Downey, 1991).

1.4.3. Auditory deficits.

Other research proposals have focussed on the idea that SRD children may have a temporal auditory deficit, the effects of which are not limited to the perception of speech. Such a "general" deficit is claimed by a variety of reports of these subjects' reduced acuity, for instance, in perceiving a brief gap between two clicks, or higher error-rates in recalling the sequence of two or more different complex tones just after presentation.

The extensive literature on auditory- and speech-perceptual abilities in children and adults with "language-impairments", or "specific reading disabilities", has recently been collated and reviewed by Farmer and Klein (1995). Results for groups of language-impaired children have often been found to be similar to those of groups of SRD children (e.g. McCroskey and Kidder, 1980). Children with reading problems often show concomitant language deficits (Stanovich, 1986) and many individual children within language-impaired samples have demonstrable reading difficulties (Bishop, 1992). Farmer and Klein also reviewed a large number of comparative studies based on different aspects of visual perceptual acuity in dyslexics, but these will not be considered further here.

The argument for a "general" temporal deficit in the processing of auditory stimuli by SRD subjects concerns the processing of speech and non-speech stimuli alike. A complication is that some results refer to LI groups, not all the members of which may have reading problems. Farmer and Klein began with studies of stimulus individuation, the determination of whether one or more than one item has been presented. This relies on the differentiation of the two stimuli on some physical dimension, or the perception of a temporal gap between two identical items. Twelve of the fifteen studies cited in this area concern visual stimuli; only three concerned auditory stimuli. The following comments relate only to auditory experiments.

*Stimulus individuation and detection.*

Two auditory studies that did provide significant effects were those by Haggerty and Stamm (1978) and McCroskey and Kidder (1980). Both of these studies used inter-stimulus intervals (ISI's) which refer, typically, to the use of pairs of stimuli which are *presented in succession.* The inter-stimulus interval is the duration between the offset (end) of the first and the onset (beginning) of the second stimulus, and is measured in milliseconds (ms). Haggerty and Stamm used clicks presented both binaurally and simultaneously and diotically, with one ear leading, to language-impaired and normal children. They found that the LI group needed a mean ISI of 1.67 ms against a normal mean ISI of 1.29 ms to separate two clicks. Farmer and Klein added that the stimulus-individuation results were confounded by the method of presenting the clicks to the separate ears, such that a spatial location cue could be introduced. The mean ISI-difference was reliable, as was the correlation between fusion intervals and consonant-discrimination accuracy for the experimental children. However, even given statistical significance for ISI-differences, with such a small absolute difference in duration it is possible that this effect might have been reduced or eliminated were test-retest reliability and possible on-task practice effects taken into account. In any case, careful study of
the details of the language-deficits of the members of this LI-group would seem crucial to the interpretation of this difference in perceptual accuracy. Kinsbourne et al. (1991) found that a group of reading-impaired adults were worse at judging the order of clicks, the duration of which was not specified. McCroskey and Kidder demonstrated that both a reading-disabled and a language-impaired group needed longer ISI's than normals to separate two 17 ms tones, with ISI's ranging from 0 to 40 ms.

The fact that the studies which show subject-group differences relate to very specific types of non-speech stimulus, and to short ISI's, limit the power of the argument for a general auditory deficit in LI groups. Unfortunately, the auditory-based studies alone are often impossible to interpret because of the sheer variability of test-centred and subject-centred factors. Many of the acuity scores for different subject-groups listed by Farmer and Klein on auditory-stimulus individuation were virtually identical. The finding by Haggerty and Stamm (1978) that LI-children were able to perform the click-separation task for gap-durations of less than 2 ms indicates that relating differences in gap-sensitivity for intervals between acoustic stimuli with few spectral components to independent evidence for speech-perceptual difficulties would not be a straightforward task.

Potential differences in the perceptual skills of SRD and LI groups for tasks concerning non-speech stimuli are illustrated by results on a tone-detection task reported by Wright et al. (1997). Broad band noise produced excessive "backward" masking on the detection of a brief 1000 Hz tone for a language-impaired group compared to that for same-age controls. That is to say, their thresholds for detection of the tone were raised appreciably when the tone was immediately followed by a burst of broad band noise. For a group of twelve SRD subjects, five showed a smaller mean-increase in detection threshold for backward masking (BM) than for the LI-children, but significantly more than for controls. The remaining seven SRD children showed no threshold increase. This stimulus-arrangement might roughly approximate to the task of detecting a stop consonant in a stop-vowel combination, for which a brief spectral burst precedes a longer,
acoustically stable segment. Alternatively, affricates have stop and fricative-like components, and acoustic events before noise (frication) might be similarly masked as for the backward masking by noise of a short duration tone. Detection difficulties might also relate to poorer discrimination of initial stops (e.g. /ti/-/ki/) for certain language-impaired groups. However, it remains very unclear as to how this finding relates to LI- and SRD-groups' typically low error-rates on such speech-based tasks, and why there was no complementary effect of "forward" masking of the same brief tone when it followed the noise, or of simultaneous masking.

Other studies, such as that by Watson (1992), showed that tests involving non-speech stimuli, such as pitch discrimination, single-tone duration and embedded test-tone loudness, did not differentiate reading-disabled, mathematics-disabled and normal subjects. The results for stimulus-individuation are unconvincing.

*Stimulus sequencing.*

Brief complex tones, often used in temporal-order judgement (TOJ) tasks, may represent a more difficult classification problem for language-impaired children. Typically in such tasks, pairs of pure or complex tones, or speech items, are presented successively with a brief inter-stimulus interval (ISI). The stimulus-pair can be physically same, or different, on any trial. The listener's task is to indicate, verbally or non-verbally, the identity and order of the stimuli. Logically, however, the actual task of temporal order judgement applies only to the "different" pairs presented. For LI subjects, the task may be, effectively, less one of temporal-order-judgement than of efficient encoding of the individual stimuli presented. If so, their perceptual difficulties would be analytical and integrative, not based on temporal factors alone (Mody, 1993; Mody, Studdert-Kennedy and Brady, 1997).

The same basic point also applies to each of the cases of significant stimulus-sequence effects reported for multiple auditory-stimuli. Examples are the studies by Bryden (1972) for 3-5 tone sequences, and by McGivern et al. (1991) and Zurif
and Carson (1970) on the Seashore Rhythm Test involving the temporal-spacing of sequences of 5 to 7 beats. Listeners have to judge whether two rhythmic patterns tapped out in quick succession are the same or different. Its objective difficulty is increased by increasing the number of beats in a pattern. The "codeability" of these tones and beats may indeed have been an overriding factor for these particular SRD-children. Furthermore, for each of these three studies, the experimental group was selected on the basis of non-identical measures and to somewhat-different criteria of reading accuracy. The studies cited by Farmer and Klein generally used brief stimuli (clicks and tones) which are also presented with very brief inter-stimulus intervals.

A number of these studies are now discussed in some detail. In doing this, considerable reference to the complex history of the performance of largely language-impaired groups of children is unavoidable. This is because the theory of "temporal perceptual deficit", which is an issue central to this thesis, is founded largely on the results of a selection of perceptual tests for this population of listeners.

Tallal developed the "repetition method" of training, where subjects were first required to respond to each stimulus presented alone by depressing one of two identical sprung panels mounted side-by-side. Each panel corresponded to a particular sound and feedback was given. After training to respond correctly to each sound separately, they were trained to respond to the four possible two-stimulus patterns (1-1, 1-2, 2-1 or 2-2) by pushing the panels in the appropriate order, provided they had reached an accuracy-criterion in the first phase.

A clear result came in the repetition task performance of a group of developmentally aphasic children, using two synthetic complex tones differing only in fundamental frequency (Tallal, 1976). Throughout training, an ISI of 428 ms was used, and 24 test-trials given, with feedback, after suitable demonstration and practice sessions. These 24 trials, however, had variable ISIs. At "short" ISIs (8 - 305 ms inclusive) the pooled error rates for adults, aphasic 8 yr.-olds, and
control children ranging in age from 4 to 8 years, showed an effect of chronological age against error-rate for all the normal groups. However, the aphasic 8 yr.-olds made more errors than even the 4 yr.-old controls, and far more (36% to 6%) than the language-normal 8 yr.-olds. At "long" ISI's (947 - 4062 ms inclusive) the order of these same tones was indicated about as well by the aphasic children as by the older control children and adults. Their performance was significantly better than that of the 4 and 5 yr.-old normals, who were regarded as more sensitive to "memory-loading" than other groups (or who showed lapses in close auditory attention over intervals of such lengths).

This indicates that for the younger children three parameters could be involved in limiting their TOJ-accuracy. These were the spectral structure and the duration of the tones, and ISI duration. Also, the temporal structure of the neural responses may be at least as important as their representation of spectral structure in determining "codeability", since the distinction may not be coded by "place" mechanisms. The ability of young normal children to analyse the structure (spectrally and/or temporally) appears somewhat limited (still producing about 20% errors for the long ISI's). Crucially, the aphasic children could apparently resolve spectro-temporal structure and correctly order the tones for trials with long ISIs, but under time-pressure the short ISI conditions seemed to block or truncate this process. The brief ISI's clearly presented this group with a particular problem.

Tallal (1980) tested the non-verbal discrimination of a group of 20 reading-impaired 8-12 year-olds using the same complex tones as had been used in the 1976 aphasia study. To repeat, they differed only in their "fundamental" frequency (100 or 305 Hz). Furthermore, they contained frequencies (appropriate to) the speech range. With tone-duration constant at 75 ms, children with a composite reading-age at least one year below CA grade-placement made about 15% tone-sequencing errors on trials with short ISI's but only 2% errors on trials with an ISI of 428 ms. Therefore, their accuracy for short-ISI trials was considerably better than chance (25%), and greater than that of the dysphasic group previously tested.” Tallal noted “a similar number” of sequencing and discrimination errors
for these children, but did not link the need to discriminate under time-pressure with the increase in sequencing errors.

Using very similar synthetic complex-tone stimuli to those used by Tallal (1976, 1980), Reed (1989) prepared a temporal-order task and presented the stimuli to groups of children differing in reading-status. She reported that, following a training phase using Tallal's "repetition" method, a group of 20 specifically reading-disabled children aged 7-10 years were significantly less accurate, overall, than 23 CA-controls for ISI's of between 10 and 400 ms inclusively. Except for the 400 ms ISI, this range corresponded to Tallal's "short" intervals. No measures of TOJ using these stimuli were made by Reed using Tallal's "long" intervals (> 900 ms). To this extent, therefore, her results replicated those of Tallal for another SRD group of similar chronological age.

As Farmer and Klein themselves confirm.... "the hypothesis that temporal processing deficits are the root cause of some cases of dyslexia is far from established" (p. 485). It is also unclear how relevant the concept of a general "temporal" deficit would be in attempting to describe the discrimination and sequencing difficulties of LI subjects. The following sections deal with some of the issues raised concerning the nature of language-impairment in children and the extent to which these children are also likely to be reading-impaired. The question of whether LI children have a phonemic deficit and not a general auditory one mainly relates to studies on aphasic children. Finally, the nature of the evidence for a temporal deficit being the basis for phonemic confusions in reading-disabled and LI groups is summarised.

1.4.3.(b). Speech related difficulties: Is there a phonemic deficit in language-impaired children?

The implicit need for complex perceptual judgements presumably puts language-impaired children with weak stimulus-coding skills at some disadvantage in executing speech-based tasks. A given child, however, may be language-impaired
for reasons not centred on the sensory perception of language but in the use s/he can make of spoken information. There may be severe cognitive deficits, but the term “language-impaired” (LI) also includes children (and adults) who have speech-production deficits and might benefit from speech therapy (as indicated by Stackhouse, 1982). Bishop (1992) considered that LI children did not differ markedly from children with hearing impairments, in that distinctive patterns of linguistic impairment arise from auditory perceptual limitations (the "auditory deficit hypothesis": ADH). Language impaired children often show cognitive impairments (such as weak lexical judgement), but Bishop linked the auditory deficit hypothesis with the "limited processing capacity" view of cognitive impairment by proposing that both can be the outcome of a fundamental deficit in LI children. Bird and Bishop (1992) found that LI children with production problems varied a great deal in their ability to discriminate between nonwords, and all their experimental children showed an ability to discriminate contrasts which they could not produce. They emphasised that the problem seemed to centre less on their subjects' criteria for phoneme categorisation than on their recognising that items can be analysed at the level of phonemic segments. The importance of studying data from individual children was also emphasised, since some of their LI children made few nonword discrimination errors.

If the aim is to study the extent to which speech perceptual problems can impact upon reading development when using language-impaired children, we need to know as much as possible about their individual patterns of language-related deficits. Typical deficits found within such groups are considered here, followed by a selection of findings on LI subjects whose deficits had been listed with varying amounts of detail. It is necessary to make clear that the terms "plosive" and its American equivalent "stop" (which refer to the consonants /b/, /d/, /g/, /p/, /t/ and /k/) will both be used throughout this dissertation.

Speech perception and aphasia.

The term “aphasia” is itself a general one. It can include a severe loss of the
ability to name objects (anomic aphasia) and the inability to comprehend the meaning of spoken words (auditory aphasia). For children, the term is “developmental language disorder”, which can include several abnormalities of language function. Aphasia correctly refers to the loss of abilities previously developed. A synonymous term is “dysphasia” which has been defined as a *disorder of language affecting the generation and content of speech and its understanding*. It is caused by disease in the left hemisphere in a right-handed person, and is *commonly accompanied by difficulties in reading and writing* (Oxford Concise Medical Dictionary, 1996).

Stark and Tallal (1979) noted that, of their group of 12 "dysphasic" children, 7 made discrimination and order errors for synthetic /ba/-/da/, but all twelve could discriminate and order synthetic /e/-/æ/ tokens. The production of /be/, /pe/, /de/, /bep/, /peb/ and /deg/ in an imitation task was reported as containing more voicing or place-of-articulation errors in those dysphasics who showed weaker discrimination skills. The dysphasic group showed greater variation in VOT for initial stops, greater vowel length before voiced than voiceless stops in CVC syllables, and exaggerated amplitude and duration of aspiration in the production of final stops. All tasks were performed accurately by a group of CA control children. These workers used rather simplified, synthetic, vowel (/e/ - /æ/) and consonant stimuli (/ba/ - /da/), the latter sometimes without release bursts.

The brief durations of stop formant-transitions were referred to as the "discriminable components" and implicated as the source of the perceptual difficulty, also being nominated as possibly sufficient to "explain the speech-disorder of these [dysphasic] children" (Tallal and Piercy, 1974). The next report was of the weaker discrimination by developmental aphasics between two synthesised vowel-vowel syllables (/ei/ and /æi/) which were similar in terms of their "brief discriminable components" to the CV-stimuli previously used (Tallal and Piercy, 1975). For these stimuli, an initial 43 ms steady-state vowel was
followed immediately by a different steady-state vowel for 207 ms. Therefore they differed only for about the first 20% of tokens. They appeared to generalise the results using this brief vowel portion to other findings involving the average duration of CV transition cueing place-of-articulation (40 ms), pursuing the idea that the brevity of the discriminable components was the basis of the problem for aphasics, and possibly for other language-impaired children. This group was not heterogeneous for a particular type of aphasia. If several of their experimental children were known to have a history of sensory aphasia, it is not clear what such findings indicate. Sensory (or Wernicke’s) aphasia is presumed to be due to lesions in Wernicke’s area, and is associated with normal, even fluent articulation. The content of the speech is empty, incoherent, and full of lexical selection and grammatical errors. Comprehension of both written and spoken language is also impaired, as is the ability to repeat phrases” (Reber, 1985).

**Speech perception and dyspraxia.**

The term "dyspraxia" refers to those who have difficulty in making skilled movements with accuracy, often due to disease of the parietal lobes of the brain. It concerns poor organisation of the necessary movements, rather than to clumsiness due to muscle weakness, sensory loss or disease of the cerebellum. Dyspraxic children are often also reading-impaired.

Sequence discrimination problems in dyspraxic children, involving both real and nonword items, were found by Bridgeman and Snowling (1988). This was related to the weaker development of lexical-phonological representations and consequent problems with output phonology. It was hypothesised that dyspraxic children have relative difficulty with the acoustic analysis of consonant clusters (specifically with /ts/ and /st/ in nonword final position), but that they have no particular difficulty with the discrimination of the single phonemes /s/ and /t/. Since they had no difficulty in discriminating consonant clusters within real words, they interpreted the cluster discrimination deficit in nonword items as
based on “non-lexical processing” in speech analysis. They stated that it was….. “not a deficit of acoustic analysis but one occurring at a later stage of processing when phonemic segments are coded in abstract terms.” Single-phone segments were, however, discriminated in both real word and nonword items by these children. The difference in discriminability for dyspraxics may relate to factors such as differences in the acoustic structure of single and clustered phonemes, and in the effect of familiarity for lexical items.

*Speech perception in child groups undifferentiated as to language-impairment.*

A language-impaired experimental group was chosen for a comparison of their speech-discrimination abilities with those of a same-age control group (5;0 to 8;5 years) in Tallal and Stark (1981). No detailed profiles of each experimental child's language-impairments were given, such as standardised scores on tests of reading (accuracy), but they were all selected on the basis of having both expressive and receptive language problems. There was no reliable group effect in the *discrimination* of /sa/ from /stɑ/, because the control group made more errors than in /sa/-/ʃɑ/ discrimination. The /sa/-/stɑ/ stimuli differed only in the duration of the silent interval (set at 0 ms for /sa/ and 100 ms for /stɑ/). However, the *identification* of /sa/-/stɑ/ tokens by language-impaired children in Tallal and Stark (1978) was reliably weaker than for controls, since they required a significantly longer silent period between the fricative and the vowel to make the category-shift. Clearly, there were differences in the tasks involving these particular tokens in the two studies, and differences in control group performance which may have been crucial to the results.

The performance of the different listener-groups might have been differently affected by the use of only two formant frequencies for the /bɑ/-/dɑ/ stimuli but three formants for the other contrasts. This potentially reduced the relevance of these findings to the use subjects might make of the full complement of acoustic cues present in *natural* tokens. It is important to note that for /sa/-/ʃɑ/
discrimination in Tallal and Stark (1981), LI children were significantly weaker than controls. This was an unexpected result for their working hypothesis of a "temporal-processing" deficiency in LI children, since primarily spectral differences applied here. They were specified as differing in the frequency distribution of the initial fricative formant frequency (centred at about 3 kHz for /ʃɑ/ and 4.5 kHz for /sa/), and in the duration of the silent interval between frication offset and vowel formant onset (set at about 30 ms for /ʃɑ/ and 0 ms for /sa/).

A recent attempt by Merzenich et al., (1996) and Tallal et al., (1996) to improve the temporal threshold and speech-discrimination of LI-children using modified speech has apparently resulted in improvements in these abilities, following intensive daily training. There are difficulties with gleaning several crucial procedural details from these brief articles. The 7 subjects in Merzenich et al. (1996) had receptive-expressive language difficulties and reading impairment. Did the LLI profiles include cognitive and/or attentive difficulties? Many of the improvement measures which Merzenich et al. illustrate relate to changes over time in the ability to efficiently sequence pairs of simple tones and frequency modulated tones at shorter (threshold) ISI's. The possibility that this form of auditory training has had much of its effect through improving the attentive skills of listeners who had prior problems in this area assumes great importance, hence the further need to have more comprehensive language profiles. Five of the 7 experimental subjects (aged 6-9 years) showed significant threshold-ISI reduction, yet most were clearly still unable to approach normal ISI thresholds for children of this age range of about 10 ms for 75 ms duration tone pairs. Thresholds of about 100 ms were more typical at the end of 4 weeks of brief but daily training sessions. A second study with a larger LLI group (n=10) and stimulus duration as a parameter also showed that training reduced both the threshold ISI and threshold tone duration in sequencing at least some of the FM tone pairs, although individual performance changes over the 20 training sessions varied widely.
The crucial experiment in study 1 concerned changes in the sequencing accuracy for CV or VCV pairs, such as /be/-/de/, /aba/-/ada/ and /fa/-/va/. Improvements in performance, measured as reductions in ISI threshold, were reported as “somewhat erratic” and “not easily compared between children.” This suggests that several LLI children failed to complete the training program for these stimuli. In study 2, Merzenich et al. report that speech identification improved in terms of reduced minimum consonant duration and ISI threshold for 6 of 11 LLI listeners, using tokens having artificially enhanced “transient elements.” The actual task here was to identify the sequence position of the target CV (first or second). An LLI control group without adaptive training and using un-enhanced speech items were reported as failing to show any such improvement.

Similar concerns relate to the enhancement of speech items in Tallal et al. (1996), in which seven LLI children received a regular training schedule over 4 weeks. Pre- and post-training “benchmark” scores revealed that the effect of the 100 or so accumulated hours of various speech-related exercises was to drive all 7 listeners to approach, or exceed, normal limits in speech discrimination and language comprehension. This pattern of results was substantially reproduced in a second study involving 2 groups of eleven LLI children aged 6-9 years. A control group receiving non-adaptive training on unmodified speech tokens made significantly less progress on standard tasks of speech discrimination (Goldman-Fristoe-Woodcock), language processing (Token test) and grammatical comprehension (CYCLE-R). It may have been the case that auditory enhancement of minimal pairs played a significant role in the improvement of identification scores (target cue), but both ISI and consonant duration co-varied with it, making its contribution obscure. Moreover, it was clear that LLI subjects trained on natural speech items also made some improvements in speech discrimination and grammatical comprehension (z scores). Improvements in post-training and follow-up tests may have been contributed to by a simple, unstructured, practice effect. The extent to which this is due to learned changes in attentional strategy to access structural
differences requires assessment. It is possible that this change in listening behaviour could have been central to improving identification at shorter ISI's and in increasing scores on standard language measures.

Elliott and Hammer (1988) used a 13-item /ba/-/da/-/ga/ continuum bearing 5 formants and formed pairs from selected tokens. They reported a non-significant discrimination difference by listener-group at age 6-7 years. However, the difference in size of "just-noticeable differences" (JND's) between LI and LN groups was significant using their /ba/-/pa/ continuum. A subsequent study by these workers, testing much larger groups of LI and normal children of similar chronological age, found significantly larger JND's for the experimental group on both of these continua (Elliott, Hammer and Scholl, 1989). It was specifically noted that there was a high incidence of reading problems amongst a further sample of language-impaired children, for which they went on to find a significant correlation between language-learning ability and measures of receptive vocabulary and receptive language (Elliott, Hammer and Scholl, 1990). Evidence for a normal developmental sequence in the ability to label and discriminate 5-formant /ba/-/da/-/ga/ stimuli has also been presented. Basically, 6-year-olds were less able to perform to a criterion on these tasks than were 10-year-olds and adults (Elliott, Longinotti, Meyer, Raz and Zucker, 1981).

Kamhi and Catts (1986) provided more information on the language-related characteristics of their experimental subjects. These included both language- and reading-impaired children, aged 7-9 years, in a study including initial- and final-phoneme deletion and segmentation (by tapping) for spoken materials. The reading-impaired children were weaker than normal controls on phoneme deletion. As no comprehensive testing was carried out of their speech-perceptual abilities, it is not possible to say that their reading-disabled children would have shown, say, discrimination problems for monosyllabic items.

There are also problems with the use of LI-groups that concern the amorphous
nature of their deficits. Goorhuis-Brewer and Wijnberg-Williams (1996) reported, for a large group of supposedly "specifically language-impaired" (SLI) children, that several also presented with, for example, mental retardation, hearing loss, speech-motor or psychiatric problems. Only some 25% of the 319 children diagnosed by a multi-disciplinary team using suitable protocols were found to be specifically "language-impaired", and 5% were even found to be linguistically normal. Part of the difficulty with such assessments, they added, was that other problems, such as attention deficits and motor functioning, are not manifest at pre-school age but emerge later. Several of these factors can retard early-reading progress but add nothing to the understanding of possible links between speech perceptual abilities and the level of reading accuracy.

If, in the above, children (or adults) had been identified whose language disorder did not include reading but who had had difficulty with speech perceptual tasks under controlled conditions, this would be of great importance for the work proposed here. This is because it is implicit in the theoretical structure of this thesis that basic problems with phonetic acuity will have an early impact on the development of spelling-to-sound correspondence and on phonological awareness, and that these weaknesses each contribute to problems with early-reading accuracy. Clearly it becomes crucial to have detailed information on the particular language problems of individuals in the experimental group.

1.4.3.(c). Speech-related difficulties: Is there evidence of a temporally-based phonemic deficit in various experimental groups?

Language-impaired children are often unable to segment words accurately, have poor awareness of syllables as well as phonemes, and are weak at discriminating stop consonants. These problems imply an impaired knowledge of some of the structural properties of spoken language, perhaps accompanied by significant auditory and cognitive deficits. It is not possible to say whether difficulties with temporally based acoustic-phonetic differences generally play a part in vulnerability to problems with language-learning, since different experimental
samples of such children with rather different profiles of language-difficulty might not have comparable problems with speech perception. Without details of their individual language-learning problems it is not possible to begin to relate these speech findings to other deficits or to compare the results of different studies on similar tasks.

Reading-impaired subjects have been shown to be less accurate in specific discrimination tasks involving stop consonants and/or to have shallower slopes in their identification functions (e.g. Godfrey et al., 1981; Reed, 1989). That these difficulties are due mainly to weaknesses in registering differences in the spectral extent and/or rate of change of frequency of formant transitions cueing place-of-articulation has tended to be assumed rather than demonstrated directly. A normative estimate of the ability to discriminate short and long isolated transitions has shown that longer transitions are more easily discriminated for frequency change (Elliott, Hammer, Scholl and Wasowicz, 1989).

Procedures designed to test the effect on speech perception, for various experimental groups, of decelerating stop consonant-vowel transitions have generally shown little change. Alexander and Frost (1982) reported that a group of language-delayed (aphasic) children, aged from 7 to 11 years, had benefitted from a number of discrimination-training sessions for synthetic /ba/-/da/ tokens where the duration of the second and third formant frequencies varied in 10 ms steps from 40 to 70 ms. It was clear that the members of this language-delayed group varied widely in the effect of training on such stimuli, a heterogeneity which the authors noted. Several did not improve over the training sessions, whilst others started with superior discrimination ability.

However, in a normative study, Keating and Blumstein (1978) investigated the effects of lengthened transitions on stop perception, using /da/-/ga/ continua containing F2 and F3 transitions of 45, 95 or 145 ms duration. Labelling and discrimination data revealed that the shape of the functions and the slope of the phoneme-boundary did not reliably vary with these changes in duration,
although identification did decrease in accuracy with marginal significance from 95 to 145 ms. In other words, there seemed to be an optimal duration for the formant transitions, for these particular tokens, of about 95 ms. A subsequent adaptation paradigm for the /da/ stimuli using various durations showed no effect of transition-length. They concluded that the slope and duration of the formant transitions contributed minimally to the perception of stop place-of-articulation in adults. Similarly, Riedel and Studdert-Kennedy (1985) found no systematic improvement in the perception of stop place-of-articulation with extended F2, F3 transition duration for aphasic subjects.

Another study looked at the perception of CVC-syllables containing stop consonants, by normal readers and dyslexics, under both 40 % compression and 60 % time-expansion of stimuli. The perceptual consequences of these changes were not as clear as for the young language-impaired subjects studied by Orchik et al. (1979). McAnally et al. (1997) predicted that dyslexics' identification performance for syllables such as /bæk/, /tæk/ and /kæb/, would be improved by the expansion condition (x 1.6) and depressed by their compression (x 0.6). Expansion and compression of these syllables in the time domain was applied uniformly to all parameters. Independent sets of these stimulus tokens were also generated for which the range of the formant frequency transitions was either stretched (x 1.4) or compressed (x 0.5), but leaving the steady-state formant frequencies of the vowel, and their overall durations, unchanged. No systematic improvement in dyslexics' accuracy following either set was found. In fact, both dyslexics and controls made more identification errors for all speech signals that had been manipulated either by time or by frequency.

A particular study of the temporal-order-judgement (TOJ) of children selected as either "poor" or "good" readers was made by Mody (1993). She found that poor readers (who had been pre-selected for their weaker performance on a TOJ-task) made most errors on a TOJ-task involving consonants differing only in place-of-articulation, namely /ba/-/da/. Reading-impaired groups have been found to be weaker on the TOJ of non-speech items such as complex tones (e.g. Reed,
but Mody et al. did not replicate this effect for non-speech. A total of twelve presentations were made for the “same-different” permutations of this pairing with the briefest (10 ms) inter-stimulus interval, and a mean of 3.7 errors (or 69 % accuracy) resulted. For the 100 ms ISI, accuracy increased to 87 %. The fact that "time pressure" was not, of itself, responsible for the bulk of errors in ordering was shown by Mody's TOJ results from the same children using the same range of ISI's for the phonemically dis-similar /ba/-/sa/ and /da/-/fɑ/ pairings. For each ISI-duration these pairs were ordered with almost total accuracy. Her "good" readers made no errors for any pairing at any interval. The pattern of results suggested that discrimination was itself a primary problem for (these) poor readers, but that their TOJ-performance was further reduced when listeners were stressed by being put under time-pressure.

Taking into consideration the Keating and Blumstein (1978) finding, there is some evidence for an optimal range of formant transition duration cueing place-of-articulation. This is to say that the identification and discrimination of speech items depends on the presence, within quite narrow limits, of particular spectro-temporal values for several acoustic components. What is interesting is that this seems also to be true for dyslexic groups, but it is not known how many of these subjects had speech-perceptual weaknesses. If some of them did have such a weakness, the Keating and Blumstein, and McAnally et al. findings suggest that neither specific changes to place-transition duration nor gross changes in the temporal- or frequency-structure of speech signals would necessarily lead to a systematic improvement in their recognition scores. The origin(s) of subjects' difficulties with integrating acoustic-phonetic information may be too diverse and complex for such discrete manipulations to be effective, perhaps to the extent of describing distinct sub-groups. The issue of heterogeneity in experimental groups is considered shortly.
1.4.4. How might an auditory temporal deficit affect reading development, and is it a unifying proposal in considering a perceptual component for reading disability?

A "general" temporal problem is unlikely to provide an explanation of children's reading difficulties because of two assumptions that the literature in this field reveals. The first is that all SRD children can be shown to have an auditory perceptual problem. The second is that a listener-group's problems with non-speech discrimination are directly translatable to speech discrimination difficulties despite gross differences in the spectro-temporal complexity of the stimuli (see Mody, Studdert-Kennedy and Brady, 1997).

The non-speech effects are few in number and often limited in scope (e.g. Haggerty and Stamm, 1978). Reed successfully replicated Tallal's (1980) result of less accurate TOJ performance in reading-impaired children for pairs of complex tones of a particular construction (Reed, 1989). The details of the various non-speech tests listed by Farmer and Klein (1995) suggest, however, that there has been little systematic effort to reinforce such claims in the auditory domain. In any case, the relevance of such findings to difficulties with beginning reading are obscured by the use, generally, of language-impaired experimental groups whose individual members commonly vary widely in chronological age and pattern of learning problems.

The theory of auditory temporal deficit is not a unifying proposal since several of the experimental groups used were reported to show heterogeneity of performance (see Bird and Bishop, 1992; Farmer and Klein, 1995). An example of the effect of type of language disorder was provided by Tallal (1980). She estimated that the discrimination and temporal-order judgement of complex tones for twelve of her twenty reading-delayed children were within normal limits.
The idea that the deficit may be "temporal" was primarily based on speech-perceptual data for language-impaired (mainly aphasic) subjects, not for SRD children. Furthermore, it was based on only a small number of contrasts (mainly stop consonants) for which it was assumed that differences in the formant transitions cueing place-of-articulation (F2 and F3) were the only discriminable components, and that these differences were realized solely in the temporal domain. The brief complex tones which SRD children found difficult to sequence had a complex, speech-relevant, spectral structure, which it may have been essential to encode analytically in the time available if the task was going to be performed adequately (Tallal, 1980; Reed, 1989).

Since speech is not produced in discrete, invariant, units of single-phoneme length, relative weakness in acoustic-phonetic analysis in some SRD children could disrupt the acquisition of phonemic information and of phonological structure. Utterances containing plosives, in particular, contain a number of acoustic-phonetic dimensions defined in terms of spectro-temporal variables, which must be efficiently encoded (integrated). Difficulty with such encoding would disrupt the acquisition of stable sound-images, and, consequently, the mapping of simple phoneme-grapheme correspondences (see e.g. Snowling, 1980). Nevertheless, it is likely that the mapping of such correspondences is never procedurally "simple" even for language-normal children (Plaza, 1997).

1.4.5. Heterogeneity of the reading-disabled population.

Discussion has been made, in the language-development literature, of the variability of experimental subjects in their ability to perform tasks which concern, for instance, expressive, motor or semantic abilities in language processing (notably Bird and Bishop, 1992; and Bishop, 1992). The form of these discussions has not been set, generally, at the level of detailing individual error-scores, or error-types, on named tasks to give profiles of language-related impairments. However, in perceptually based research involving reading-impaired subjects, there has been occasional mention of wide within-group
differences in performance-level on particular tests. This is not surprising in light of the fact that individual differences in the perception of speech contrasts have been demonstrated even for groups of language-normal adults (Hazan and Rosen, 1991).

Lieberman et al. (1985) made a point of noting that the identification-consistency of individual dyslexics varied quite widely, and that the performance of some was not significantly different from control-group means for certain tests. In their review, Farmer and Klein (1995) specifically considered at some length the matter of subject-heterogeneity within the reading-disabled population. They noted, for example, the results of a study employing 7 to 9 year-old SRD-children (Tallal and Stark, 1982). The experimental subjects, selected on the basis of having shown no evidence of either an expressive or a receptive language deficit, did not differ from controls in their performance on tests of phonics skills or those involving temporal perception. They were impaired, it seems, on tasks involving serial-memory, concept generalisation, segmentation into syllables and visual scanning. The implication from this is that those children who have an auditory perceptual/coding problem will be found from within groups of children whose language-related difficulties centre on, or at least include, receptive-expressive disorders. A deficit that is related to temporal processing appears not to be generally relevant to reading-disabled children. As Farmer and Klein commented..."it seems unlikely that a single underlying cause will be found for (their) reading difficulties."

The review also showed considerable variation, across studies, in the criteria used for subject-selection. Some reading-impaired groups had a reading-delay of 1 year, others had a delay of 2 or more years. Some workers have relied on teacher selection of those children who were reading-delayed, whilst others have measured reading level but tended to use a wide range of different tests, including some of comprehension and others of single-word decoding. If adolescent dyslexics are tested, some may be experiencing amelioration of their
deficit as a result of developmental changes and/or remedial teaching. The choice of selection criteria for their reading-group sample (n=12), coupled with the use of a very small chronological-age control group (n=4), could have been instrumental in the findings that the labelling consistency and discrimination of stop consonants by dyslexic children were not inferior (Brandt and Rosen, 1980). The discrimination functions for the SRD-children showed generally less-sharp peaks using pairs taken from a /d/-/t/ continuum, but otherwise, essentially normal perceptual skills seemed to characterise this group. The variability of the selection criteria evident across studies is, of course, distinct from the variability of subjects' speech-perceptual skills.

Before reviewing the evidence for phonological deficits in reading-impaired (and LI-children), it is necessary to appreciate that the use of the terms "phonology" and "phonemic awareness" tends to be somewhat different in different disciplines. This issue is considered next.

1.4.6. Phonology and "phonemic awareness".

Preliminary notes on the meaning and use of what is meant by "phonology" are placed here in an attempt to make explicit some differences which have become established across different fields of research.

No clear and reliable distinction seems to be made, in the mainly psychological research literature concerning speech perception in language-impaired children and adults, between a "phonemic" and a "phonological" deficit, at least in the descriptive manner in which the terms are employed. The word "phonology" is used to refer to any sequence of phonemes, particularly in discussions of grapheme-phoneme (letter-sound) correspondences and multi-letter sequences (orthography). There are also some inconsistencies in the use of the terms "phonetic" and "phonemic" perception. Reference is made to "phoneme" perception when what is actually being discussed is "phonetic" perception. Workers in phonetics and speech perception have much more specific uses for
Phonology in the broadest sense concerns the study of the sound systems of languages, with the aim of demonstrating the patterns of distinctive sound found (Crystal, 1995). It may be supra-segmental (covering up to several sequential words) or segmental (sub-lexical). Many of the speech-based experiments reported in the literature on reading-disabled subjects have studied their ability to process "segmental" phonology. A phoneme is a theoretical abstraction that relates to a family of particular speech sounds (phones) which may all be categorised in the same way, so that the same contrastive function is maintained. Phonemes in fact, for a speech scientist, signal differences in meaning for a language, and can be studied separately from, or as part of, phonology. They can be abstracted from the flow of speech, providing contrastive value at the linguistic level. A simple example would be the stop place contrast created by substitution of the initial /g/ in /gəut/ ("goat") by /k/ to produce /kəut/ ("coat"). Studies that relate to either the production or the perception of speech sounds are referred to as "phonetic" studies, concerning sequences of varying length of particular speech sounds (phones). In other words, they concern particular utterances, whether natural or synthetic. The speech perceptual studies of psychologists or phoneticians on language-impaired, hearing impaired, reading-delayed or aphasic children, for instance, basically involve "phonetic" judgements.

The meaning of the terms "input" and "output" phonology have their origin outside the study of phonetics, and require clarification. Phonology, for a cognitive scientist, has orthographic and lexical referents, which have the potential to link the sound-system of a language to its symbolic (alphabetic) form. "Input" phonology relates to a complex series of operations determining the syllabic-structure of the speech-signal, its attributed phone-sequence, and the fact that these signals are understood as being composed of a sequence of "phonemes". The translation of the acoustic information compatible with the identification of particular phones into a phonemic-sequence is necessary. Only
the more abstract, but perceptually stable, "phoneme categories", supported by "phoneme-blending" routines, can enter into phoneme-grapheme correspondence (Snowling, 1980). The adequate knowledge and application of such correspondences determine, with other grammatical and morphophonemic rules, the alphabetic structure of the signal.

"Output" phonology refers to another complex series of operations which results in the access of these orthographic and lexical stores for appropriate letter-sounds, word-finding (e.g. naming), and sentence structure by a speaker, who may be in conversation or reading orally. Since silent reading is also understood to involve the assembly of accessed phonology for decoding from print to speech, such that the correct lexical entries are efficiently summoned and grammatically parsed, it also involves the implicit use of "output" phonological operations. A speaker may correct himself by attempting to re-address the phonological output-lexicon and orthographic store after estimating how and where a previous utterance failed to match the intended utterance.

In short, input phonology refers to sensory-perceptual and perceptual-cognitive processes involved with the recognition of a speech signal through its reconciliation with "corresponding" stored-structures at morphophonemic-, syllabic- and word-levels. Output phonology, on the other hand, is concerned with the fluent selection from entries in these stored-structures of the intended, prosodically legal, speech-items. As input and output phonology are seen as central to the mediation of, respectively, the normal perception and the normal production of speech, they are regarded as independent indicators of phonological knowledge and "phonemic awareness". Recent discussions concerning the relationship of phonological knowledge to beginning reading have emphasised the fundamental reliance reading progress has on the richness and integrity of this knowledge (e.g. Byrne and Fielding-Barnsley, 1989; Gathercole and Baddeley, 1993; Hatcher, Hulme and Ellis, 1994; Masterson, Laxon and Stuart, 1992; Seymour and Evans, 1994). The phonetic characteristics of visually-presented rhyming and non-rhyming words were also
shown to differentiate "good" from "poor" beginning readers in a recall task (Mark, Shankweiler, Liberman and Fowler, 1977).

It is not possible to produce a stop consonant (plosive) as an isolated phone (e.g. /b/ or /t/) since at least a reduced vowel sound must follow for the stop to be realised. In English this is schwa (/ə/), hence /ba/ or /ta/. Therefore, in practice, well-controlled laboratory tests of "phonemic awareness" typically measure the ability of subjects to identify the presence of, or discriminate between, particular phonemes in a string of two or more phones. The consonants to be discriminated can be synthesised or recordings of natural utterances, involving such nonsense syllables as /ba/-/da/ or /su/-/ju/. Thus the discrimination of phonemes contained within such minimal pairs unavoidably involves the processing, by listeners, of phonological information.

A further difficulty arises with the widespread use, primarily by psychologists, of the umbrella-term "phonemic awareness". It is essentially undefined and loosely employed. It does not refer exclusively to children's growing sensitivity to changes in meaning based on phonemic changes. Phonemic awareness has been defined operationally as... "the ability to explicitly manipulate speech segments at the phoneme level" (Cunningham, 1990). As such, it implicitly represents the end product of a perceptual learning process spanning both "input" and "output" phonology, and including the auditory segmentation of blended phones. It seems to imply the need for the stable representation of phoneme-categories, despite the occurrence of subtle acoustic changes in the speech signal. Changes such as allophonic variation, and the devoicing of some word-final consonants nevertheless relate to particular phones in different word-positions and/or different phonemic contexts. In production terms, "phonemic awareness" includes the ability to blend adjacent phones and to assemble the sequence of phonemes in a word, through "output" phonology, in a fluent and reliable way that corresponds to an acceptable pronunciation.

The term "phonemic awareness" has been used to refer to subjects' levels of
accuracy in several types of task. Examples of these tasks are: 1) syllable-substitution and transfer (e.g. Seymour and Evans, 1994), 2) appreciation and/or generation of rhyming words (e.g. Lenel and Cantor, 1981), 3) the distinction of the proposed "onset" and "rime" segments of words (e.g. Goswami, 1993; Kirtley, Bryant, MacLean and Bradley, 1989), and 4) the "oddity" task (Bradley and Bryant, 1983). These demonstrations are all, properly, derivatives of phonetic acuity (i.e. the generality of subjects' accuracy with the perception and production of speech sounds).

1.4.7. Evidence that poor phonological skills are associated with reading impairments.

It has been found that language-impaired children with poor speech-perceptual skills have reading difficulties (Bird and Bishop, 1992), but it does not follow that all SRD-children necessarily have speech perceptual difficulties. For instance, reading-disabled children often have difficulty with visual processing tasks, such as letter naming, which require either overt or covert speech recoding (Legein and Bouma, 1981). Certainly the variety of phonological limitations shown by SRD-children strongly suggests the relevance of sub-lexical skills to the development of literacy (Bentin, 1992). The poor representation and recovery of phonology in SRD children is inferred from their difficulty in providing words that rhyme with other (given) words. It is also inferred from their appreciation of rhyme (Bradley, 1988), their difficulty with alliteration (Bryant, MacLean, Bradley and Crossland, 1990), phoneme-confusion (Tallal, 1984; Tallal and Stark, 1982), and their limited understanding of the "oddity task" which requires the ability to categorise speech-sound sequences (Bradley and Bryant, 1983). In a recent study, weak (or "unstable") internal representations of phonology for a range of speech contrasts were reported for a group of older children with reading problems despite within-norm audiometric results, and for two adults who had largely overcome their developmental reading problems (Masterson, Hazan and Wijayatilake, 1995). Overall, it is clear that phonological difficulties are common to SRD subjects.
What is also becoming clear is that the origins of those phonological difficulties, across a given sample of experimental subjects, are potentially diverse.

1.4.8. How disordered phonological skills presage limited reading progress.

The awareness of phonemic categories and their phonological "distinctiveness" are necessary, through analysis of the sound-structure of words, for the appreciation of corresponding phoneme-grapheme units and the use of combinations of alphabetic symbols (Snowling, 1980; Snowling, Goulandris, Bowlby and Howell, 1986). Normal early-reading development (see below) is thought to concern mainly the alphabetic principle and the mastery of orthographic (rule-based) knowledge of particular spellings (e.g. Frith, 1985). The ability to resolve (perceptually) a "phonetic-feature matrix" implies the use of phonological processing. Reading has been regarded as proceeding by the use of such a matrix (Fowler, Liberman and Shankweiler, 1977), which may suggest that awareness of segmental phonology and the growth of linguistic knowledge in beginning readers can arise out of the normal development, and integration, of complex sensory-perceptual skills. It has also been shown, using 2 lexical-decision tasks, that the acoustic representations achieved in silent reading are best characterised as "inner-speech" (Abramson and Goldinger, 1997). A significant deficit in phoneme segmentation and manipulation has been noted in SRD-children (Plaza, 1997). However, it appears that, in some cases, poor phonological processing capacity can be compensated-for by the development of superior orthographic processing ability (Holmes and Standish, 1996). A theory of "phonological state", discussed more fully later in this chapter, has been developed to explain the differences in the abilities of skilled, beginning and pre-readers (Stuart and Coltheart, 1988). The following section considers the empirical evidence for some form of phonetic deficit in SRD children and other experimental groups.
1.4.9. **Empirical evidence for a phonetic deficit in SRD subjects.**

The major part of this body of evidence of relative auditory-phonetic problems is based on the performance of subjects whose language difficulty is specifically of reading-impairment. The exception in this section is a study that used LI children who were understood to be predominantly reading-disabled (Merzenich et al., 1996). Where perceptual differences have been found in the labelling-consistency and discrimination-accuracy of speech items for different reading groups, they have typically been subtle but statistically significant. Several of the studies used child experimental groups, but evidence is also available from a number of speech perceptual studies of adult dyslexics. The results of some speech-based experiments on SRD-children are considered first.

Werker and Tees (1987) found that reading-impaired children's identification of synthetic /ba/ and /da/ tokens was consistently less categorical than that of age-matched controls (in the chronological age-range of 8-14 years). They were also significantly less accurate on an AX ("same"-"different") discrimination task involving the same stimuli, but showed similar accuracy as controls on the within-category task using particular pairings of tokens on the synthetic continuum. These results supported those of Godfrey, Syrdal-Lasky, Millay and Knox (1981), who had used synthetic continua for the identification of both /ba/-/da/ and /da/-/ga/ tokens by similar-sized groups of dyslexic and control children aged about 10 years. Discrimination weaknesses were also found for the SRD-children. An important point to note from the latter study was that the /da/-/ga/ tests were more difficult for both groups for acoustic reasons: it was cued only by changes in the third formant transition, whereas /ba/-/da/ was cued by changes to both the second and third formant (F2, F3) transitions. In both studies, then, a significant relationship was found between reading level and speech discrimination, such that the SRD-children gave evidence of less robust (distinct) phonological categories.

The ability of first-grade children with good or weak reading skills to
discriminate stop consonant place-of-articulation using selected pairs of tokens from a synthetic /pA/-/tA/ continuum was examined by De Weirdt (1988). The SRD-children were found to be less accurate than controls. The group-difference for identification of these same tokens was in the same direction, but less pronounced. Less-sharply defined categories were also found for dyslexic children aged 7 to 10 years compared to age-matched controls by Reed (1989) using a synthetic /bA/-/dA/ continuum. This sample of SRD-children was also weaker on an AX discrimination task using these tokens. Reed also found that the SRD-children showed a large effect of lexical status near the category boundary for synthetic /bæp/-/dæp/ and /bædʒ/-/dædʒ/ continua, but their phonological difficulties did not generalise to recalling the temporal order of various pairings of the vowels /e/ and /æ/. She considered that..." an important part of becoming aware of phonological structure may be learning to segment the initial consonant or consonant cluster from the rest of the syllable." This would involve the segmentation of syllables into "onset" and "rime" (Treiman, 1985b, 1988). In fact, phonological structure is defined in terms of constituent phones.

The pattern of both discrimination and identification difficulties for SRD children has often been related to synthetic stop contrasts. Discrimination difficulties using recorded natural /bi/-/gi/ tokens were reported by Hurford and Sanders (1990). They used two SRD groups of different mean chronological ages (8 yr. 11 mo. and 10 yr. 9 mo.). Second grade SRD-children were significantly weaker on this discrimination task than a group of 2nd grade (age-matched) controls. Older SRD-children (fourth grade) performed similarly, however, to 4th grade (age-matched) controls on the same task. The ISI duration was varied between 10 and 240 ms but discrimination accuracy did not vary with ISI for any of these groups, suggesting no differences in the efficiency of very short-term memory as a function of reading-status. The recall of temporal order for pairs of synthetic /bA/-/dA/ nonsense syllables was reportedly less accurate for a group of LI children having predominantly a reading-impairment
than for same-age controls in a perceptual training study by Merzenich et al. (1996). This again confounds rate of presentation with intrinsic temporal differences in the acoustic-phonetic content of stop consonants (see Mody, Studdert-Kennedy and Brady, 1997).

Mody et al. (1997) tested second-grade good and weaker readers (respectively a mean of 5 months above and below grade level), matched by chronological age and intelligence to controls, and selected to differ significantly on a /ba/-/da/ temporal-order judgement (TOJ) task. This revealed an effect of reader group, but there were no group-differences on a TOJ task involving more-easily discriminated syllables (/ba/-/sa/ and /da/-/ʃa/). This was presumably because they differed by more than one phonetic feature. Performance on a "same"-"different" discrimination task with non-speech analogues of /ba/-/da/ (incorporating rapid spectral changes) did not differ between groups, therefore the generality of a "temporal" effect was not supported. The conclusion was that perceptual confusions by the SRD group related to the phonetic similarity of these syllables rather than a specific difficulty with perceiving rapid spectral changes. There is, then, little experimental support for the proposal that all SRD children necessarily have a problem in discriminating second and third formant transition duration for different stop place contrasts. A "simple" temporal deficit of this kind should also apply to the discrimination of a range of non-speech stimuli. The remaining studies in this section principally concern adult dyslexic subjects.

A comparison of the speech perceptual abilities of adult dyslexics aged 18-51 years, using undergraduate and graduate students with normal reading and hearing as controls, was made by Lieberman, Meskill, Chatillon and Schupack (1985). A consonant identification test used a variety of recorded /b/, /d/, /g/ + vowel utterances produced by an 18-month-old child, and a vowel identification test used nine vowels having the same overall duration, fundamental frequency and F3 values. The ability to identify the vowels was measured by scoring their accurate repetition. It was found that the SRD group was less accurate on both
identification tasks, but Lieberman et al. also noted that two different sub-groups of 4 of the 18 experimental subjects could clearly be distinguished. One sub-group did not differ from controls on vowel identification, whilst the other sub-group was within norms on stop consonant identification. Only one SRD subject was common to both sub-groups. For their stop consonant identification test, a further sub-group of five SRD adults produced a higher mean error-rate than did the SRD group as a whole. These experimental subjects may, individually, have had very different (speech) perceptual deficits...."rather than a general auditory deficit involving the rate at which they can process perceptual information."

Subjects participated in one identification and two discrimination tasks for each of three continua: /a/-/a/, /ba/-/da/ and /sa/-/sta/ in a comprehensive study of speech perception in eighteen SRD-adults and eighteen adult controls by Steffens, Eilers, Gross-Glenn and Jallad (1992). These continua were chosen to measure subjects' ability to use steady state, dynamic and temporal cues. The SRD group required longer silence duration to shift perception of /sa/ to /sta/ but were generally able to perceive categorically and discriminate synthetic vowel and consonant stimuli. They showed shallower identification functions for /ba/-/da/ than controls. Also, some errors were made by SRD's on within-category discrimination trials, suggesting that they lacked a degree of precision on these tests. Groupwise, their "categorical perception" for tokens not at the extremes of the continua seemed to be rather weaker than that of controls, but they also noted heterogeneous performance across the experimental group.

The Watson and Miller (1993) study of speech perception in 24 adult dyslexics revealed that accuracy of discrimination of the syllables /ta/ and /ka/ when the pair is preceded and followed by the syllables /fa/ and /pa/ respectively was.... "strongly related to phonological variables such as phoneme segmentation ability and short-term memory", and that these variables were, in turn, .... "strongly related to reading ability." Having used a structural equation
approach for these and other measures such as word attack, passage comprehension and non-verbal temporal processing, Watson and Miller concluded that the speech discrimination and repetition tasks..."may contribute significantly to individual differences in the phonological abilities necessary for skilled reading." This relationship was not found to apply to reading-groups' accuracy on the chosen non-verbal auditory temporal processing tasks of single-tone duration, pulse-train discrimination, embedded test-tone loudness and temporal order for tones. However, their use of four-syllable strings in discrimination (such as /fa/, /ta/, /ka/, /pa/ followed by /fa/, /ka/, /ka/, /pa/) may have introduced difficulties of temporal-order judgement within each string.

Masterson, Hazan and Wijayatilake (1995) employed a voicing continuum (/ba/-/pa/) identification test to assess the phonemic processing abilities of two adult developmental phonological dyslexics (SB and RE). Seven naturally-produced consonants (/p/, /b/, /f/, /v/, /θ/, /ð/ and /h/) followed by each of three vowel “environments” (/i/, /a/ and /u/) provided a second consonant identification test. The identification functions of subject RE were generally within normal limits, showing labelling in a categorical manner for the full-cue natural-edited stimuli and a boundary shift in the "VOT alone" condition. Subject SB's labelling was much less certain, showing the expected boundary shift but within a non-monotonic function, and having shallower gradients for the reduced-cues, stylised syntheses. Confusion matrices for the direct-responding mode of the consonant identification test showed that SB mis-identified /p/ and /b/ with each other and confused /ð/ as /v/ most often, whilst RE confused /ð/ with /θ/ and /v/. However, not all studies have found perceptual effects by subject-group. Overall, no differences between normal and dyslexic adults were found in a study of the identification of CV syllables (Cornelissen, Hansen, Bradley and Stein, 1996). Nine syllables, in quiet and under different levels of white noise masking, were presented randomly. The pattern of confusions for the two subject-groups, for all listening conditions, was
generally similar, but the dyslexics did confuse /tʃa/ for /ʃa/ and /pa/ for /fa/ more frequently.

The twelve research papers cited above have shown, in the main, subtle but significant effects across reading-groups for discrimination tasks, and a variety of identification tasks, using different synthetic continua and natural-voice stimuli. The accumulated evidence for problems with the perception of contrasts defined either by voicing or by place-of-articulation for stops and certain fricatives appears firm. The main conclusion of the Masterson et al. (1995) study was that the incidence of weaker phonemic categories (particularly for stops and fricatives) may be associated with poor nonword reading ability. Poor nonword reading ability is the central characteristic of "phonological dyslexia".

It seems that certain phonemic categories may remain weak into adulthood, persisting in some cases despite considerable success with other techniques to enhance reading fluency, such as the use of context (Funnell and Davison, 1989; Holmes and Standish, 1996). If there is a marked improvement in the reading abilities of adult dyslexics compared to their age-appropriate accuracy and fluency as children, can it be assumed that spontaneous improvements in phonetic skills have taken place in the intervening years and contributed to an amelioration of their literacy problem? In fact, there is considerable evidence from adults (who were discovered as children to be "developmental phonological dyslexics") that problems relating to speech perception do not resolve spontaneously. Some of this evidence is reviewed in the following section.

1.5. The Persistence of Phonological Problems.

Knowledge of spelling-sound correspondences and phonics are necessary to forming sub-lexical skills for the analysis of print. They are, plausibly, amongst the skills normally adopted by children during early reading instruction which draw upon their awareness of individual speech sounds. Limited sub-lexical
awareness could be seen as severely precluding the formation and use of a sub-lexical decoding strategy, and may be particularly weak in "phonological" dyslexics.

1.5.1. Experimental evidence.

Two research reports already discussed have provided illustrations of the persistence of speech-perceptual difficulties. Masterson et al. (1995) showed that 2 adult subjects assessed as being "developmental phonological dyslexics" made confusions amongst stops and amongst certain fricatives, but the larger group of 18 SRD-adults studied by Steffens et al. (1992) presented a more complex picture. These listeners required longer durations of silence to shift from perception of /sa/ to /sta/, but their discrimination of synthetic vowel and consonant stimuli was comparable. Their labelling of the more-extreme tokens in a /ba/-/da/ continuum was generally categorical but the slope of the function was shallower than for controls. Clearly these results for stop discrimination differed from that of Masterson et al., the larger experimental group showing heterogeneity of performance. Is there further experimental evidence for the existence of persistent problems of phonemic-awareness? Other lines of experimental evidence of the persistence of the phonological awareness problems of phonological dyslexics are available.

Firstly, for example, a case study concerning a female adult phonological dyslexic (Louise, aged 35 years) was reported by Funnell and Davison (1989). Interestingly, despite successful completion of training in the International Phonetic Alphabet (IPA) and being able to read real words accurately, she had a poor knowledge of phoneme segmentation for nonwords. If Louise had been experiencing difficulty with the discrimination of phonemes and with phonology using alphabetic but not when using phonetic scripts, her difficulties could have been predominantly with learning the many irregular sound-spelling relationships within conventional (English) orthography. Phonetic transcriptions involve, by definition, regular sound-spelling relationships. Therefore, it would
have been valuable to know what proportion of Louise's lexical responses were orthographically regular, or involved regularisation errors.

Secondly, a comprehensive study of the phonemic awareness of child, adolescent and adult subjects was carried out by Bruck (1992). The reading problems of several of her subjects had been at least partially remediated. The tasks were: syllable counting for taped nonwords, phoneme-counting for monosyllabic nonwords, and deletion of the first sound of CVC nonwords. For the normally reading controls, reliable increases in phonemic awareness were associated with age and reading-level. She found that dyslexics, on the other hand, did not acquire appropriate levels of such awareness "regardless of their age or reading levels, although they (adults) eventually acquire appropriate levels of onset-rime awareness".

These findings, taken together, strengthen the suggestion that some appreciable progress with reading development is possible despite poor phonetic acuity, phonological dyslexics' decoding of print perhaps proceeding by the increasing use of, and heavy reliance upon, contextual information from a vocabulary based on largely-visual features. Poor phonemic awareness did not suggest a simple developmental delay because SRD's were shown never to have achieved levels of facility appropriate for either their age or their individual reading ability. Bruck's argument would perhaps have been strengthened by being able to show weaker phoneme counting and phoneme-deletion effects in dyslexic adults using familiar spoken real-words rather than nonwords as stimulus items. The phonological unfamiliarity of nonwords may impact on the phonemic representation or "mapping" of sounds, particularly if a member of the experimental group is only weakly aware of phonemes in the "onset" position of lexical items. The question arises as to whether a proportion of the subjects who showed what Bruck described as poor "phonemic awareness" in her segmentation tasks would also have performed relatively poorly on a range of appropriate speech perceptual tasks. Nevertheless, a reliable finding is that accumulated perceptual experience of speech per se does not appear to result in
improvements in phoneme recognition for developmental phonological dyslexics.

1.5.2. Studying the extent and possible nature of persistent phonological problems.

Despite the research interest in this area, there has been little *systematic* testing of the proposal that SRD subjects have most problems with the perception of stop consonants. Neither has the assertion been adequately tested that the ability to resolve formant transitions of short duration cueing place of articulation is the basis of the "temporal deficit" hypothesis for speech items. Formant transitions are less prominent cues to the classification of fricative-vowel than of stop consonant-vowel stimuli. Therefore, evidence of weakness in SRD children for the discrimination of fricatives in (intervocalic) stimuli would require this hypothesis to be made more specific, as would similar evidence concerning other types of consonant contrast. It is proposed to provide a broadly based and systematic test of the "temporal" hypothesis, and of the extent of perceptual weaknesses across individuals in the SRD-group, by asking children to discriminate different classes of phoneme. Further discrimination tests involving consonant onsets in pairs of familiar (vocabulary-relevant) words will be used to examine the extent of any perceptual weaknesses, measured in terms of acoustic-phonetic variables.

Before the test-battery can be formulated it is necessary to define more precisely the potential nature of the relationship between reading disability and speech perception which should be tested empirically. There is the implication that the existence of reading-delay in a subject is sufficient for the prediction of a speech-perceptual problem, but much may depend on the nature of the task given (Mann and Brady, 1988). Considerably more reading-impaired subjects may show difficulties with such tasks as phoneme-deletion and syllable-transposition, for instance, than show limitations of phoneme-identification and/or discrimination. These and a number of other types of task have tended to
fall under the common rubric of "phonemic-awareness" or "phonological skills" but not all rely on accurate speech perception as such.

There has been the specific proposal that..."information transfer within the language apparatus is uni-directional, beginning at the lowest level with phonological processing, and proceeding upward to the semantic and syntactic parsers" (Shankweiler, Crain, Brady and Macaruso, 1988). Certainly, the observed weakness of SRD subjects' linguistic skills, in contrast to their frequent success on non-linguistic tasks, could be efficiently explained by proposing that..."reading is predicated on spoken language skills" (Mann and Brady, 1988). Limited resolution of the sound-structure of different words will also be effective in constraining a listener's phonological skills. Is there a model of normal speech perception that might indicate how deficits in its operation might lead to certain perceptual confusions?

There have been several interpretations as to the nature of the phonological deficit widely judged to be central to the problems of reading-impaired children. Arguments in the literature have tended to centre on the use of such experimental constructs as "the analogy model" (e.g. Goswami, 1993), "phonological sensitivity" (Bowey, 1994), "the direct mapping hypothesis" (Rack et al., 1994) and "phonological distinctness" (Elbro, 1996).

However, a recent and influential paper has been that of Metsala (1997), which will be considered first. It dealt with spoken word recognition rates in a gating task, rather than phonological distinctness as such. The rate of recognition here was measured by reference to the number of "forward gates" required of reading disabled (RD) and CA control children (age range 6-14 years) to correctly guess the identity of monosyllabic words. It calls upon the concept of "neighbourhood density" for individual words, where lexical items are stored in phonological space. This space varies in "density" according to the number of phonologically similar items which exist in proximity to a target word, which may be new to an individual listener. Using words of either high or low frequency and with few
or many similar-sounding word neighbours, Metsala found that RD children needed more input (more 50 ms gates) to guess the low-neighbourhood words. The importance of neighbourhood density in forming lexical entries and causing vocabulary to grow is emphasised by the apparent lack of an effect of item-frequency in this study.

The amount of speech input required for recognition predicted the youngest children’s reading performance, having controlled for differences in phonemic awareness and receptive vocabulary. The proposal was that “neighbourhood density” of similar-sounding words re. the target word…. “may play a role in structural changes in lexical representations in normal development, and these changes may be delayed in RD children.” Since the reading groups differed in rate for the low-density neighbourhood words only, neighbourhoods of high density are understood to “push” the listener/reader towards more detailed processing of new words, leading to a restructuring of vocabulary primarily in dense regions. Metsala reasoned that spoken word recognition itself is developmentally delayed in RD children, and may play a causal role in the failure the acquire alphabetic knowledge. If it is the case that some RD children have no problems with phonological/phonetic acuity tasks such as same-different discrimination and labelling, they may find it possible to develop their vocabularies in this way, but what of those RD children who do have a speech perceptual problem? Alternatively, if all RD children have some form of “phonological deficit”, how do they overcome the high-density neighbourhood condition for which, by definition, greater discriminatory care would seem to be essential in establishing a new word which is phonologically “close” to several other items?

What is also not clear is how relative slowness in word-completion (guessing on the basis of gated versions) in RD children can be clearly distinguished from individual differences in phonological acuity. Metsala’s measures of phonemic awareness were an initial and a final phoneme deletion task, and represent the inverse of the gating task. An effect of rate in gated word recognition of low-
neighbourhood words irrespective of word-frequency was obtained after controlling for ability on phoneme deletion, but did the words in the deletion (PA) tasks vary similarly in frequency and neighbourhood density? Despite some individual differences, it may be the case that gating task difficulties for certain words in RD children are due to systematic group differences in speech perceptual acuity for adjacent phones, and/or in word assembly/recall from a lexical store. It has been repeatedly shown that RD children tend to be rather slower and less accurate than CA controls in object naming tasks, again implicating overall (group) differences in word assembly procedures.

The body of research into other aspects of the phonological deficit hypothesis has thus far tended more explicitly to tackle the issues surrounding distinctness, or discriminatory weakness, for the development of word recognition skills. The analogy model of early reading (Goswami, 1988; Goswami and Bryant, 1990 and Goswami, 1993) proposes that the phonological awareness of many children entering school enables them to make use of orthographic analogies between particular word-pairs in beginning reading lessons (e.g. “beak”-“peak”). This use of analogies is possible because there are consistencies in the spelling-to-sound relationships between many pairs of words in the written vocabulary to which beginning readers are typically exposed. They have developed a sensitivity to (an appreciation of) rhyme (Bradley and Bryant, 1983). Crucially, the structure of these analogies follows closely their “onset-rime” division. Since LN children generally have a strong appreciation of rhyme before school entry, they tend to base their analogies for the pronunciation of new orthographic sequences on either the common onset (e.g. “trim”-“trot”) or the common rime (e.g. “beak”-“peak”). They are said to use this more than any other orthographic relationship between word pairs (e.g. “desk”-“risk”, “beak”-“bean”). This argument assumes that a child has knowledge of the phonological structure of the word at the level of the phoneme (initial-final consonant or initial-final consonant cluster) and of letter-strings, and can accurately relate this division to the orthographic string presented. In other words, the child shows an impressive degree of phonological awareness and can read several CVC words.
It is not clear from the analogy model how children develop knowledge of individual phonemes simultaneously with that of onset-rime division, or whether they are able to make comparisons between the spelling patterns of selected words before they have an adequate phonological underpinning of these same items. The latter point is especially relevant since phoneme-grapheme relationships are complex for many of the words used (for instance “beak” and “peak” have indirect phoneme-grapheme mappings – Guthrie and Seifert, 1977). Children who show poor appreciation of rhyme are apparently unable to make use of the orthographic analogy between known words and new, presumably because they are less sensitive to the phonological structure of the corresponding sound-patterns for words which are nevertheless within their spoken vocabulary. It is quite possible, though, that the ability to relate ‘onset’ and ‘rime’ portions of a word to its orthographic structure is merely one result of the achievement of sensitivity to the phonetic/phonemic structure at the sub-syllabic level of the speech pattern of, say, CVC and CCVC words. If so, it is not clear what the strict relevance of the analogy model would be to such sensitivity in LN children, or to the nature of the phonological deficit in SRD children (see Hanley, Reynolds and Thornton, 1997).

Kindergarten and first-grade children may have increasing sensitivity to phonological structure due, in part, to their limited reading experience. Bowey (1994) presented groups of novice and non-reading 5 year-olds with various tests of phonological and phonemic awareness, preferring to characterise them as tests of phonological sensitivity. Reading group performance was compared on phonological (sub-syllabic) oddity, initial/final phoneme oddity and phoneme identity tasks. Some 30% of the non-readers and 80% of the novice readers were able to perform above chance on the two phoneme identity tasks. Novice readers scored higher even than non-readers having similar letter knowledge on sub-syllabic oddity and phoneme identity. Among the non-readers differing in letter knowledge, marked differences on the four measures were found. Some non-readers did show sensitivity to single phonemes, but this was revealed only
when task requirements were simplified. It could be the case that phoneme sensitivity arises before, but remains latent as, letter knowledge increases, so that letter-sound correspondences are able rapidly to be established when exposure to print begins formally and regularly.

One of the most interesting points made by Bowey (1994) concerned differences in performance for the different groups on her chosen tasks. All found the phonemic oddity task too difficult, and most of the children forming her two groups of novice readers found the onset identity task (e.g. “dry”, “draw”, “plough”) too easy. In particular, she reported that “sub-syllabic oddity performance differences were consistently observed alongside other reliable between-group differences in phonological sensitivity”. The phonological oddity task was described as problematic only for “fragile phonological concepts”, perhaps explaining why “phonological oddity tasks differentiate between older, less-skilled readers and younger reading-level matches.”

With good ability in phoneme identity, a child aged about 5 years who also has good letter knowledge will be able, at least potentially, to complete some decoding from the start. Novice readers using this link will tend to “quickly understand the significance of the other letters within words as additional cues to word identity” (Ehri, 1992). Letters corresponding to only the more prominent (spoken) segments of high-frequency words were used to test their effectiveness in word reading for 5 year-olds by Rack et al. (1994). Their hypothesis was that children normally utilise their phonological skills in the form of a “direct mapping” mechanism. “good phonological skills facilitate the learning of relationships between the written form of words and their spoken counterparts.” If Bowey’s (1994) estimates of phonological sensitivity and letter knowledge were correct for LN children, then many of them should be able to relate three- and four-letter simplifications of word spellings to the words themselves, even when one such letter is changed (does not correspond to the correct pronunciation). Their performance should be weaker on “control” simplifications of spellings that do not have such a close phonological
relationship to the spellings of the same words. Two lists of words were used, in which either the middle or the initial letter was changed. The control words were of equal visual similarity to the source words and were intended to test whether pre-readers did better with visual cues whilst beginning readers did better with letter sequences which provided phonological cues (these children had been taught letter-sounds rather than letter-names). Association learning of 24 target-cue pairings took place over 3 days. There was a strong effect of cue-type, phonetically similar cues being learned more easily than control cues, but not of letter position. When the difference between the target and the cue letters was phonetically "close" the effects of cue-type and position were both significant, as was the interaction. Regular target items were better recalled than irregular ones.

What is not clear from either of these studies is the extent to which young LN children are able to utilise letter-sound relationships for vowels – Rack et al. followed Ehri and Wilce (1985) in ignoring vowel graphemes because they were considered less important than consonants in forming partial associations. This is a dangerous assumption since the uniform discreteness of consonant and vowel patterns in the orthography of target words is not matched by discreteness in the details of the corresponding phonology. An obvious test would be, in the regular word list, to include one appropriate vowel grapheme in each of the simplified representations and examine whether the overall recall rate would be higher than in the condition without them, having followed a similar training regime.

Bowey (1994) showed that pre-readers at age 5 years have some potential to decode from the start of reading lessons: their "phonological sensitivity" could thus have been utilised in the corresponding groups in the Rack et al. (1994) study in a similar way. This is not surprising since speech identification tasks for a full-cues continuum of the "coat"-"goat" contrast has shown reasonable categorical perception by about the age of 4-5 years (Simon and Fourcin, 1977). That young, pre-reading children have at least some phonetic sensitivity had also
been demonstrated by Chinnery (1992) for 3 year-olds. More than half were able to solve metalinguistic tasks at different levels. These were those of phoneme (synthesising e.g. /h/, /æ/, /ʌ/ → “hat”), morpheme (selecting the correct endings of words in sentences e.g. plural /s/ or /z/, or agent + “er”) and word (segmenting word chains such as “balloontreeshirt”). As Bowey showed, much depends on simplifying the design of the task and the way in which it is described to young children.

So what is the nature of the phonological deficit in SRD children? Fowler (1991) suggested that lexical representations become increasingly segmental between 1 and 8 years of age, and she proposed a “segmentation” hypothesis that it is difference in segment size which emerges as a central factor in generating differences in linguistic/metalinguistic development which are constantly employed in reading practice. Elbro (1996) attributed the difficulties of some children in establishing complete phonological representations (“prototypes”) in long-term memory to the structural incompleteness of representations, such that they often lack a degree of distinctness. That is, children who become dyslexic have... “poorer access to the most distinct variants of spoken words than other children.” Indistinct representations were proposed to be... “an inferior basis for the acquisition of phonological sensitivity (and for the later development of phonological awareness).”

In an attempt to link the phonological deficit of SRD children to weakness in a picture naming task (using only words which corresponded to pictured items that had been correctly named by different reading groups) a set of phonological awareness tasks was presented by Swan and Goswami (1997). These were: syllable tapping (up to 5 syllables), onset-rime judgement, where all word-pairs used mono-syllables and the onsets were 2-consonant clusters (e.g. “crust”-“cross”, “stop”-“stick”), initial/final phoneme judgement (e.g. “brush”-“block”, “cake”-“duck”), and a phoneme tapping task. For each task, the number of high- and low-frequency items was balanced. The “adjusted” scores (concerning only items which had been successfully named) revealed that syllable tapping
was at ceiling for all 4 groups, as it was for onset-rime judgement. In both cases, there was no effect of frequency, but there had been in the “unadjusted” scores which included all responses. However, the initial/final phoneme judgement task produced adjusted scores that continued to show accuracy varying with reading group. The SRD and “poor” readers were still impaired on phoneme judgements, as they were on phoneme tapping.

It is questionable whether naming performance relies specifically and entirely on the quality of phonological representations, since such naming efficiency in SRD’s has been shown to be improved following a training period involving frequent repetitions of the same naming task (Lemoine, Levy and Hutchinson, 1993). It is quite possible that the removal of items named inefficiently in the unadjusted scoring removed, predominantly, the low-frequency items which had been less often practiced. Practice in accessing particular phonological representations for the purposes of improving naming efficiency could benefit both reading-disabled and younger control children to a similar extent. That is, poor naming may be more strongly related to practice effects than to representational quality.

1.6. Some Theoretical Models of Speech Perception, and a Possible Link between Difficulties with Speech Perception and Beginning Reading.

In order to attempt to provide a conceptual framework for these issues which may help to formulate specific research questions, the following sections consider a selection of the models put forward for normal speech perception, normal reading development and reading-difficulties in children. This is necessary since a theoretical link between speech-perceptual processes and phonological awareness is required, whilst evidence of heterogeneity amongst SRD-children for accuracy on speech-perceptual tasks would need further explanation. Also, if there are clear differences in the dyslexic profiles of children in a group of SRD listeners, this may have a bearing on the pattern of speech-perceptual results if that heterogeneity is lawful rather than random.
1.6.1. The question of the "decision unit" in the skilled perception of speech.

For some considerable time, there has been widespread acceptance of the idea that speech is not perceived by processing a "string" of phones individually and serially (Cole and Scott, 1974; Liberman et al., 1967). Rather, a range of different types of acoustic cue has been hypothesized to require integration. Transitional, steady state and waveform envelope cues also operate over time-periods of different length. Emphasis shifted to the recognition of syllables within the speech stream (Cole and Scott, 1973, 1974).

The issue of the size of the "perceptual unit" in speech was addressed by Massaro (1974). Units of input, he reasoned, must be held in some form of storage until.... "the sound-pattern is complete", and the necessary recognition procedures have been applied to it. He used a vowel and CV-syllable recognition task where a masking noise followed the segment after some variable interval of silence. For very short intervals, errors were made at a higher rate than was the case without the noise. Performance improved for interval lengths of up to 200-250 ms. What Massaro called "pre-perceptual auditory storage" in the perceptual processing of speech was inferred not to exceed the 250 ms interval, implying that transformations (recognitions) could occur at a rate of about 4 per second. By relating this estimate to typical speaking-rates, Massaro proposed that stimulation falling within this duty-cycle must form a perceptual unit, and that its length is therefore roughly syllabic. A proposal that processing is carried out in fixed syllable-length chunks runs into difficulty when considering duration-times associated with the production of such monosyllabic words as "thrift" and "speech".

Experimental evidence in support of the partially-parallel processing of consecutive phones, rather than a purely serial-processing approach, was provided by Remington (1977). Remington's subjects were asked to indicate
whether two CVC-syllables were the same or different. A tone cue occurred at varying times after onset of the second CVC and often interrupted its presentation. Comparisons of subjects' accuracy as a function of time were compared across the first, second and third phones, and showed that some information accrued simultaneously. Accuracy for matching a given phone was above chance before presentation of a previous phone was complete, so that processing must have been at least partly in parallel. Much of this parallel information could arise from acoustic correlates of anticipatory coarticulation, such as when certain stop-burst and fricative-noise spectral peaks correspond closely to those of the onset of the following vowel (see e.g. Soli, 1981).

Language-normal children would need to use these particular perceptual skills, but may vary in the rate at which they develop for different phoneme-classes. If phonemes are routinely "recovered" more in parallel than serially from the speech stream by the processing of acoustic cues distributed across neighbouring phones, then listeners need to be able to make complex judgements about the perceptual-significance of a matrix of varied cues.

Consonants are identified by reference to their detailed spectro-temporal structure (see e.g. Stevens, 1980). As a consequence, much more processing effort would be applied to the consonant member of one of Massaro's CV-syllable units than to the vowel. This implies that a fixed unit-size for analytical purposes would have little value in itself and perhaps would not be relevant in practical terms, given the obvious variations in the depth-of-analysis across different phonetic categories.

If speech perception is segmental in nature, what type of "process" is it? The original "motor theory" proposed a direct link between speech perception and the articulatory movements necessary to produce the "candidate" speech segments (Liberman, Cooper, Harris and MacNeilage, 1963) but has proven controversial despite being often-modified. Klatt (1989) produced a paper reviewing selected models of speech perception. In this paper, the Liberman
and Mattingly (1985) update to motor theory was considered, according to which the basic processing units were the "intended gestures" associated with a phonetic segment during speech production. A still later version of motor theory emphasised that speech is recognised by matching the input precisely with the neural commands to articulators that would be necessary to reproduce the signal. Evidence which provides difficulties for Liberman and Mattingly's claim that speech production and perception are linked, so as to have a common "representation" and common processing strategy, is provided by Atal et al. (1978). It appears that a given set of formant shapes can be produced by several different vocal-tract configurations, there being generally at least one plausible shape for any selected vocal-tract length. In any case, such a transformation is technically demanding because of difficulties with the efficient tracking of formant frequencies. The nature of the transformation must be provided by motor theorists, who also have the problem of allowing for changes in vocal tract length and shape as a result of anticipatory coarticulation.

A further difficulty for motor theorists is how listeners could distinguish, in real time, those articulatory parameters which Stevens' observations have suggested define quantal changes in acoustic parameters from other articulatory parameters which do not. His "Quantal Theory" refers to how acoustic patterns appear to..."show a change from one state to another as the articulatory parameter is varied through a range of values". These acoustic, auditory and articulatory parameters were suggested as being used to signal distinctions in spoken language, so clearly the perceptual mechanism would need to take full account of their effects (Stevens, 1989).

Another development has been the proposal by Stevens (1986) that Lexical Access from Features (LAFF) can proceed without reference to any interpretation of segments. Instead, it operates by accessing the lexicon directly from a set of distinctive features, even if the features are not simultaneously present. Those given binary values are listed as, for instance, either (+ vocalic) or (- vocalic), and the major assumption is, as Klatt (1989) points out, that the
lexicon itself is represented as compiled from a feature-matrix to facilitate matching with the sequence of attributes extracted from running speech. Each feature is "weighted" according to its importance in the lexical decision process. It is not known in any detail how the computations of the features proceed or how the feature-weightings are arrived at, but at least this model has the advantage that it is not tied to a pre-determined segmental analysis and can, by monitoring feature-change events, allow for context-conditioning.

By relating the process of lexical access directly to the processing of spectra, the Lexical Access from Spectra (LAFS) model put forward by Klatt (1986) utilises stores of expected spectral patterns relating to words and to cross-word-boundary re-codings. It assumes that any phonetic transition is representable by one or more spectral sequences, and that lexical matching can be achieved at the level of spectra. This latter point makes the further simplifying assumption that spectral templates are somehow stored at the word level in an appropriate lexicon within long-term memory. The decoding network for any input must be fully expanded, allowing exhaustive searches if necessary, to include all possible word-combinations of English.

Klatt (1989) himself states that the model has several weaknesses, one of which is that spectra can not easily be re-processed to normalise across speakers. Speech spectrograms are characterised by rapid and extensive changes in spectral composition associated mainly with consonants, yet it is clear that, for the latest class of spectral representations used computationally, highly-smoothed estimates of local spectral change dramatically reduce the error-rate in many speech-recognition tasks (Rabiner, 1987).

Direct-realist theory (Fowler, 1994) is similar to motor theory in that it is proposed that listeners to speech do not "hear" acoustic speech signals but the phonetic gestures which produced the signal. For motor theorists, coarticulation problems are addressed by invoking biological adaptation of the human brain to cope with universal signal variability; adaptation which is somehow able to
specify the neural correlates of the intended gestures with respect to the listeners own speech-motor system. In direct-realist theory the main aim of speech processing, as with all perceptual systems, is to model the environment. In vision, light and shade give rise to the perception of form in the observer, whilst in speech perception the medium is sound-pressure waves which contain the phonological structure (form) of a language from phonetic sequences.

In great distinction to gestural models are information-processing models of speech perception. They assume the existence of distinctive, hierarchically-organised levels of processing, central to which are limited-capacity perceptual and memory "stores" in speech-signal analysis (Cutting and Pisoni, 1978). A typical example is the model put forward by Pisoni and Sawusch (1975) which exhibits "auditory feature analysis" from the output of a sensory information store followed by "phonetic feature analysis". The recognition device also contains a feature "buffer" of data extracted at the phonetic level, and allows significant feature combination before output is made. All of these stages interconnect independently with short-term and long-term memory stores, and all depend on the quality of the output of a preliminary auditory analysis of the acoustic input. Later stages to derive syntactic and semantic contexts are also assumed. Such models are, typically, vague concerning the details of how these analyses are partitioned from each other and how they proceed.

A model of phoneme identification which has been influential and which addressed the need for featural integration from multiple acoustic cues was that known as "fuzzy logic" model of perception or FLMP (Massaro, 1989; Massaro and Oden, 1980). Essentially, FLMP incorporates three operations: feature evaluation, prototype matching, and pattern classification. Features are evaluated on a continuous rather than a binary scale for the degree to which they are present in each unit of analysis (stretches of speech sound). For each of them, values between 0 and 1 are assigned (indicating the probability of the presence of each of them). Feature-profiles are then matched to stored prototypes - these represent idealisations of the acoustic correlates of each
phoneme. These profiles effectively select which algorithms should be used in pattern classification. The chosen algorithms are then applied to these profiles to generate a goodness-of-fit measure between the input and the prototypes, so that operations 2 and 3 are part of a single recognition process. The ability to continuously evaluate features provides a means of incorporating the often-reported finding that, at least for adults, detailed (acoustic) information remains available for reference in speech perception. This remains so despite the particular demands of categorical perception (Elliott, 1986; Elliott, Hammer and Scholl, 1989; Liberman et al., 1957; Miller, 1994 and Samuel, 1977). One of this model's strengths is that it does not rely on exact matches and so can deal with several aspects of acoustic variation.

The incorporation of variability of the speech signal into word recognition was emphasised in a review chapter by Pisoni and Lively (1995). Their work had concerned the role of sources of speaker variability, which appeared to assist rather than complicate the process of /r/-/l/ discrimination learning in Japanese listeners. Their main point was that variability is lawful and informative; that spoken language is composed of complex category structures from which detailed stimulus information is encoded and retained. “the emphasis on mapping speech onto discrete symbolic units has entailed an idealisation in research methods which has involved approaches which traditionally seek to reduce or eliminate sources of stimulus variability.” Pisoni and Lively maintain that it is wrong to treat such variability as a source of noise.

At the level of the sentence, speech perception has also been discussed in terms of the pre-determined knowledge which a listener can be expected to have with respect to a given conversation. Speech intelligibility depends, apart from the quality and contents of the signal, on variations in dimensions of listener knowledge (for instance, short- and long-term lexical and grammatical information). Allowing the signal- and listener-based sources of information to vary is central to what has become known as the “Hyper and Hypo” (or H and H) Theory (Lindblom, 1990). The speaker has basically to ensure that.... “the
linguistic units have sufficient discriminatory power for making the correct lexical identifications, not necessarily that they be invariant" (Lindblom, 1995). A “running estimate” is said to be made of the level of need of the listener for explicit information, with performance level (speech effort and precision) increasing from “hypo” to “hyper”. Temporal overlap tends to decrease in tandem. Therefore…. “the context dependence of articulatory and acoustic patterns is minimal in hyper- and maximal in hypo- speech”. Evidence for this possibility is, for instance, the variation within and across speakers of the frequency values of, say, the second formant frequency (F2) of a particular word, despite which listeners readily appear to hear the intended item correctly provided a semantic context is available.

Recent research has tended to suggest that adaptive speech production may also be relevant to infant and child listeners. For instance, there are reported to be indications that the infant-directed speech used by a parent towards the child (usually the mother) shows patterns of variability not unlike those of adult-to-adult speech (Davis and Lindblom, 1994). “H and H” Theory claims that this is done by…. “storing in phonetic/phonological memory exemplars of phonetic/phonological forms together with contextual information.” Therefore…. “prototypes for phonetic segments are not single points in phonetic space but prototype functions capturing significant and lawful patterns of co-variation”. This would suggest that, perhaps, fairly long sequences of utterances need to be routinely stored and processed in order to be able to derive and extract expressions of such lawful patterning, despite gross differences in their detailed acoustic structures. The need for ready communication enforces some consideration of word recognition theories. Prosodic detail has been proposed as a vehicle for guiding the listeners attention to strong syllables as opposed to weak ones in fluent speech. It may be an efficient way, it has been proposed, to…. “focus attention and initiate segmental analysis and lexical access.” It would rely on long-term (i.e. supra-segmental) analysis rather than strict left-to-right processing as in “cohort” theory (e.g. Marslen-Wilson, 1987).
The emphasis on some form of supra-segmental analysis is also evident in the work of Jusczyk (1993) concerning the development of infant speech perception, which emphasises their need to make holistic comparisons between portions of the speech input and various stored representations which may be acoustically-similar. Jusczyk's WRAPSA model ("Word Recognition and Phonetic Structure Acquisition") involves a preliminary analysis of the signal, where "[innate] auditory analysers provide a description of the spectral and temporal features present." The overall position of this model is that infants are innately able to analyse signals in such a way as to provide... "a very fine-grained description" of them. This is supported by reference to the empirical findings of syllable discrimination in infants (e.g. Aslin, 1987; Jusczyk, 1992 and Studdert-Kennedy, 1986). However, it is difficult to be certain how accurately infants' discrimination response of head turning reflects their actual discrimination abilities throughout a test session.

Therefore, it is evident that a range of current models of speech perception address issues of feature-analysis and item-recognition at either, essentially, the segmental or the supra-segmental level, with information processing models somewhere between them. It is quite possible that fluent speech can be said to be "perceived" only after making reference, where relevant, to all the sources of structured (lawful) information which may be available to the speaker from moment to moment, including visual information (lip-reading cues). This means the accruing of sensory-perceptual evidence for particular phonological patterns which construct a "candidate" utterance in sequential fashion, in conjunction with gross supra-segmental control at the level of semantically-plausible word/phrase entries. Supra-segmental analysis would seem to be accommodated, in part, by reference to, for instance, the amplitude envelope, periodicity and intonation pattern of a particular utterance (Rosen, 1992).

To refer to the question posed at the end of section 1.5.2., there does not seem to be a single model of speech perception which illustrates how deficits might lead to perceptual confusions of the kind reported for SRD children and adults. For
language-normal groups it has been found that 4 year-olds tended to make “close” errors in phonological analysis (Gerken, 1995), whilst many 8-12 year-olds differ to some extent in the contrastive use they make of formant frequency transition and voicing cues (Adlard and Hazan, 1998; Hazan and Barrett, 1998). From these results, taken with the work of Nittrouer on formant transition “weighting” (e.g. Nittrouer, 1992), it appears that young children’s global representations of native phonology reflect sensitivity to particular acoustic cues but are not necessarily “fine-grained” throughout. The rate at which a given child achieves the ability to make adequate auditory analyses of continuous speech may vary markedly compared to that of another child in the same mainstream junior school class. It also seems possible that individual differences in the fine-grained development of speech perception may persist into the adolescent and adult years of language-normal listeners. How these may relate to differences in same/different discrimination and labelling tests will be of central importance in this dissertation.

The strictly serial recognition of phones in speech perception is neither feasible in real time nor plausible because of contextual effects. It is proposed that normal speech perception must be an efficient system requiring the passive integration of cue-information about adjacent phones, arising from a definitive response-pattern of some kind. Decisions about the identities of the phones present in the signal are consequent on several sources of acoustic-phonetic information within successive phonological segments, i.e. that this perception is segmental. Theorists have also emphasised that speech perception is likely to be a multi-stage process, and that some acoustic-phonetic cues are more variable than others (e.g. Pisoni and Sawusch, 1975; Pisoni and Lively, 1995). The minimum "size" of a phonological segment in running speech is logically equivalent to two (adjacent) phones, e.g. a CV or a VC combination. SRD children and SRD adults showing difficulties with speech discrimination and/or labelling tasks are understood to be less able to adequately represent, and therefore to process, the variety of cue-information within phonological segments. For ease of description, such variety of information is referred to as
defining a "cue matrix". Recognition difficulties, and errors of temporal-order judgement in short-term memory, are regarded as consequent on the perceptual confusions and processing delays imposed by certain sensory limitations.

1.6.2. Theories of reading development.

There has been considerable debate on the contribution of visual and "phonological skills" (Seymour and Elder, 1986; Chall, 1967,1983), and different levels of "phonological awareness" (Goswami and Bryant, 1990; Morais, Alegria and Content, 1987; Stanovich, Cunningham and Cramer, 1984; Wagner and Torgesen, 1987) for the normal development of beginning reading. In short, there have been no clear demonstrations: a) that all SRD listeners have speech perceptual problems at least to a similar degree, and b) that the "phonological deficit", which has become broadly accepted as the root of reading problems, can be understood with clarity in terms other than those concerned with fundamental aspects of speech perception and phonetic acuity.

The area of reading development of most interest here would be one whose organisation contains a key element which could be intimately associated with individual-differences in phonetic acuity. Approaches concerning proposals for sequences of developmental "stages" in reading progress have been prevalent. That is the approach selected here for an outline discussion because it is judged to have potential for linking-in with issues of phoneme recognition, or more particularly, with children's phonetic acuity.

However, the "stages" format has typically described, only in very broad outline, changes in reading strategy which normally take place over several years of instruction. It will be necessary to try to concentrate on part of this sequence in discussing the possible role of speech perception. Against these, a theory of reading which emphasises children's underlying "phonological state" prior to reading experience has been put forward by Stuart and Coltheart (1988). This theory is also considered in a later section because of its relevance to discussions
about differences in the speech perceptual abilities of children aged about 4 to 6 years. The maturity of these abilities may allow many children to analyse speech sounds efficiently, and show early competence in a range of "phonological" skills.

There are many similarities in the content of the proposed stages of reading development put forward by Frith (1985) and Marsh et al. (1981), despite the variety of names used (e.g. Stuart and Coltheart, 1988; Goswami, 1993). In view of these similarities, the stages outlined below will use Frith's simpler terminology.

The "logographic" stage.

Both Marsh et al. (1981) and Frith (1985) emphasised that the first word-level entries to the individual lexicons of pre-literate children are achieved on the basis of whole-word or "logographic" processing. The logographic stage for Frith is equivalent to the "linguistic guessing and rote learning" stage of Marsh et al., and represents the first level of strategy for the processing of words in print. It was held to be the case that children had no formal reading training before they enter the school system, which is at age 5 years in Britain and age 6 years in, for instance, the United States. This can no longer be strictly true, because of the popularity of television programmes, such as "Sesame Street", which include some alphabetic-awareness training for pre-schoolers. For the sake of practicality, experiments with pre-school children have assumed that explicit alphabetic training has not been available, and that their word-knowledge (at the age of about 3 or 4 years) depends on domestic and environmental exposure to material such as picture-based story books and media advertising. Their mental lexicons contain entries which are recognised on a whole-word basis, with wholistic features such as estimated word-length, print size and the position of any ascending or descending lines (such as for the graphemes "d" or "g" respectively) being relevant.
The "alphabetic" stage.

The ability to examine words at the alphabetic level corresponds to the second or "alphabetic" stage for Frith (1985). This broadly corresponds to the second and third stages of Marsh et al. (1981), which are "discrimination net guessing", based largely on using discrete visual and linguistic cues, and "sequential decoding", which permits the reading of unfamiliar words at the level of regular CVC's. Both of these stages relate to the building-up of a "sight vocabulary" by beginning to use a simple form of analysis.

There has been disagreement as to how far, if at all, language-normal beginning readers are able to use alphabetic knowledge. An experiment run by Seymour and Elder (1986) with children aged about 5 years concluded that, if new words are presented holistically (without phonology) then they "...could be read only after they had been taught." The implication here was that letter-sound associations were restricted to spelling and writing practice of those words. For Seymour and Elder the children were beginning to form a "logographic" lexicon. However, Frith (1985) proposed that the need to deal with increasing numbers of similarly constructed words as a child's written vocabulary grew meant that the early "logographic" process became overwritten, or gradually superceded by, later analytical achievements based on alphabetic knowledge (e.g. the consistent sound of certain recurring multi-letter segments). Whatever the exact means, the significant growth of a language-normal child's written vocabulary after the first two years of regular reading instruction at school must clearly depend on the adequate development of some form of powerful, perhaps multi-purpose, representational tool.

An "alphabetic" principle in early reading lessons is often addressed by regular "phonics" training, one form of which was widely and systematically used by Orton (see Orton, 1937). This promotes the learning of how to accurately match first single consonant and vowel sounds with their graphic form (initially in lower case), and then in combination as a simple CV- or VC- syllable.
Importantly, there are several combinations of letters which form initial (e.g. "st", "pr" and "cl") or final clusters (e.g. "gh", "ch" and "It"). In some cases these consonant clusters are represented by a single phoneme, such as /ʃ/ for "sh" in "sheep" (/ʃɪp/), and /g/ for "gh" in "ghost" (/gɔʊst/). They do not, therefore, correspond to clustered phonemes, as /s/ and /p/ in "speak" (/spɪk/) do. It would seem that children about to enter school are typically on the verge of becoming able to segment the sounds within a word into units of at least syllabic length, and are thus able to make rapid use of at least a few alphabetic "strings" (e.g. Treiman, 1985a).

This would suggest that children entering school at age 5 or 6 years are able to take advantage of methods of reading instruction which emphasise phonics and alphabetic structure, thus increasing their written vocabulary. Substantial confirmation of actual improvements in children's reading ability in this age group has been made (e.g. Bradley and Bryant, 1983; Lundberg et al., 1988; Treiman and Baron, 1983; Vellutino and Scanlon, 1982). Therefore the "wholistic" approach studied by Seymour and Elder would be less efficient at promoting word-recognition because the relevant analytical tools are, by definition, not made available (Masterson, Laxon and Stuart, 1992). Attempting to read without phonology is inefficient because it seems that attention to the sound-structure of new words is a basic principle both of shaping a decoding strategy and of increasing phonological skills. The Cumbria-York study of 128 SRD-children over a 20-week period concluded that practice in phonological awareness has most effect on learning to read when combined with reading training (Hatcher, Hulme and Ellis, 1994). Explicit training of word reading using various multi-letter units was found to be widely effective for a group of Dutch children (Van Daal, Reitsma and van der Leij, 1994).

A study by Cunningham looked explicitly at how rapidly the word-recognition skills of 5 and 6-year-old children can be developed by manipulating the type of training given concerning early reading skills (Cunningham, 1990). She set up one lesson per week for ten weeks for three groups each containing children of
different ages, which received only "skill-and-drill" training, "metalevel" training or a control training procedure. The metalevel training allowed more explicit teaching of the particular value of segmentation and phoneme blending for reading, whilst skill-and-drill training concerned procedural knowledge of segmentation and blending. The control group listened to stories, answered questions on them and had the story summarised by the teacher.

It was found that, after this set period, children of both ages in both experimental groups made significant improvements in tasks of initial phoneme deletion, phoneme oddity and auditory conceptualisation (Lindamood, 1979), but that control children did not. Differences in the content of some training methods do appear to lead to differences in performance. Between the two experimental groups, the first-graders (6-year-olds) made particular advances in their subsequent reading achievement. Although the older group probably already had at least some knowledge of letter-sound correspondences through exposure to the alphabet, the post-training results suggest rates of learning which would be hard to achieve only by a process of visual analysis. According to Muter (1994) some language-normal children may require exposure to the alphabet in combination with speech-sounds to develop observable levels of letter-sound knowledge and make rapid progress with CVC-word recognition in their initial lessons. Treiman's (1985a) comment that children about to enter school show latent ability for segmentation of at least syllabic length for certain words was supported by Cunningham. Cunningham concluded that...."(they) are capable of displaying a certain level of proficiency in phonemic awareness, and when stimulated with training, perform better than a first-grade control group. This knowledge, however, does not appear to develop fully without some impetus from the environment."

Tunmer and Nesdale (1985) had noted that early-readers' skill-level for phoneme-grapheme knowledge and letter-sounds were related to (could be shaped by) the method used to teach reading. Explicit instruction and repeated exposure made even the decoding of vowel digraphs more reliable. Masterson
et al. (1992) in fact demonstrated that 6-year-olds were already showing, in their accuracy for reading aloud and their comprehension of single words, clear effects of word-regularity and word-frequency. High frequency, regular words were understood to be processed by whole-word (rapid) recognition. Clearly, frequency of exposure allows the increasingly-rapid recognition of longer letter-strings, emphasising the importance at this stage of "episodic" learning, but it is not so clear how a purely "visual" analysis of these words could account for the observed faster recognition of most "regular" than of most "irregular" words.

In summary, research studies have supported the view that the vocabulary of pre-school and first-year schoolchildren develops rapidly when their exposure to words includes an analytical component relating the letters and letter-groups to distinctive utterances, and a synthetic component when children are asked to practice the blending of the sounds.

The relationship between speech-perceptual development and the development of word recognition in kindergarten and first-graders could, then, concern the ability to relate single letters (and certain digraphs) to a particular speech-unit or combination of speech sounds. To some extent, they could be able to relate consistencies in the way in which phones, diphones or phone-combinations are produced to the constancy of the discrete alphabetic code. Different language-normal children could vary considerably, though, in the rate, consistency and accuracy with which they make these associations.

*The orthographic stage.*

The third and last of the overlapping developmental stages is the "orthographic" stage, which, according to Seymour and MacGregor (1984), involves the internalisation of a sophisticated model of English orthography. It proposes that an "alphabetic" lexicon (word file), with knowledge of letter-sound correspondences, are developed to cover the relationships which are possible between multi-graphemic units and pronunciation. Conventions of orthography
particular to a language (such as "qu..." in preference to "kw..." in English) are noted. That such rules are used was shown by a study of young language-normal adults by Baron and Strawson (1976). Subjects were found to read aloud more quickly each of five lists of 10 mono- and bi-syllabic words which conform to spelling-sound correspondence rules (e.g. "sweet" and "along") than five lists of 10 mono- and bi-syllabic words which don't conform (e.g. "sword" and "honey"). The upgraded alphabetic lexicon, by the application of these many conventions governing the pronunciation of irregular or "exception" words, is then understood to be, increasingly, an "orthographic lexicon". It is therefore seen to serve as a general-purpose system for translating from print to pronunciation, or from phonology to writing.

Any deficit at the orthographic stage is probably not due to simple lack of successful experience with reading. There is evidence that age-matched children have generally larger "written" vocabularies than dyslexic children (Aguiar and Brady, 1991), and that SRD children are able to make less use than reading-age matched children of orthographic analogies (Hanley, Reynolds and Thornton, 1997). Also, adult dyslexics who have developed functional reading skills through the use of non-alphabetic reading strategies, and who experienced difficulties with certain phoneme contrasts as beginning readers, can retain the same auditory difficulties of identification, remaining unable to master the regular pronunciation of unfamiliar (nonword) material (Masterson et al., 1995). They suggested that phonemic processing problems..."lead to a failure to develop alphabetic strategies in general", leaving developmental phonological dyslexics..."with only a primitive capacity for non-lexical processing".

There is general acceptance of the proposal that..."children with reading disabilities often have deficits in basic phonological processing skills" (Jorm and Share, 1983). It may be possible here to outline the possible nature of some problems with phonological processing and how this might affect phonemic awareness. The normal development of phonemic categories, and the appreciation of phonics and correspondence rules, would seem to rely intimately
on a child's ability to compare and contrast, in real time, the acoustic-phonetic features of a given matrix of cues. Reduced ability, on a proportion of occasions, to process this variety of acoustic information can be understood as weakening a subject's appreciation of which acoustic variations relate to a change of phoneme and which to instances of a number of different phones of the same phoneme. Difficulties with the establishment of a full range of internal representations of phoneme classes could relate to a particular pattern of difficulty with decoding regular, but unfamiliar, orthography in developmental dyslexia. A summary of two of these patterns of difficulty is made in the following section.

1.6.3. Distinguishing performance-related "sub-types" of developmental dyslexia.

Not all workers in the field of developmental dyslexia agree that a clear difference in the reading difficulties of individual children can be related to different sub-types. However, there is a consensus that the great majority of these children have some form of phonological difficulty (e.g. Laxon, Masterson and Coltheart, 1991; Morais, 1991; Stanovich, 1994; Wagner and Torgesen, 1987; Wilding, 1989). A recent paper by Stanovich, Siegel and Gottardo (1997) has gathered considerable empirical evidence in support of this system of subtyping both by re-analysing the original data from Castles and Coltheart (1993) and by completing their own study of the distribution of irregular word and nonword reading-accuracy scores. The distinction made by Seymour and MacGregor (1984) is used here because it centres on phonological difficulties, emphasising that most reading-disabled children have problems with either irregular or nonword decoding (or both). It follows the atypical reading-spelling patterns suggested by Boder (1973) for developmental dyslexics.

Seymour and MacGregor (1984) carefully described three sub-types of developmental dyslexia, namely "phonological", "morphemic" and "visual-analytical". The details quoted below are selected from those with regard only
to the first two of these classes, since this dissertation is not concerned with such issues as the possible effect of format distortion on single-word reading described under "visual-analytical" dyslexia.

1.6.3.(a). Developmental Phonological Dyslexia.

Seymour and MacGregor (1984) defined this in the following way:

"Phonological dyslexia is viewed as a disturbance in the development of the alphabetic and orthographic lexicons which has its primary cause in the phonological processor. It is likely that this involves the representation of sub-syllabic speech categories and their temporal location. On the other hand, the phonological disturbance need exert no adverse effect on the extension of the logographic lexicon to cover a widening range of vocabulary. The following predictions can be made:

1. Word reading, especially for items of higher frequency, should be more efficient (in terms of vocal reaction time and accuracy) than non-word reading.

2. Tasks involving semantic access should be performed better than tasks involving phonological access.

3. Word reading should not be sensitive to variations in spelling-to-sound regularity, but may be affected by semantic or syntactic variables."

Put at its most basic, Seymour and MacGregor (1984) suggested that the distinction between these two types of developmental dyslexia is that "phonological" dyslexia concerns a deficit in the phonological processor, whilst "morphemic" (or "surface") dyslexia relates to a deficit in the graphemic (string) processing of whole words. Variations within this latter classification have been proposed (Temple, 1985).

1.6.3.(b). Developmental Morphemic (Surface) Dyslexia.

Seymour and MacGregor (1984) defined this as:
"A developmental disturbance affecting both the logographic lexicon and the orthographic lexicon. Such an effect would derive from a primary defect of the wholistic and en bloc functions of the visual (graphemic) processor. Serial processing would, on the other hand, be compatible with the formation of an alphabetic lexicon designed for recognition of individual graphemes and their correlation with sound. The combination of serial visual processing and an alphabetic form of lexical organisation predicts:

1. Serial letter-by-letter processing should be indexed, across a range of reading tasks, by a tendency for reaction time to increase linearly with word-length. The processing rate (i.e. the slope of the regression of reaction time against number of letters) should be slower than that observed in normal readers.

2. Non-word reading, though somewhat defective on account of the absence of an orthographic lexicon, will be better than reading of lower frequency words, especially [with] irregularities of [letter-name] to sound.

3. Word reading need not be affected by irregularity in the higher frequency ranges, but there should be a large effect for lower frequency words. Errors on irregular words should often be phonetic regularisations. Semantic and syntactic variables should produce no effects."

The use of square brackets above indicates editing by the present author.

"Phonological" deficits (i.e. weaknesses of "phonetic acuity" and phoneme recognition) jeopardise the decoding of words into letter-sounds which are then to be modified and blended in proceeding from the sub-syllabic to the lexical level. Morphemic dyslexics tend to have a good knowledge of letter-names and sounds (they can spell words phonemically), but are weak at assembling and integrating these identities into multi-syllabic units. In either case, therefore, the appropriately blended speech sounds are often not mapped efficiently onto grapheme-strings so that a valid pronunciation is not constructed.

Poor phonemic awareness may also have direct relevance to the spelling difficulties of dyslexic children. Is spelling ability governed by visual-memory for grapheme-strings, or by the subjective distinctiveness of the phonology of words? Many young language-normal children are weak at spelling. Do the patterns of their spelling errors deviate from, or bear resemblances to, those of
children whose spelling difficulties are an indication of dyslexic-type problems? The phonological distinctiveness of certain phonemes is seen to be important in determining the accuracy of the spellings of both normal and SRD-children. Speech-perceptual acuity in pre-schoolers is implicated in predictions of reading development in a recent theory considering segmental phonology and appreciation of "phonics".

1.6.4. Theory of "phonological state".

The implication that the ability to manipulate phonemes arises only as a result of introduction to the alphabet and some phonics training, after a "logographic" stage had been passed through, was challenged by Stuart and Coltheart (1988). They undertook a longitudinal study of 36 language-normal nursery-class children on tests of rhyme production and rhyme detection, supplying item-final syllables and phonemes, and identifying and segmenting the initial phoneme.

The ability of children to perform successfully on these phonological tests was measured at regular intervals from the age of about 4 years to about age 8 years. This data was related to individuals' scores on reading and letter-naming tests. The level of these skills pre-literally was such as to suggest to Stuart and Coltheart that..... “children who are phonologically-skilled before learning to read might use their phonological skills from the beginning. Children who are not phonologically skilled might initially treat reading as a visual-memory task.” This conclusion was reached on the basis of arguments from two sources.... “firstly, the relationship between the children's scores on phonological tests given in the nursery, their letter-sound scores, their IQ scores, and their reading-ages on different dates; and, secondly, from the relationship between patterns of substitution errors in single word reading, the children's letter-sound scores and scores on phonological tests given in the nursery.” By means of partial-correlations they were able to show that knowledge of both letter names and sounds are strongly correlated with phonological scores.
To the extent that children might become able to "abstract" phonemes from within spoken words and learn to associate a particular grapheme with them, the study of phonetic deficits in reading-disabled children has most relevance to the "alphabetic" and "orthographic" stages of reading development. The refinement of speech perception and the growth of knowledge of letter-sound regularities could relate to improvements in phonetic acuity.

Stuart and Coltheart concentrated on how children become able to translate from sound to print. They suggested that... "the child with good phonemic segmentation skills and good knowledge of letter-sounds can begin to construct an orthographic lexicon without necessarily having any formal experience of printed words." Knowledge of letter-names seemed to develop more gradually and may not be essential to beginning readers. Children with poor segmentation skills could therefore have problems at the speech-perceptual level or with the isolation and temporal-ordering of the phones comprising an utterance, or with both.

1.6.5. Skilled reading.

Whenever it is stated that reading is a complex skill, reference is being made to the levels of data processing that a successful skilled adult reader is able to employ. These include sensitivity to the effects of both local and general context, syntactic rules, semantic relationships, holistic word recognition and the ability to ignore some function-words.

Skilled readers are thought, by several workers in this field, to utilise two complementary procedures or "routes" to decoding individual words (e.g. Castles and Coltheart, 1993; Seymour and MacGregor, 1984; Snowling, 1980). The so-called "dual-route" model of skilled reading refers to lexical and sub-lexical procedures (Coltheart, 1978; Marshall and Newcombe, 1973). It has received wider support than single-route models (e.g. Marcel, 1980). Reading aloud via the lexical route involves retrieving, from a mental lexicon, the entire
phonological form appropriate to a particular orthographic stimulus, particularly when handling irregularly spelled words (e.g. "island", "soup" and "break"). Reading aloud via the sub-lexical route involves using correspondence rules between orthographic and phonological segments to assemble appropriate pronunciations of words. The sub-lexical route is thought to be primarily responsible for dealing with unfamiliar and nonsense words. This model has empirical support from studies of acquired dyslexics (brain-lesioned subjects) who very often show a selective loss of one or the other of these skills (e.g. Baddeley, Logie and Ellis, 1988).

1.6.6. Pre-readers, beginning readers and sub-lexical skills.

The developed "phonological state" of some pre-readers, who go on to make good reading progress, appears to allow them to quickly master a range of letter-sounds and abstract speech-sounds from their knowledge of segmental phonology. If this is the case, then sub-lexical skills are likely to be central to beginning reading (see Byrne and Fielding-Barnsley, 1989; Catts, 1993; Ellis and Large, 1987; Gathercole and Baddeley, 1993; Liberman, Shankweiler, Fischer and Carter, 1974 and Seymour and Evans, 1994). Is there evidence that reading-disabled children are weaker in their ability to analyse speech signals into smaller segments than normal children when both groups are at a chronological age when reading skills are modest? Two studies, one involving rhyme-judgement and the other concerning speech discrimination in kindergarten and first-grade language-normal children, are outlined below to address this question. The second study also provides some evidence that children of these ages who are making slower progress with reading already tend to show weaker sub-lexical skills. A third study indicated that normal preschoolers are not necessarily able to analyse speech at the level of a single phoneme.
Rhyme judgement.

One of the main experimental devices using auditory discrimination has been the "oddity task", which relies on the "onset" and "rime" sub-divisions of both monosyllabic real word and monosyllabic nonword items (Bradley and Bryant, 1983). Assuming that an item does not begin with a vowel, the onset is held to consist only of the initial consonant or consonant-cluster, whilst the rime consists of the first vowel and all subsequent consonants and vowels. The basic task is to select the word from a set of items which doesn't rhyme with the others. In a normative task requiring children to select a word which rhymed with a (single) target word, Lenel and Cantor (1981) systematically varied both the number and position of the phonemes which were the same and different in the non-rhyming and stimulus words. On each trial, monosyllabic words were presented aurally in sets of three to 4, 5 and 6 year-old children, with corresponding picture cards presented on each trial for the youngest children. There were 48 subjects in each age group. It was shown that the pre-school group was able to perform significantly above chance, even for the most difficult categories. They showed some ability to analyse and compare the phonemes comprising "rimes" in order to make their selection.

Phoneme discrimination.

Chinnery (1985) found that 4 and 5-year old children had difficulty in discriminating between paired fricatives and paired stops in CV and VC targets when the vowel context changed. When only the consonant identity was varied they showed greater accuracy for stop than for fricative discrimination. The indications are that kindergarten and beginning-readers are able to perform some phonetic comparisons at a syllabic (sub-lexical) level, but their discrimination judgements may be dependent on how part of the relevant acoustic-phonetic information is distributed across a syllable's constituent phonemes. Less accurate phoneme discrimination was found for those beginning readers with weakest reading ability, and for an independent group of weaker readers.
Single-phoneme analysis.

The importance of Chinnery's observation, that relevant acoustic-phonetic information distributed within stimulus items can influence the discrimination-judgements of normal children at about age 4 years, was emphasised by the findings of Gerken, Murphy and Aslin (1995). They evaluated the proposal that young children's lexical representations are based on overall acoustic-phonetic properties rather than on phonetic segments. They asked 3 and 4 year-olds to match, using a plate-pressing design, a series of nonwords presented auditorally with an invariant "target" word. The test stimuli varied in the degree of phonemic-feature correspondence with the target, the position(s) within the stimuli at which they might differ, and whether they differed on one or two segments. An example of a stimulus set used is:- target = "little" (/litl/), nonword comparisons = /nitl/, /letl/ and /ligl/. Confusions were found to be influenced by the extent of the "featural overlap", but not by segmental position. Stimuli differing from the target by two features on a single segment were more often confused with the target word than those differing by a single feature on two segments.

Young children's discrimination abilities may indeed be dependent on how some of the acoustic cues to items are distributed. It appears that this dependence may be reduced, or reducing, developmentally in the language-normal population by the time explicit classroom instruction in phonics, letter-sound correspondences, reading and spelling begin. The evidence from the spelling errors of language-normal and SRD-children further emphasises the importance of phonological variables. Some of this evidence is reviewed in the next section.

1.7. Spelling Development in Normals and SRD Children.

The development of spelling accuracy is dependent on the subject's ability to select letter-shapes from an orthographic store as required by the content, for
known words, of input phonology. This can not be fully functional if selection and/or sequencing operations are impaired. Experiments have shown that the normal development of spelling is error-prone, piecemeal, and strongly dependent on the child's detailed awareness of the phonological structure of the input. New words will often be spelt by analogy with the spoken-form of words which they do know how to spell, and many spelling errors will be phonologically-plausible.

The following section reviews some of the key findings of studies of the development of accurate spelling in both language-normal and SRD-children. The theoretical interest in doing so relates to the possibility that SRD children with speech perceptual difficulties might have markedly weaker phonological awareness than other SRD children. Spelling-to-dictation, like phoneme deletion, is a task which directly concerns phonological awareness, individuals' accuracy with which might vary systematically with speech perceptual skills. Does empirical evidence exist that some SRD children are markedly weaker spellers than others? If so, are these children identifiable as "phonologically dyslexic"?

1.7.1. The role of phonological processing in spelling development.

There is a body of experimental evidence that emphasises the importance of the perceptual prominence of phonemes in the normal development of spelling strategies in young children. Indeed, Read (1971) proposed that many spelling errors... "can be explained by recognising that children's phonological judgements are embodied in their spelling and that their representations have a phonetic basis." The extent of acoustic analysis necessary to the perceptual distinction of two consonant phonemes in word-initial consonant clusters may not generally be achieved by children aged about 6 years. Their limited phonological representations of such segments may be informing their reading and spelling of words containing them.
Treiman (1985a) produced evidence that a sample of children of this age made 74% errors when reading CCV's, tending to read them as beginning with a singleton consonant, e.g. "san" /sæn/ for "sna" /sna/. They also made 61% errors on reading CVC's, making singleton substitution errors. Second grade children (about 7 years) had less pronounced difficulty with the reading of CCV's. By pooling their spontaneous writings, Treiman estimated that normal beginning spellers aged 6-7 years failed to spell the second and third consonants of "onset" clusters over 20% of the time. They spelled "blow" as "bo", "tree" as "te", "street" as "set" and "sret", and "haystack" as "hasak". This normative tendency at around age seven gave Bruck and Treiman (1990) a baseline, and a set of error-types, by which to judge the performance of older SRD's using combinations of CVC, VCV, CCV and CCVC items. That language-normal children in 2nd and 3rd grades tend to make progressively fewer phonemic simplifications in spelling than in first grade was shown by Hoffman and Norris (1989), a trend which Treiman at al. (1993) confirmed. Children will reduce clusters by substituting a related sound for two or more of the consonant graphemes, (e.g. "ges" for "dress") or, as was illustrated above, by direct grapheme-deletion.

A further illustration of just how important phonology is to the spelling of beginning readers is given by a study of the spelling of words containing syllabic consonants such as "l" in "easel" and "n" in "carton", by Treiman, Berch, Tincoff and Weatherston, (1993). Vowel omissions and mis-orderings were found in the spellings of groups of kindergarten, 1st. and 2nd. grade school-children (i.e. children aged between 4 and 7 years). Young children also seem unsure of the more abstract rules which dictate how vowel digraphs are pronounced in particular words. They are also expected to be less accurate than older control children in the reading of monosyllabic nonwords, since these often contain (legal) vowel digraphs (see e.g. Laxon, Masterson and Coltheart, 1991).

The variety of different spelling-errors illustrated above can be quite neatly
summarised. Treiman et al. (1993) estimated that children in the 6-8 year age-bracket have a tendency to prefer spellings... "which allow each unit of sound to map onto a single letter." There seem to be few, if any, digraphs in their spellings. Simplified phonological representations are normal in children who are beginning readers. However, these representations typically come to be fairly quickly amended (if improvements in spelling accuracy are a guide) following structured experience of phonics (explicit training in a particular set of grapheme-phoneme correspondences), and reading practice.

1.7.2. Phonology and the spelling patterns of SRD children.

Comparative data on such identification tasks by dyslexic and normally-reading children were provided by Bruck and Treiman (1990). They tested the phonological awareness of item-initial singleton consonants and two-consonant clusters, since a survey of several phonological awareness tasks by Stanovich, Cunningham and Cramer (1984) had led to the conclusion that...."performance was better when the critical sound was at the beginning of the word than at the end".

Substantially as had been reported in the study by Stanovich et al. (1984), Bruck and Treiman found that the spellings of the two subject groups (SRD and normal) for the above item-structures were similar:- both made more illegal spellings for the CCV words and nonwords than for CVC items, but the SRD's error rates were significantly higher. Similarly, both groups omitted a consonant from both words and nonwords more often when it was the second consonant of a CCV than when it was the first consonant, and this trend was stronger for the SRD children. Therefore, to some extent, the reading-disabled group appears perceptually disadvantaged in incorporating the reduced salience of coarticulated phones relating, in orthographic terms, to the second-consonant positions within CC-clusters.

Implicit in the theory of "phonological state" of children's reading and spelling
development, is the conclusion that it is not possible for a child to achieve age-appropriate sub-lexical reading skills whilst s/he also has appreciable problems with speech-perceptual tasks. As was stated above, the evidence from other studies on children impaired with respect to language-learning indicates that some members of these groups have problems with speech perception, and that these children have reading difficulties (e.g. Bishop and Edmundson, 1986). However, research on groups of SRD children does not seem to indicate markedly more problems for some individuals than for others in generating phonologically plausible spellings. The main experimental phase of this study will not, therefore, include a spelling task.

1.8. Summary and Development of the Current Study.

Points emerging from the above areas of discussion are as follows:

* The strongest recurrent evidence is that reading-disabled children have simultaneous problems with access to, and manipulation of, phonological variables.

* There is little consistent evidence for a general auditory (temporal) problem, of any magnitude, which applies to a variety of non-speech tasks.

* The existing evidence for a phonemic / phonological deficit in developmental dyslexia is based on evidence from a relatively small number of speech contrasts.

* There is no consistent evidence that the subtle problems with discrimination of stop- and fricative-pairs noted in the literature are based solely on problems with short-term memory (STM) as it relates to acoustic-phonetic stimuli.

* Speech-perceptual difficulties would be expected to impact on the learning of the "alphabetic principle" in (sub-lexical) reading through disruption of phoneme-grapheme mapping. This could be because accuracy in sub-lexical
reading may be predicated upon speech-perceptual acuity, in terms of segmental phonology.

* The normal development of reading skills to adult levels of fluency requires, minimally but crucially, the development of two levels of "phonological" representation. The first involves the emergence of adequate representations of a full range of language-relevant phonemic-contrasts, whilst the second would concern detailed knowledge of abstract pronunciation rules (over-riding the simple alphabetic rules) to cover irregular words in an individual's written vocabulary. These would correspond to the "alphabetic" and "orthographic" stages of reading development put forward by Frith (1985). It appears possible that the range of reading performance on the regular, irregular and nonword lists in any SRD group would be large enough to generate an overlap between the basic error-patterns for "phonological" and "morphemic" dyslexia. Many dyslexic children might show neither pattern exclusively, but some combination of the two, as Castles and Coltheart (1993) suggested. This would not mean, though, that these two distinct types of problem with decoding are indistinguishable; merely that several SRD subjects are likely to exhibit difficulties with both levels of representation, but to varying extents.

* Speech-perceptual difficulties may be congenital but discoverable only much later through problems at appropriate stages in the normal developmental sequence. Such a possibility would give rise to a causative (certainly directional) relationship with phonological awareness and early-reading difficulties.

* Practice at reading (whether generally successful or not) does not seem to eliminate speech-based confusions which individual SRD's may experience.

* The existence of heterogeneity of performance in standard speech-perceptual tasks amongst SRD-children needs to be explored systematically.

* There may be a functional relationship between speech perceptual difficulties
and the type of reading problem which individual SRD-children present with.

* The existing evidence for speech-perceptual limitations in SRD-subjects is largely based on the use of stylised synthetic continua, yet, to be ecologically valid, similar results must be demonstrated for natural speech items.

1.9. The Area of Study in this Dissertation.

1.9.1. Research questions.

Question 1. Are discrimination errors by SRD-subjects related to the synthetic nature of the stimuli, or would they also arise using exclusively natural speech?

The desirability of control over individual aspects of the speech signal led to the widespread use of synthetic speech in this field of research. Some of the stop consonant-vowel (CV) speech tokens tended to vary in the number and/or stylisation of their acoustic components, for instance in comparing the /ba/-/da/ tokens of Tallal and Stark (1981) with those of Godfrey et al. (1981). Also, the /ba/-/da/ tokens of Tallal and Piercy (1974) seemed to have been constructed without release bursts. Would it be possible to show discrimination errors in SRD children using natural speech?

Question 2. Which phonetic classes are reliably less-well contrasted by SRD than by control children?

In both the pilot tests and the main phase of experiments it is proposed to use real-word minimal pairs to contrast a selection of stop, fricative, nasal and approximant consonants in item-initial position.

The discrimination of fricatives and nasals is said to be a task of intermediate complexity, since these consonants contain fewer acoustic components and
spectral changes, and are generally of somewhat longer overall duration than stops (Philips and Farmer, 1990). The issue of phonetic "complexity" is therefore also of relevance in such an analysis. To demonstrate weaker discrimination for these phoneme classes would remove the possibility that previous results for experimental children were stimulus-bound (i.e. applicable only to the acoustic-phonetic properties of the limited range of stimuli presented).

Question 3. Do most reading-disabled (SRD) children show problems with speech perceptual tasks, or do such difficulties only relate to those individuals in the group who are most likely to be "developmental phonological dyslexics"?

Several references were made above to studies where the individuals comprising the experimental group clearly did not perform uniformly, for example, on TOJ or discrimination tasks, with appreciable numbers within some samples behaving indistinguishably from normals. Clearly, part of the observed heterogeneity of reading-disabled groups could originate from the different selection criteria used; such as the age-range, mean reading-delay, or the presence/absence of receptive-expressive difficulties with language. Measures will be taken in this dissertation to control selection by attempting to set reasonable upper and lower limits for both reading-delay and dyslexics' chronological-age (CA) range.

It is proposed that one such source of heterogeneity may not be random, but lawful, in that it may relate fairly precisely to the underlying nature of the reading problem which certain individuals present. Only by measuring the extent of individuals' weaknesses with particular reading materials (regular and irregular word lists, and a nonword list) can this proposal be tested.

Would the heterogeneity of the experimental group for speech-perceptual accuracy be well represented by partitioning of those who had one particular
"type" of reading-accuracy profile when using these lists? The remaining subjects might have no such perceptual problems. The interest in the theoretical potential for partitioning the experimental subjects into sub-groups is quite specific. It is proposed that a "sub-group" of children might be shown to have consistent problems with a range of speech-perceptual tasks, and that these problems generate phonemic confusions which can hinder the development of knowledge of a range of grapheme-phoneme correspondences. Thus their knowledge of the alphabet (letter-names and letter-sounds) and, more particularly, their ability to benefit from routine training in phonics and appreciate subtle details of how letter-sounds change when blended in different combinations, could be impaired.

The complementary proposal is that those SRD-children who make few errors in speech perception have a reading problem primarily with learning the abstract pronunciation rules of irregular orthography. They would thus tend to present a "morphemic"- or "surface"- dyslexic pattern of more-accurate nonword than irregular word reading (see e.g. Castles and Coltheart, 1993; Frith, 1985). This is not to say, however, that the distribution of reading-profiles will be exactly or clearly demarcated. Castles and Coltheart found many children (using fairly large samples) whose performance did not fit with either pattern. What would be necessary to show here, however, is that SRD-children making speech-perceptual errors could be associated with the "phonological" pattern, whilst, ideally, none of those children producing a recognisably "morphemic" pattern show significant error-rates.

**Question 4. Do reading-disabled children produce reliably higher confusion-rates for non-speech discrimination tasks?**

To examine the argument for a relationship between "speech-perceptual" difficulties and developmental dyslexia, it is intended to develop and present a range of psychoacoustic (non-speech) discrimination tests.
1.9.2. Summary of methods.

The following methods will be used across either the pilot or the main test-battery phase of experimentation:

**Standardised tests.**

Reading accuracy, reading comprehension and non-verbal intelligence will be tested using internationally recognised standard tests. Children will be seen individually and tests will be run according to recommended procedures.

**Reading lists.**

**two** vocabulary-controlled lists of words, one regular and one irregular;  
**one** list of nonword items.

**Speech-perceptual testing.**

The "same"/"different" (AX) method of discrimination will be used throughout for consonant contrasts in minimal-pair format. These will consist of various sets of:

- taped, naturally-produced, monosyllabic real words;
- taped, naturally-produced, bi-syllabic nonwords;

If perceptual confusions are due to the properties of the speech stimuli themselves, they should be apparent if the inter-stimulus intervals used are of sufficient duration not to create time-pressure on the task. The approach used here will be to use single ISI durations in speech discrimination tests of about 1 second throughout.

Identification, using a computer-controlled adaptive technique, of:
one stop and one fricative contrast using a total of five copy-synthesised continua.

Copy synthesised versions of the selected words were prepared using the KLSYN88 version of the Klatt synthesiser (Klatt, 1980). In these copy-syntheses, each synthetic token was closely modelled on an utterance produced by a phonetically-trained female speaker via a comparison of the short-term spectra of the natural and synthetic utterances. Contrary to parameter settings in more stylised synthetic continua, parameters such as formant frequency and amplitude values therefore varied throughout each utterance.

Repetition-accuracy for speech-items presented individually.

This concerns sets of:
taped, naturally-produced, monosyllabic real words,
taped, naturally-produced, monosyllabic nonwords,
taped, naturally-produced, polysyllabic nonwords.

Phonemic awareness testing.

Initial (consonant) phoneme deletion.

Psychoacoustics.

one test of the detection of silent gaps ranging in duration from 0 (no gap) to 20 ms;

one test of the detection of the modulation of a 1 kHz reference tone ranging in depth from 0 (no modulation, the reference tone being paired with itself) to 300 Hz in steps of 60 Hz;

two tests of tone discrimination: a) relating to fundamental frequency
discrimination where a 125 Hz fundamental was paired with itself and a range of frequencies from 129 to 145 Hz in 4 Hz steps, and \textbf{b}) a 1 kHz tone-pulse, shaped to simulate the waveshape of glottal pulses, was to be paired with itself and other similar tone-pulses ranging in frequency from 1 kHz to 1.2 kHz in 40 Hz steps.

\textit{Basic selection criteria.}

It is considered necessary to try to ensure that members of the experimental group have a receptive language problem without one of expressive language. The presence of problems with expressive language could result in complications for interpretation of results of work proposed concerning nonword repetition. Therefore, for the purposes of this study, children will be considered for entry to the experimental group of SRD children if: 1) their language difficulties are specific to reading, more exactly to reading accuracy (e.g. they have no cognitive or expressive problems); 2) they have no history of a loss of pure-tone sensitivity outside normal limits; 3) they have English as their mother-tongue, and 4) they are of at least average intelligence (as judged by general school work).

Assumptions have been made about the ability of an IQ-reading discrepancy to define cases of developmental dyslexia. The demonstrations by some workers that verbal IQ measures can not sensibly be used in indicating dyslexic or other language-impairments (e.g. Siegel, 1988,1989; Stanovich, 1994) mean no screening of children for intelligence will be made here. A test of intelligence will be used as part of the test-battery, but will be non-verbal and included to measure the degree of either positive or negative correlation with reading-delay. Between-groups estimates of non-verbal IQ in this dissertation were found to be not significantly different (low correlation values), and so were ignored. All subjects, including the youngest controls, must have reached at least 7;0 years of chronological age, and have no emotional problems relating to either social or environmental factors.
1.9.3. Definition of selected terms.

Fuller definitions of some terms which relate to key concepts and will recur frequently in Chapter 3 and Chapter 4, such as "salience" and "complexity", are provided here.

Salience.

"Salience" is intended to refer to the acoustic-phonetic distinctiveness of speech stimuli. It can be regarded simply as the prominence which such cues have in terms of amplitude (acoustic energy), frequency and duration differences, but there are levels at which salience operates which differ according to the number of phonemic features which are shared between a minimal-pair. The more such features a given pair shares, the lower the salience of the contrast which the relevant cues (still salient in themselves) distinguish. This is because cues can provide information only on the feature(s) which differ. The pair "face" - "race" (/feɪs/-/ræs/) differ in manner of production, in voicing and in place-of-articulation, thus the acoustic-phonetic cues distinguishing the initial voiceless labio-dental fricative from the initial lateral approximant can be said to have, acting together, an extremely high degree of "salience". Here, there are different types of acoustic-phonetic cue, such as the presence of low frequency energy, or of frication, in only one of the two initial phones.

The pair "Sue" - "shoe" (/su/ - /ʃu/) differ only in place-of-articulation, therefore the only discriminable cues relate, potentially, to the centre frequency, spectral range and friction duration difference of frication, and the direction, duration and frequency-span of the second and third formant transitions from consonant to vowel. All such acoustic-phonetic information is regarded as of high acoustic similarity, even in combination, because they are not acoustically prominent in terms of spectro-temporal difference. They also typically occur
only briefly, whilst the difference in the duration of friction is small. Also, the inherent brevity of the relevant formant transitions, combined with the similarity of the acoustic energy of formant frequency transitions before vowel phonation begins, confirms the low salience of the contrast. A consonant contrast which differs only in the presence/absence of a voice bar (for example the dental fricative contrast “Sue” - “zoo” /su/-/zu/) would also be of low salience. In this instance, relevant factors would be the brevity of the voice bar when present, limited differences of friction duration and friction spectrum, and the similarity of the paths of the formant frequency transitions (F2 and F3) cueing place-of-articulation to the same following vowel.

**Complexity.**

Acoustic-phonetic “complexity” is understood to be high when the overall number of cues which differ, for instance, in spectral range, rate-of-change, and duration which are naturally present within an item, is high. This will be the case for an item-initial 2-consonant cluster composed of a fricative followed by a stop such as /st/ in “start” (/stat/) because it contains friction spectrum and centre-frequency cues plus those of burst spectrum, burst duration and voice-onset-time. These two consonant phones differ in manner of production but are coarticulated. In the consonant-cluster (substitution) test, “start” was contrasted with “smart” (/smat/) where two consonant phones also differ in manner, but are again coarticulated. The acoustic-phonetic cues here would include those of nasal murmur, voicing, friction duration, friction spectrum, friction centre-frequency, F1 onset-frequency and intensity-differences. This particular pair (“start”-“smart”) is also, however, an example of a contrast high in acoustic-phonetic salience with regard to the featural properties of the second consonant in the respective clusters. Other clustered consonants in the “substitution” discrimination test were low in salience whilst being high in complexity (such as “spill”-“still” /spil/-/stil/) because the second consonant in each cluster shared manner and voicing features. The discrimination of consonants in intervocalic
consonant minimal-pairs and of initial consonant phonemes in CV nonsense syllable minimal-pairs concerns items of low complexity because of the relatively limited number of brief and spectrally-complex acoustic-phonetic cues involved when consonants are contrasted as singletons. Although they were not used in this work for reasons of complications of phoneme-grapheme mapping, the two English affricates, /dʒ/ and /tʃ/, are also “complex” because they contain a stop followed by a fricative sound, thus will involve a high density of acoustic-phonetic cues differing widely in duration and spectral properties. Had they been presented in a “same”-“different” nonsense-syllable discrimination task it is expected that they would have been relatively frequently confused by some SRD subjects.

Perceptual weighting.

This can only be defined by reference also to such concepts as “cue-trading” and “perceptual equivalence.” A suitable description of these was contained in the introduction to a paper by Nittrouer, Crowther and Miller (1998) and is used here as a source. For its identification, certain acoustic-phonetic properties of a phone are evaluated (perceptually) according to particular “trading relations”. Nittrouer et al. continue that….. “Changes in the settings of one of multiple acoustic properties will affect the result of integration of this information in phonetic perception. To elicit a specific phonetic decision, the settings of other properties need also to change [in a reciprocal way]. These reciprocal relations among acoustic properties are known as “trading relations” and have been demonstrated by numerous labelling experiments (e.g. Bailey and Summerfield, 1980; Best, Morongiello and Robson, 1981; Dorman, Studdert-Kennedy and Raphael, 1977). However, stimuli having different combinations of a parameter setting across properties could elicit the same category response from listeners while remaining perceptually discriminable, especially given that typical labelling experiments employ only two category labels.”
The perceptual equivalence of distinct cues were regarded as... “having their effects on the same perceptual dimension” (Best et al., 1981; Fitch et al., 1980). Both groups of workers independently manipulated the duration of silence after /s/ and the first formant frequency (F1) at vowel onset for CV stimuli. When the F1 onset was relatively high, adult subjects tended to report more /s/ + stop decisions (i.e. more /stei/ than /set/ responses). Discrimination was best when both cues (one temporal and one spectral) cooperated, worst when they conflicted in their settings. Morrongiello, Robson, Best and Clifton (1984) found that perceptual equivalence in 5 yr. old children’s labelling of /set/ versus /stei/ employed the same acoustic properties as adults but that longer silent gaps were needed to elicit /stei/ responses for stimuli with relatively high F1 onset (correlating with less-extensive F1 transitions). Morongiello et al. concluded that children (of this age)... “integrate multiple acoustic properties in a phonetically-relevant manner (as adults do) but were more sensitive to transitional cues than were adults.” They were said to “weight” the relevant properties in a different way than adults, the term being used to reflect differences in the values, in this example, of silence duration and F1 onset frequency required to maintain “perceptual equivalence” in a cue-trading relationship. Such cue-weighting differences have also been demonstrated for language normal children, aged between 3 and 5 years, using a synthetic /s/ - /ʃ/ continuum (Nittrouer, 1992).

Acoustic similarity.

Acoustic (phonetic) similarity relates to the fact that speech contrasts differing only in the place-of-articulation, manner of articulation, or the voicing feature are marked principally by a small number of cues. The spectro-temporal and/or amplitude characteristics of these discriminable cues are comparable for each token, differing only in their relatively fine detail. For instance, the contrasts used in at least one of the discrimination tests in this dissertation differ only in place-of-articulation or in voicing and are therefore high in acoustic similarity.
Clearly, contrasts which differ in two or more phonetic features, such as /ba/-/sa/, are less similar in acoustic-phonetic terms.

1.10. Structure of Thesis.

1.10.1. Pilot testing.

* A rationale is given for the need for, and relevance of, the tests chosen. Appropriately selected materials would be used to test minimal-pair discrimination, phonemic awareness and speech-repetition accuracy. The details of the presentation of instructions enabling completion of task-requirements would be appropriate to the chronological age of children. 
* Three tests will be presented to children on an individual basis. 
* Selected materials will test minimal-pair discrimination, phonemic awareness and speech-repetition accuracy. 
* The aims were to discover whether individual performance-differences for the experimental group apply, whether such differences are consistent for each test, and whether they could be generated by the use of natural-speech stimuli.

* Subject selection.
  * Test materials.
  * Test preparation.
  * Results.
  * Discussion.
  * Conclusions.

1.10.2. Main experimental battery.

* Three fundamental aims were to investigate whether all SRD children had speech-perceptual problems, whether they made errors on a given test at similar or widely-differing rates, and whether those who had difficulty on one test also tended to make more errors than other subjects on other speech-perceptual and speech-repetition tests.
* The hypothesis stated above, that children with a phonological pattern of reading difficulty would be those associated with making speech-perceptual errors at higher rates, depended on the provision of regular, irregular and nonword lists for oral reading.
* Selection of a comparison measure of intelligence.
* Subject selection.
* Test materials.
* Test preparation.
* Test procedure.
* Results.
* Comparison with other studies.

1.10.3. Discussion Chapter.

* Brief discussion
* Outline model.
* Proposals for further research.

1.11. What is Original in the Design and Aims of this Work?

The concern to provide, wherever relevant, natural-speech tokens as the stimuli to be discriminated, and to ensure that they are in the form of vocabulary-relevant real-words, is in contrast to the many studies which have based their conclusions on the use of synthesised nonsense-syllable stimuli. If reading-group differences in speech-perceptual accuracy arise for initial-phoneme contrasts in natural, familiar stimuli, it is proposed that this would provide a suitably robust, and ecologically valid, demonstration of phoneme-confusions. Note, though, that Manis and his colleagues (1997) used a computer-edited continuum for “bath”-“path” based on natural tokens.

At the outset, it is intended to test the extent of any speech-perceptual deficits by presenting a large range of minimal-pairs for discrimination. They will differ,
across pairs, in the type of consonant-phoneme contrasted. They will also differ in the number of phonetic-features which they share, so as to investigate the effect of both voicing and place-of-articulation contrasts. Much attention has been paid in the research literature to whether different experimental groups (e.g. reading-impaired, dyspraxic, aphasic children/adults) are able to identify or discriminate stop consonants reliably less efficiently than language-normal control groups. Some studies of speech identification and/or discrimination have been made using fricative contrasts (e.g. Tallal and Stark, 1981; Masterson, Hazan and Wijayatilake, 1995). However, none concerning groups differentiated by reading-status has involved nasal or approximant contrasts (except that of Masterson et al. (1995) who used the Wepman word-discrimination test which contains a nasal contrast).

It is also intended to study the discrimination of several different manners-of-articulation in each of four distinct experiments for specifically reading-disabled (SRD) children and two control-groups. A demonstration of perceptual errors, by SRD-children only, on contrasts not primarily marked by rapid spectral changes would be evidence against Tallal's argument that categorisation difficulties arise only from the limited ability of these children to perceive differences in formant frequency transition characteristics.

Apart from the proposed effect of vocalic context on consonant discrimination accuracy for SRD-children, a further novel proposition is that these children will also be affected by changes in the acoustic-phonetic “complexity” of the to-be-discriminated segments of items. Research results showing a phonemic-similarity effect on recall (e.g. Wickelgren, 1966), and perceptual discrimination errors for pairs differing in only one phonetic feature (e.g. Godfrey et al., 1981 and Mody, 1993), has encouraged the assumption that such effects will only be found for minimal-pairs sharing two features. Indeed, the impression has been that discrimination errors arise from phonemic “closeness” or “similarity”.

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If it is shown that:

1) some instances of larger phonetic-difference can, under certain conditions, be
   associated with frequent perceptual confusions, and/or

2) that some contrasts differing only in a single phonetic feature are easily
discriminable by all listeners

the need for some broadening of the theoretical framework of these subjects' speech-perceptual difficulties would be clear. Another major prediction is that not all reading-impaired subjects will show appreciable difficulties with any speech perceptual or repetition task. This would be in keeping with the indications of heterogeneity of performance reported for different speech-perceptual tasks by Farmer and Klein (1995), but not systematically examined.

It is specifically proposed that the SRD-children who show such difficulties will also show the phonologically-dyslexic pattern of reading accuracy (see Castles and Coltheart, 1993; Manis et al., 1997). To this extent, there may be a lawful relationship between type of reading difficulty and speech-perceptual errors. An associated proposal is that it will be the same sub-group of reading-disabled children who will make most errors on several, if not all, of the speech-related tests presented. This will be expected if limited "phonetic acuity" necessarily relates to problems with the decoding of regular orthography, since this aspect of decoding is more directly dependent on the presence of a full and stable inventory of "phonemes".
CHAPTER 2.

PILOT TESTING.

2.1. General Introduction.

The set of three pilot tests was chosen to examine the potential of distinct perceptual tasks for generating significant reading-group differences. All three were tasks which had been used in research on language-impaired groups and reported in the research literature.

The first test consisted of minimal pair discrimination. As was clear from the previous chapter, this has been a widely used speech perceptual task. Research reports have most-frequently used computer-generated CV tokens of plosive place contrasts presented to language-impaired or SRD-children, or adults (e.g. Reed, 1989; Steffens et al., 1992; Stark and Heinz, 1996a; Werker and Tees, 1987), but some have involved appropriate natural voice recordings (e.g. Hurford and Sanders, 1990). Most such studies have used naturally- or synthetically-produced CV tokens of plosive voice contrasts (e.g. De Weirdt, 1988; Masterson et al., 1995), whilst others have involved the discrimination of isolated vowels with either SRD- or language-impaired subjects (e.g. Reed, 1989; Steffens et al., 1992; Stark and Heinz, 1996b; Tallal and Stark, 1981). The corresponding task here was designed to investigate more systematically the range of phonemic contrasts which reading-disabled children might find difficult to discriminate, but for real-word rather than nonsense-syllable items. This is to test the proposal that stop consonants are not the only class of phoneme which SRD children show perceptual confusions with. In particular, it will attempt to replicate the demonstration by Masterson et al. (1995), as discussed at the end of the introductory chapter, that at least some fricative pairs can also present discrimination problems for SRD subjects.
In choosing real-word minimal-pairs it was necessary also to consider the number of phonetic features which are shared in pairs associated with the majority of perceptual errors in the experimental group. Pairs which share two of the three features of manner-of-articulation, voicing, and place-of-articulation are those which are closest phonetically, and shown to be those most likely to be confused by reading-impaired children (e.g. Mody, 1993; Masterson et al., 1995).

The second pilot test concerned the repetition of monosyllabic word and nonword items. The use of two types of item of the same syllabic-length, presented in separate lists, allowed the testing of a possible effect of lexical status on accuracy. Nonsense word repetition had been found elsewhere to generate errors in 2- to 5-syllable items which increased in rate with item-length. Gathercole, Willis, Emslie and Baddeley (1994) had reported high variability in children's monosyllabic nonword repetition accuracy. Such a test was prepared here to examine the level of accuracy of different reading-groups of children who were rather older than those tested by these authors.

The third pilot test, of initial phoneme deletion, was chosen to study whether familiar real-word items might generate problems for SRD-children on this task, and whether all of the experimental children had comparable levels of difficulty. The nature of the deletion errors might also indicate whether these children made a particular type, or more varied types of error, reflecting a limited knowledge of the sound-structure and orthography of the words.

2.2. Rationale and Aims.

2.2.1. Minimal-pair discrimination.

Previous research had suggested that phonemes sharing the same manner of production but differing in either voicing or place-of-articulation are confused by SRD groups of listeners more frequently than by groups of matched controls (e.g. Godfrey et al., 1981; Mody, 1993; Masterson et al., 1995 and Watson, 1992).
Less-similar phonemes tended not to be confused. Therefore, if errors in the current tests were concentrated on pairs with initial consonants differing only in voicing or place-of-articulation, no attempt would be necessary, in the later Main Phase testing, to use other minimal-pair stimuli. A wide range of minimal-pairs differing in one feature would then be selected for presentation in the main phase, in order to provide a test of whether or not discrimination errors were limited to stop consonant pairings.

The aims for this task were:-

1. To determine the level of feature-similarity between pairs of phonemes which must pertain in order to generate discrimination errors.

2. To show the existence of discrimination errors where the carrier-items are familiar real words which are likely to be within the spoken vocabulary of the youngest children taking part.

2.2.2. Item-repetition.

It was noted in the Introduction that the inaccurate repetition of non-words is regularly found for SRD-children (Gathercole et al., 1994) compared to the performance of both same-age (CA) and reading age (RA) control groups. The Gathercole et al. repetition test for children (known by the abbreviation "CNRep") concerns only nonwords, but confounds stimulus-unfamiliarity with production accuracy. The mono-syllabic item repetition pilot on both real and nonword lists was set up to establish whether familiarity has an effect on performance. It was not known if SRD-children would make significant numbers of errors when repeating familiar monosyllabic real-word items, therefore a list of such items was presented to each subject as a stronger test of production difficulties in SRD-children.

The aims here were:
To investigate the rate at which repetition-errors are made for
monosyllabic nonword items by children of different reading-status.

To test the implicit assumption that the repetition of familiar
monosyllabic words is accurate for all reading-groups.

For both sets of items, to note the types of errors made and discuss
the possible extent to which repetition accuracy is undermined by individual
listener's perceptual errors.

2.2.3. Initial-phoneme deletion.

The task of deletion of an initial phoneme requires subjects to listen to a (real-
word) item, mentally-delete the first phoneme (segment) from the phonology, and
then produce the remainder of the word. For instance, "dog" /dog/ becomes /og/
and "boat" /bɔt/ becomes /ɔt/. An experiment using this technique was carried
out by Pratt and Brady (1988) and referred to as an "auditory-analysis test". Their
older group of SRD subjects (about 32 years) had much the same difficulty with
deletion as did their younger SRD group (about 8 years), being significantly less
accurate than the normally-reading children. The low error-rates reported for
control groups show that this is not an intrinsically difficult task. The results of
tests of initial phoneme deletion have also been reported by, for example, Firth
(1972), and, using first-grade subjects, by Fox and Routh (1980). It appears to be
a powerful measure of phonemic awareness and, as such, has validity in assessing
whether all the SRD-children in a sample group are similarly inaccurate in
retaining and segmenting the sound-structure of words.

The aims of this test were:

1. To be able to demonstrate a relative weakness for SRD-children in the ability
to perform the phoneme-deletion task even for familiar, monosyllabic real-word
materials.

2. To investigate the evidence for a range of error-type in their efforts to "miss off" the first sound, despite subjects' clear understanding of the task instructions.

3. To determine whether each of the SRD-children show similar weakness in this aspect of phonemic awareness.
2.3. Subject Selection.

As the focus of these pilot tests was an initial evaluation of a range of familiar and ecologically-valid speech materials, the experimental subject-group was not highly controlled in terms of age-range and reading-delay. Children were, whenever possible, chosen from the same school classes, ensuring that their chronological ages were similar.

Subjects were selected from a volunteer population attending mainstream (state) junior schools, so that the upper age-limit would of necessity be 11-12 years. Parental consent had been sought formally by teaching staff, and received in each case. Six SRD experimental children were tested, with six chronological age-matched (CA control) and six reading-age matched (RA control) children. They had been recommended by their class teachers as normally-reading for their age but were not formally tested. No attempt was made to match children according to any pre-existing measure of intelligence, nor to take details of "socio-economic status", in order to make paired matches.

The qualifying criteria used were:

(a) the actual age of a child in any group to be no less than 7;0 years and no more than 12;0 years. A minimum age of reading-age controls of 7 years was necessary as real-word speech-materials were based on vocabulary appropriate for 7 year-old children. The mean age of the RA-control group would be expected to be about 8 years so, allowing for an upper limit of reading-delay of as much as 3;6 to 4;0 years, the upper-limit of chronological age for SRD-children was determined;

(b) listeners should have English as their mother-tongue. The addressing of English real words in the experiments was considered to be potentially complicated by the influence on children of being brought up in a bilingual home;
(c) that no SRD (or, indeed, normally-reading) child would participate if it had been reported by teachers or parents that they suffered, currently or in the recent past, from stress or emotional difficulties, however caused;

(d) that the lower limit of the estimated reading-delay (accuracy) of each experimental child regarded as reading-impaired should ideally be 18 months (an implicitly-accepted cut-off value in many speech-based studies of SRD-children, e.g. Castles and Coltheart, 1993; Godfrey et al., 1981; Hurford and Sanders, 1990; Mark et al., 1977; Snowling and Goulandris, 1994). For some of the children in the pilot SRD-group this limit was not, however, easy to ensure (see below). A lower figure would, it was thought, increase the possibility of some experimental subjects being wrongly drawn from what would emerge as a delayed-but-normal population for reading;

(e) that all children should have hearing within normal limits as measured by standard audiometric tests. School records and class teachers were consulted with respect to these; and

(f) that all children should be without production difficulty as regards fluent conversational speech.

Experiments comparing listeners' performances on speech perceptual tasks and on (standardised) reading tests must attempt to control for the key variables. The use of a same-age (CA) group controlled for the amount, and variety, of exposure to speech which the experimental children have had, selecting all subjects from the same monolingual background. A reading-age (RA) group was also used to control for reading experience and skill-level, to minimise the possibility that differences in speech-perceptual performance could be related to differences in orthographic knowledge. For these pilot tests, the experimental group's mean chronological age (n = 6) was 9;8 years, ranging from 9;0 to 10;11 years. The mean chronological-age of the CA group (n=6) was 9;9 years (range 8;7 to 10;8 years), whilst that of the RA group was 8;3 years (range 7;10 to 8;6 years). Their
mean age was therefore some 17 months younger than the experimental group.

Recent estimates of the reading-delay of SRD children had not been made in all of these particular cases by remedial staff. In one of the six cases, an estimate of reading-delay was not available. Further investigation showed that four of the six children had been assessed within the last 6 months, but one further child had last been tested some 18 months earlier. Also, three of these children had been presented with two different standard tests of reading. Across this group, the most common test used was the Neale Analysis, but the Schonell and Salford "A" tests had also been used in certain other cases. Where two tests had been used for a child, the accuracy estimate taken here was that which gave the higher reading-age. The children were based in different schools, and had experienced somewhat-different remedial regimes. The reading-age estimates of the SRD-children, based on 5 of the 6 children in the group for whom information was available, ranged from 6;6 to 8;1 years, with a mean of 7;4 years, whilst their mean reading delay was 31 months. Given these sources of variation, pairwise matches with reading-age controls could not be satisfactorily made. They were made on the basis that the younger normals had been judged by their class teachers to be reading with "average" (age-appropriate) accuracy.

2.4. Test Materials.

2.4.1. Minimal-pair discrimination.

It was essential that the real-word stimuli used in this discrimination test were known to even the youngest of the subjects. In order to be certain that all of the items were recognised by reading-age control children who might be as young as seven, a conservative measure of the vocabulary of English 7-year-olds was used. The exclusive source was the "Alpha-list" (7), from "Words Your Children Use", Edwards and Gibbon (London, 1964). It is a set of different lists of those words, of given alphabetic length, which a sample of children of that chronological age have used in their written work, including any which were judged to be plausibly
mis-spelt. An explicit vocabulary control such as this was felt to be more functionally relevant than a standardised test of vocabulary, such as the Peabody Picture Vocabulary Test (PPVT; Dunn and Dunn, 1981). The inaccurate and slow naming of familiar objects is amongst several word-finding problems known to be associated with developmental dyslexia (Denckla, Rudel and Broman, 1981; Katz, 1986; Wolf and Goodglass, 1986).

Unfortunately, the restrictions imposed by the use of this vocabulary-control meant that words containing initial nasal and approximant place contrasts were less available than words having either initial stop or fricative contrasts. Consequently, words bearing initial nasal, fricative, stop or approximant consonants were combined with certain other words with which they differed only by the initial consonant to make minimal-pairs in which either one or two phonetic features were shared, or none at all (e.g. "dish" - "wish" /dɪʃ/ -/wɪʃ/ and "race" - "face" /reɪs/ -/feɪs/). Each of the three groups (lists) of minimal-pairs was short because of some considerable difficulty in finding pairs of words which differed only in the initial phoneme, and which shared phonetic features in the way outlined above. It was necessary for many of these to be suitably shared between the different pilot tests and the main-phase discrimination tests.

Pairs were divided into 3 stimulus-groups. As can be seen below, mixed levels of difference were present within the first two groups. Groups 1 and 2 were similar to each other, in terms of the number of pairings having the same degree of feature difference, but differed in the lexical items used. Most minimal-pairs derivable from the "Alpha" list were contrasted by only one phonetic feature. Similar numbers of stimuli were to be provided in each group. It was not felt that mixing of levels of phonemic-feature difference in these groups would bias the results in any way.

List 1 minimal-pairs consisted overall of 7 "different" pairs of words each presented twice (order-reversed), three differing in three features, two in two features and two in one feature. The eight "same" pairs each presented once,
giving 22 trials in randomised order. The phonemic-features not shared by a particular pair are indicated in the listings below, by the use of the letters "M", "V" and "P", respectively, for Manner-of-articulation, Voicing and Place-of-articulation.

1. feed need /fid/ /nid/ MVP
2. kiss kiss /kis/ /kis/
3. sand hand /sænd/ /hænd/ P
4. gate late /geit/ /leit/ MP
5. most most /moust/ /moust/
6. lid hid /lid/ /hid/ MVP
7. sale sale /seil/ /seil/
8. head red /hed/ /red/ MVP
9. dish wish /dij*/ /wij/ MP
10. walk walk /walk/ /walk/
11. near dear /nɪə/ /dɪə/ M
12. hid lid /hɪd/ /hɪd/ MVP
13. love love /lɑv/ /lɑv/
14. hand sand /hænd/ /sænd/ P
15. wish dish /wɪʃ/ /dɪʃ/ MP
16. left left /lɛft/ /lɛft/
17. need feed /nɪd/ /fɪd/ MVP
18. late gate /lɛt/ /gɛt/ MP
19. seek seek /sɪk/ /sɪk/
20. red head /rɛd/ /hɛd/ MVP
21. make make /mɛk/ /mɛk/
22. dear near /dɪə/ /nɪə/ M
23. cut cut /kʌt/ /kʌt/
24. race face /reɪs/ /fɛs/ MVP
25. tea sea /ti/ /si/ M
26. nine nine /nain/ /nain/
27. ball call /bɔl/ /kɔl/ VP
28. park dark /pɑk/ /dɑk/ VP
29. join join /dʒɔin/ /dʒɔin/
30. toy toy /tɔɪ/ /tɔɪ/
31. poor more /pɔ/ /mɔ/ MV
32. him him /hɪm/ /hɪm/
33. can ran /kæn/ /ræn/ MVP
34. give give /ɡɪv/ /ɡɪv/
35. sea tea /si/ /ti/ M
36. /niə/ /dɪə/ M
37. /nain/ /nain/
38. /bɔl/ /kɔl/ VP
39. /pɑk/ /dɑk/ VP
40. /dʒɔin/ /dʒɔin/

List 2 items consisted of 7 "different" pairs of words (each presented with one order-reversal) and 9 "same" pairs. There were therefore 23 randomised trials in all. Two "different" pairs differed by one phonetic feature, three differed by two features, and two differed by three features, as described in the previous paragraph. The order of presentation was as follows:

23. cut cut /kAt/ /kAt/
24. race face /reis/ /fets/ MVP
25. tea sea /ti/ /si/ M
26. nine nine /nain/ /nain/
27. ball call /bəl/ /kəl/ VP
28. park dark /pɑk/ /dɑk/ VP
29. join join /dʒɔin/ /dʒɔin/
30. toy toy /tɔɪ/ /tɔɪ/
31. poor more /pɔ/ /mɔ/ MV
32. him him /hɪm/ /hɪm/
33. can ran /kæn/ /ræn/ MVP
34. give give /ɡɪv/ /ɡɪv/
35. sea tea /si/ /ti/ M
List 3 items were designed to be, overall, the most difficult set of word-pairs to be discriminated in terms of the number of shared phonemic features. This block was randomised and comprised 21 trials. The 6 "different" pairs were presented twice (order-reversed) and all differed by a single feature, either place-of-articulation or voice. The 9 "same" pairs were each presented once. Minimal-pair selection was constrained by the availability of suitable words within the Alpha (7) list. In the event, five of the six "different" pairs were plosive contrasts and the remaining one a fricative contrast.

Of the total of 66 pairs over the three stimulus-groups, 26 were "same" trials, giving an overall catch-trial rate of 39%.
2.4.2. Real word and nonword repetition.

For real-word production, all items were monosyllables taken from the Alpha (7) listings, selected to provide a wide range of manner-of-articulation with respect to the word-initial phonemes (7 plosives, 6 fricatives, 3 nasals, and 4 approximants). Words, listed in random order, were semantically unconnected and produced in citation form.

The non-words for this test were derived from the word list by vowel-substitution, e.g. "wet" /wet/ became "wut" /wʌt/ and "girl" /ɡɜl/ became "garl" /ɡəl/. In three instances the new item was homophonic for another real word. It was decided to let these stand as none occurred in the Alpha (7) list. These homophones were "ren" /ren/ (= "wren"), "furm" /fɜm/ (= "firm"), and "nuce" /nus/ (= "noose").

Items in the first block occurred in the following order:

1. wet /wet/       11. lend /lend/
2. need /nid/      12. fast /fast/
3. farm /fæm/      13. mend /mend/
4. tell /tel/      14. wish /wiʃ/
5. run /rʌn/       15. keep /kɪp/
6. girl /ɡɜl/      16. ball /bɔl/
7. soft /sɔft/     17. part /pɑrt/
8. day /deɪ/       18. hope /həʊp/
9. vase /væz/      19. cot /kɔt/
10. hole /hɔʊl/    20. nice /nais/

The order of nonwords in Block 3 was as follows:

1. hile /haɪl/     11. wesh /weʃ/
2. mond /mɔnd/     12. cet /kɛt/

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2.4.3. Initial-phoneme deletion.

The 20 monosyllabic real words, which had not been used in any previous test, were chosen from the Alpha (7). These items contained a wide range of different word-initial phonemes: 10 stops, 5 fricatives, 2 nasals and 3 approximants. To illustrate the items one complete sequence of the stimuli (Block 1), together with the correct response for each, is given below:

<table>
<thead>
<tr>
<th>STIMULUS</th>
<th>CORRECT RESPONSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. life</td>
<td>/laif/</td>
</tr>
<tr>
<td>2. pop</td>
<td>/pop/</td>
</tr>
<tr>
<td>3. mean</td>
<td>/min/</td>
</tr>
<tr>
<td>4. cut</td>
<td>/kʌt/</td>
</tr>
<tr>
<td>5. rose</td>
<td>/rəuz/</td>
</tr>
<tr>
<td>6. dog</td>
<td>/dɒg/</td>
</tr>
<tr>
<td>7. sail</td>
<td>/sæIl/</td>
</tr>
<tr>
<td>8. fit</td>
<td>/fɪt/</td>
</tr>
<tr>
<td>9. push</td>
<td>/puʃ/</td>
</tr>
<tr>
<td>10. give</td>
<td>/gɪv/</td>
</tr>
<tr>
<td>11. best</td>
<td>/best/</td>
</tr>
<tr>
<td>12. wind</td>
<td>/wɪnd/</td>
</tr>
<tr>
<td>13. hape</td>
<td>/heɪp/</td>
</tr>
<tr>
<td>14. tull</td>
<td>/tʌl/</td>
</tr>
<tr>
<td>15. saft</td>
<td>/sæft/</td>
</tr>
<tr>
<td>16. pirt</td>
<td>/pɜrt/</td>
</tr>
<tr>
<td>17. wut</td>
<td>/wʌt/</td>
</tr>
<tr>
<td>18. koop</td>
<td>/kʊp/</td>
</tr>
<tr>
<td>19. furm</td>
<td>/fɜrm/</td>
</tr>
<tr>
<td>20. nuce</td>
<td>/nʌs/</td>
</tr>
</tbody>
</table>
For all three pilot tests, a phonetically-trained female RP-speaker recorded the utterances onto high-quality digital audio (DAT) tape ("TDK" DA-R60). The recording was made in an anechoic room, and the signals digitised onto a Sun computer at a sampling rate of 44.1 kHz, and re-sampled at 20 kHz. A check was made for clarity, and extraneous noise was edited-out whenever necessary. The entire output was played back and recorded onto one experimental audio-tape (Maxell UR-60). An inter-trial interval of 5 seconds was used.

2.5.1. Minimal-pair discrimination.

The "same"-"different" two-alternative forced-choice discrimination paradigm was used (AX). Each child understood the concepts of "same" and "different". The interval between words in each pair, the inter-stimulus interval (ISI), was approximately 1 second. This duration is appreciably greater than those, up to 400 ms, which were associated with problems with temporal-order-judgements in reading-disabled children (Reed, 1989). Such judgments were not required here.

2.5.2. Word- and nonword-repetition.

For each type of stimulus, two instances of each utterance were recorded. The same
list of 20 words was recorded twice using different random orders to create Blocks 1 and 2, and the same procedure was used for the non-words to create Blocks 3 and 4.

2.5.3. Initial-phoneme deletion.

The list of 20 words was recorded twice using different random orders to create two blocks of physically different stimuli.

2.6. Test Procedure.

2.6.1. Method of presentation.

The tape, on each occasion, was played to subjects using an UHER 240 tape recorder, and their responses were simultaneously recorded onto a second UHER 240 tape recorder connected to an UHER M-646 microphone. This allowed the later checking of all individuals' response sheets completed at the time by the experimenter. The audio cassettes were played via SENNHEISER 414 headphones to the right ear only. Unilateral presentation to the right ear was selected because there is some published evidence for a right-ear advantage for the identification of CV-syllables, particularly fricatives (e.g. Darwin, 1971) and for stops (Cutting, 1974; Shankweiler and Studdert-Kennedy, 1967). This advantage had earlier been revealed in dichotic tests of speech perception (Broadbent and Gregory, 1964).

Stimuli were presented at a pre-set comfortable level which averaged 61 dB SPL for each of the tests, measured using a Bruel and Kjaer Type 2231 hand-held sound level meter. This level was constant for each subject during testing since volume control was set accurately and consistently to a marked position.

For all of the pilot tests, each child was tested individually and seated throughout. It was felt important in the first session, and particularly for the youngest of the participants, to put a child at ease by talking first about their interests and describing
in a general way what the work was about. It was also explained that the microphone was there only to help the experimenter check the answers they gave. Subjects were informed that they were free to self-correct during the silent inter-trial interval (ITI). Their final attempt was taken as the response to be scored. In practice, the presentation of the next trial did not interfere with responding to the previous trial because any self-corrections tended to be fairly rapid. Also, the children could request a test to be stopped at any time if they wished to rest or briefly leave the room. A test was rarely interrupted for any such reason. On no test-occasion was a subject suffering an ear or an upper-respiratory infection, headache or other health problem.

2.6.2. Minimal-pair discrimination.

Before the experiment began, a few example trials with feedback followed by a short practice session, were given orally. For this, attempts at lip-reading by subjects were prevented by the experimenter either having covered his mouth or facing away from the child when presenting the stimuli. Some simple contrasts differing in several phonetic-features, which did not occur in the test itself and which were present in the Alpha (7) listing, were given as "example" and "practice" trials for each child. They were used to ensure that no confusion about task-requirements remained before the tape was started. Subjects were to repeat the two words presented, but told to concentrate more on making their discrimination decision ("same" or "different"). Only the discrimination response was scored. The overt repetition of each pair of items was attempted in order to provide listeners with an aid to memory together with an opportunity to directly estimate individual mis-perception rates. In the event, listeners quite often omitted this aspect of the response and the data was discarded.

A performance-criterion of six correct matches out of seven was set for all subjects in the practice trials. It was rare for a child not to readily respond correctly on all seven trials. If the criterion was not met, the pairs wrongly discriminated were repeated, and the child then invariably responded correctly. The details of these
preliminary trials are illustrated in Appendix A.

A description of, and instructions for, this test were given orally to listeners as follows:

"In a moment, you're going to hear someone speaking just two words at a time, one after the other, and then it will be quiet. When the tape is quiet I'd like you to repeat the words, and say if they were the "Same" or "Different". Then you'll hear another pair of words and quiet again for you to speak in, until the end when I'll switch off the tape."

The tape was stopped for 1 or 2 minutes after each group (set) of minimal-pairs to create a rest period. The three minimal-pair lists were presented to each child in the same pre-recorded order: firstly Group 1, then Group 2 and lastly Group 3. The run-time for this test was approximately twelve minutes. Each child completed it at a single sitting.

2.6.3. Real-word and nonword repetition.

During the inter-stimulus interval the subject was to repeat the single recorded word, or nonword, that s/he had just heard. The selection of several phonologically-simple, but not necessarily orthographically-regular, practice words was deliberate because the only requirement was to ensure that the children understood the aim of the experiment and had some practice at making the response at the required pace.

The first block of 20 words was presented, with a total run-time of less than two minutes. After a 2-minute pause, the second presentation of each of these words was made. The two blocks of 20 nonword items, in different orders, were presented with a similar pause between them. The elapsed time for administration of the entire test was about 13 minutes.
2.6.4. Initial-phoneme deletion.

The test procedure was as described above. The task was to listen to each word, presented one at a time and then delete ("miss off") the initial phoneme, producing only the remainder of the word. These would be, therefore, mostly nonword responses. The inter-item interval was about 5 seconds, allowing time for the completion of each response, and there was a 2-minute rest at the end of the block.

Two examples and then six practice trials were given verbally by the experimenter to each child, in the same order:

EXAMPLES

"Take the /k/ from "kite" (/kait/) and I say "ite" (/ait/) ."

"Take the /s/ from "some" (/sʌm/) and I say "um" (/ʌm/) ."

Correct responses were indicated provisionally on the answer sheets during the test. Final responses to each item were later checked with reference to broad phonemic transcriptions of the lists (see above).

In order to assess whether individual children might have difficulties with the segmentation of particular words, a second presentation of the above words was made using a different randomisation. Children's spontaneous comments reflected closely the apparent confidence with which they proceeded with the task. The total elapsed time for the running of this test was about ten minutes, and completed the pilot phase.

2.7. Results.

2.7.1. Minimal-pair discrimination.

Missing a "different" minimal-pair by responding "same", or giving a "false-
positive" response to a "same" pair by responding "different", are discrimination errors. The number of errors made by the six children in discriminating each list of pairs, by subject group, and the percentage error-rates for each subject-group and list, are given in Table 1. How these errors were distributed across each of the possible combinations of feature-difference for the three subject-groups is shown in Table 2.

A 2-way ANOVA showed that the effect of subject-group was significant ($F(2,15) = 6.60, p = 0.0088$). Post-hoc testing (Duncan's Multiple Range) showed that the experimental group was significantly less accurate at minimal-pair discrimination than were either control group, which did not differ significantly from each other.

The majority of errors made by the SRD-children involved place-of-articulation contrasts and "same" pairs. Error rates for the /mo/-/po/ contrast, which occurred in List 2 and differed in both manner-of-articulation and voicing, were similar for all three listener-groups. Errors (including response-omissions) occurred with higher frequency to particular pairs presented in List 3 for the SRD-children. These were "till-kill" (5) and "fit-sit" (5). Statistical tests were not run on the distribution of errors by feature-difference.

### Table 1. Groupwise error-totals for the "same/different" discrimination of real-word minimal-pairs divided into three stimulus-lists. For each subject-group, $n = 6$. The error-rates in percentage terms are given in parentheses, on which subject-group error-means and standard deviations are based.

<table>
<thead>
<tr>
<th>SUBJECT GROUP</th>
<th>EXP</th>
<th>RA</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>List 1</td>
<td>4 (3.0)</td>
<td>0 (0.0)</td>
<td>1 (0.8)</td>
</tr>
<tr>
<td>List 2</td>
<td>6 (4.3)</td>
<td>3 (2.2)</td>
<td>2 (1.4)</td>
</tr>
<tr>
<td>List 3</td>
<td>20 (16.9)</td>
<td>4 (3.2)</td>
<td>1 (0.8)</td>
</tr>
<tr>
<td>M n (%)</td>
<td>8.1</td>
<td>1.8</td>
<td>1</td>
</tr>
<tr>
<td>S.D.</td>
<td>7.1</td>
<td>1.6</td>
<td>0.3</td>
</tr>
</tbody>
</table>
TABLE 2. Distribution of the rate of discrimination error (%) according to phonetic feature-difference for real-word minimal pairs, across lists for each listener-group. The column headed "none" refers to errors following the presentation of "same" pairs. Error-totals made in discriminating pairs differing by one, two or three phonetic features are itemised under appropriate headings. The letters M, V and P indicate manner-of-articulation, voice and place-of-articulation respectively.

<table>
<thead>
<tr>
<th></th>
<th>EXP.</th>
<th>RA.</th>
<th>CA.</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>V</td>
<td>4.2</td>
<td>0</td>
<td>2.8</td>
</tr>
<tr>
<td>P</td>
<td>18.1</td>
<td>1.4</td>
<td>8.3</td>
</tr>
<tr>
<td>MV</td>
<td>8.3</td>
<td>8.3</td>
<td>8.3</td>
</tr>
<tr>
<td>VP</td>
<td>4.2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MP</td>
<td>8.3</td>
<td>0</td>
<td>4.1</td>
</tr>
<tr>
<td>MVP</td>
<td>3.3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

2.7.2. Real-word and nonword repetition.

A response was counted as an error if it did not correspond to the pronunciation of the speaker. Failures to respond were counted as omission errors. Any changes in stress were ignored. Individual error-totals are given in Table 3.

TABLE 3. The number of real word repetition errors made by individual children over 40 items in each of the three listener-groups. Group means and standard deviations are based on percentage error-rates, given in parentheses.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>SUB.</th>
<th>EXP.</th>
<th>RA.</th>
<th>CA.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 (7.5)</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2 (5.0)</td>
<td>3 (7.5)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1 (2.5)</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4 (10.0)</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>3 (7.5)</td>
<td>1 (2.5)</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

A one-way ANOVA showed that there was a significant effect of subject-group [F(2,15) = 6.10, p = 0.0115], whilst a post-hoc test (Duncan's Multiple Range) showed that the experimental group were markedly weaker than the two control groups, which did not differ from each other. There was evidence of a clustering of repetition errors to particular items within the twenty presented. Three errors were made concerning each of the items "day", "vase" and "lend" by the reading-
impaired group (69% of the SRD group total). None of the three repetition-errors made by subject RA (2) related to any of these three particular words.

TABLE 4. The number of nonword repetition errors made by individual children in each of the three listener-groups. The error rates (%) are given in parentheses, on which subject-group error-means and standard deviations are based.

<table>
<thead>
<tr>
<th>SUB</th>
<th>EXP</th>
<th>RA</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6 (15.0)</td>
<td>4 (10.0)</td>
<td>2 (5.0)</td>
</tr>
<tr>
<td>2</td>
<td>4 (10.0)</td>
<td>5 (12.5)</td>
<td>0 -</td>
</tr>
<tr>
<td>3</td>
<td>0 -</td>
<td>2 (5.0)</td>
<td>0 -</td>
</tr>
<tr>
<td>4</td>
<td>0 -</td>
<td>2 (5.0)</td>
<td>0 -</td>
</tr>
<tr>
<td>5</td>
<td>5 (12.5)</td>
<td>1 (2.5)</td>
<td>2 (5.0)</td>
</tr>
<tr>
<td>6</td>
<td>3 (7.5)</td>
<td>1 (2.5)</td>
<td>0 -</td>
</tr>
</tbody>
</table>

Mean 7.5 6.2 1.7
S.D. 6.3 4.1 2.6

A one-way ANOVA revealed that the effect of subject group was not significant \([F(2,15) = 2.67, p = 0.1017]\). For both the EXP and the RA groups, the errors made were distributed across several individuals.

2.7.3. Initial-phoneme deletion.

An error was recorded for each occasion when a subject did not respond, repeated the item presented, deleted a phoneme other than the initial phoneme, substituted another phoneme for the phoneme to-be-deleted, or added, substituted or transposed phoneme-segments in any other item-position.

A one-way ANOVA procedure showed a highly-significant effect of subject-group \([F(2,15) = 12.68, p= 0.0006]\). Duncan's Multiple Range post-hoc test showed that the SRD-children were worse at phoneme deletion than either control group. The performance of the control groups did not differ from each other. The ability of even the young control children to isolate and delete the initial phoneme from an orally presented monosyllabic real-word was much better than that of all but one of the SRD-children.
TABLE 5. Individual numbers of errors and error-rates (%) for initial-phoneme deletion. The individual error-rates (%) are the basis on which the means and standard deviations are based. The number of trials per subject was 40.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>SUB.</th>
<th>EXP.</th>
<th>RA.</th>
<th>CA.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40 (100)</td>
<td>0 -</td>
<td>0 -</td>
<td>0 -</td>
</tr>
<tr>
<td>2</td>
<td>24 (60)</td>
<td>0 -</td>
<td>0 -</td>
<td>0 -</td>
</tr>
<tr>
<td>3</td>
<td>13 (32)</td>
<td>0 -</td>
<td>0 -</td>
<td>0 -</td>
</tr>
<tr>
<td>4</td>
<td>40 (100)</td>
<td>2 (5)</td>
<td>0 -</td>
<td>0 -</td>
</tr>
<tr>
<td>5</td>
<td>4 (10)</td>
<td>1 (2)</td>
<td>1 (2)</td>
<td>1 (2)</td>
</tr>
<tr>
<td>6</td>
<td>14 (35)</td>
<td>3 (7)</td>
<td>1 (2)</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Mean</td>
<td>56.2</td>
<td>2.3</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>37.5</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

2.8. Discussion of Results.

The aim of these pilot tests was to determine whether a particular procedure has potential for demonstrating reliable performance-differences between SRD-children and the two control groups. Any procedure which showed such potential would be considered for re-formatting for use in the main test battery. Important factors in judging suitability are that no procedure be stress-inducing for children as a result of its subjective difficulty, and that the requirements for the correct execution of the task can be easily and quickly communicated to the youngest subjects.

2.8.1. Minimal-pairs.

On average, the minimal-pair discrimination by SRD-children of word-initial consonants was weaker than that of normally reading children, although overall error-rates were low. Statistics were not carried out on the error-data for the first two lists of minimal pairs.
List 1 errors.

Four of the six experimental children performed perfectly for this set of stimuli. Error-rates were very low, and it is quite possible that momentary inattention resulted in each of these errors, and in one non-response to a voicing contrast. No errors on List 1 pairs were made by any individual from the reading-age matched (RA) group.

List 2 errors.

The three reading-groups made discrimination errors on a total of 5 distinct minimal-pairs within this list, which represented a range of phonemic-feature differences and manner-of-articulation. There was no concentration of errors on a particular contrast for any of the subject-groups.

List 3 errors.

For List 3 pairings, twenty discrimination errors were associated with the reading-disabled (EXP) group. No subject was error-free (range 1 to 8 errors each), with only subjects 4 and 6 making fewer than three errors. Each control group made a very small number of errors in total (CA = 1, RA = 4). Those for the RA controls were associated with "same" pairs in each instance. It is possible that all subject-groups made a small number of errors due to momentary lapses in attention, but the EXP and RA groups had greatest perceptual difficulty with the accurate discrimination of word-pairs which are the same, or differ in one phonemic-feature. What should perhaps be emphasised is the further possibility that both the experimental and younger control groups are showing evidence of a certain number of "weak" (or unstable) phonemic categories. In the tabulation below, two of those minimal pairs which were most frequently, and four examples of pairs which were least frequently confused by the SRD group are combined to enable a direct comparison across all listener groups.
TABLE 6. The number and percentage of discrimination errors made by each listener-group for all six of the List 3 minimal-pairs which differed by a single feature. The relevant feature is indicated by V (voice) or P (place-of-articulation). P.F. = phonetic feature. The total number of presentations per subject-group for each of these pairs was 12. Percentage error-rates are given in parentheses, on which the means and S.D. scores are based.

<table>
<thead>
<tr>
<th>P.F.</th>
<th>EXP (%)</th>
<th>CA (%)</th>
<th>RA (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;tühl&quot;-&quot;kill&quot;</td>
<td>P 5 (42)</td>
<td>0 - 0 -</td>
<td></td>
</tr>
<tr>
<td>&quot;fit&quot;-&quot;sit&quot;</td>
<td>P 5 (42)</td>
<td>1 (8) 0 -</td>
<td></td>
</tr>
<tr>
<td>&quot;gaue&quot;-&quot;cave&quot;</td>
<td>V 1 (8)</td>
<td>0 - 0 -</td>
<td></td>
</tr>
<tr>
<td>&quot;die&quot;-&quot;guy&quot;</td>
<td>P 2 (17)</td>
<td>0 - 0 -</td>
<td></td>
</tr>
<tr>
<td>&quot;boat&quot;-&quot;goat&quot;</td>
<td>P 1 (8)</td>
<td>0 - 0 -</td>
<td></td>
</tr>
<tr>
<td>&quot;big&quot;-&quot;pig&quot;</td>
<td>V 0 - 1 (8)</td>
<td>1 (8)</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>19.5</td>
<td>2.7</td>
<td>0.2</td>
</tr>
<tr>
<td>S.D.</td>
<td>18.2</td>
<td>4.1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Therefore, one fricative place and one plosive place contrast were, together, responsible for a considerable proportion of SRD-group errors found for the "List 3" stimulus set. The error-distribution for these pairs across the SRD children was uniform for "fit"-"sit" (one error for 5 of the 6 children), whilst three of these children were responsible for the discrimination errors with "tühl"-"kill".

The main findings were that a significant effect of discrimination accuracy was found in testing just six children in each subject-group, and that group differences appeared to be based largely on only two pairs each differing in a single phonetic feature. Although these minimal-pair data are limited both in the number of pairs used and the size of the subject-groups, there is an indication that the SRD-subjects may not have discrimination problems with all minimal-pairs differing in only one feature. The pairs which caused them the most perceptual confusion (resulting in errors on about half of all presentations) had in common the vowel /i/ following the initial consonant. However, this vowel was present in /big/-/pig/ amongst phonetically "close" minimal-pairs in the same list, but this pair created a voicing rather than a place-of-articulation contrast, and here the error rate was very low for all groups. Often, it was not possible to provide word-pairs from the chosen vocabulary-source which provided alternative consonant-contrasts preceding the same vowel, of particular interest (retrospectively) in the case of the vowel /i/.
second formant frequency (F2) of /i/ is relatively high, and its path is close to that of its third formant frequency (F3). In these two particular cases, as noted above, discrimination accuracy was close to chance-level. The possibility is that both the similarity of the initial phonemes and the acoustic consequences of particular vowel environments will combine to provide perceptual confusions for the SRD-children in discrimination tests.

There was evidence of another source of perceptual confusion for the experimental group. The 10 errors made by SRD children to "same" pairs distributed across the three stimulus-groups concerned the use of nine different words (see Table 2). Of these ten word-pairs, seven bore either a single voiced or a single voiceless plosive in initial position, two bore fricatives (one each of /f/ and /h/), and one was a nasal (/m/).

Although: (1) all word-pairings were produced directly by the speaker and the "same" pairs did not consist, therefore, of physically identical stimuli, and (2) the overall error-rate was low, these results argue for the relative instability of receptive phonology in SRD-children. At this stage the above conclusions are tentative, but the initial-phoneme classifications in the phoneme-confusions specified above substantially corresponded with the findings of Masterson et al. (1995).

The task was performed by the RA- and CA-matched controls alike with high levels of accuracy for all minimal-pairs. A further point of interest is that these discrimination-errors occurred despite the provision of good quality natural-voice recordings of familiar, real-word stimuli.
2.8.2. Repetition tests.

2.8.2. (a). Real-word repetition.

SRD group.

This test resulted in low error-rates, overall. Twenty different word-items were presented (twice each), and thirteen were correctly repeated by every SRD-child. For only one subject, just one word was mis-pronounced following both presentations: the word "lend" was repeated first as /len/ and then as /lent/. The total of thirteen groupwise errors listed below represented an overall error-rate of only 5.4%. This rate was similar to that found for poor readers aged about 9 years for the repetition of monosyllabic high-frequency real words by Brady, Poggie and Merlo (1986), and for a group of 3rd. grade "poor" readers, using the same monosyllabic word-list, by Brady, Poggie and Rapala (1989). Both studies used clear listening conditions (silent backgrounds to their recordings). As can be seen from Table 7, a small number of cluster reductions were apparent from recorded responses, three of the four instances involving a stimulus with a final voiced-plosive clustered with a nasal consonant.

It was noted that some children tended to speak softly when using the microphone, particularly in respect of word-final phonemes. This occurred despite requests for them to try to speak clearly throughout. In these circumstances, the evidence of some cluster-reductions presented a real problem of interpretation as far as error scoring was concerned. In the case of final consonant omission there is the possibility that their responses were too acoustically weak to be recorded on tape. Recordings were played back at high volume several times for each subject.
TABLE 7. List of number of errors and error-responses in the real-word repetition of particular items by SRD listeners.

<table>
<thead>
<tr>
<th>ITEM</th>
<th># ERRORS</th>
<th>ERROR RESPONSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;vase&quot;</td>
<td>3</td>
<td>/baG/, /maz/, /haz/</td>
</tr>
<tr>
<td>&quot;lend&quot;</td>
<td>3</td>
<td>/len/, /lent/, /ven/</td>
</tr>
<tr>
<td>&quot;day&quot;</td>
<td>3</td>
<td>/bei/, /dgei/, del/</td>
</tr>
<tr>
<td>&quot;mend&quot;</td>
<td>1</td>
<td>/men/</td>
</tr>
<tr>
<td>&quot;soft&quot;</td>
<td>1</td>
<td>/snf/</td>
</tr>
<tr>
<td>&quot;fast&quot;</td>
<td>1</td>
<td>/ast/</td>
</tr>
<tr>
<td>&quot;hole&quot;</td>
<td>1</td>
<td>/hould/</td>
</tr>
</tbody>
</table>

An area of research which suggests the importance of speech perception for another measure of word recognition and phonological knowledge comes from studies of spelling errors in normal and mixed normal-and-SRD child-groups. Early spelling, at least, does seem to be phonologically-based (e.g. Hoffman and Norris, 1989). The spelling-to-dictation errors of both language-normal and SRD-children indicates that children have a tendency, even at the age of 8 years or more, to omit letters when their corresponding phonemes are not, for them, perceptually prominent (e.g. Bruck and Treiman, 1990; Treiman, 1985a). Interestingly, these omissions tend to occur most frequently for the second consonant of two-consonant initial clusters, for final singleton consonants, and for absolute-final consonants in word-final clusters. Phonemes (usually in clusters) which may not be perceptually prominent for certain children, and lead to spelling errors, might be responsible for corresponding errors in the repetition task. In this pilot test, there was no consistency of errors being made on particular words across the children comprising this SRD-group, even as regards word-final cluster-reduction. From the response-recordings and the independent evidence of spelling-errors for consonant-clusters, it was decided that the small number of cluster reductions in single-item repetition represented a real (perceptual) effect. They were therefore counted as errors.

The error corpus related to a total of sixteen phonemes. There was evidence of only
one occurrence of vowel mis-pronunciation, this resulted in a substitution of /e/ for /ei/, in this instance with an intrusive final approximant (/l/). Overall, there seemed to be, where errors occurred, a tendency for an initial consonant phoneme to be substituted by another consonant phoneme, and for final phonemes to be omitted. For these stimuli, all the word-final omissions resulted in cluster-reduction. This is to say that, whenever an item ended in a vowel or in a single consonant phoneme, there were no repetition errors, except for the one instance of /dei/ ("day") being repeated as /del/ ("del"). Overall, there were no errors with items containing final vowels or word-final single consonants.

The repetition of familiar real words immediately after hearing each item was less accurate for the SRD-group than for either control group. Brady et al. (1989) had found that certain real words of known frequency, some of them high, were inaccurately repeated by their CA children. In this dissertation, there was some evidence that the repetition of initial consonants in real words by SRD children can involve the substitution by other consonants differing in manner and place (/v/ → /m/) or voicing and place (/v/ → /h/). They made errors relating to fricative production (initial position). Fricatives were substituted by other fricatives, by a stop and by a nasal.

**Chronological-age controls**

The CA group made no errors on real-word repetition. This was a somewhat higher rate of performance for the repetition of high-frequency items than had been found by CA controls by Brady, Poggie and Merlo (1986) and by Brady, Poggie and Rapala (1989), which was indistinguishable from that of their poor readers. In these studies, word frequency estimates were obtained by reference to their rate of occurrence in children's literature according to the "Word Frequency Book" prepared by Carroll, Davies and Richman (1971). The Alpha (7) vocabulary lists used in this study do not quote frequency-estimates for items.
Reading-age controls.

The total number of real-word repetition errors for this group was only four, restricted to the items "nice", "vase" and "tell", and comprised two phonemically close phoneme-substitutions and two vowel errors. Their overall error-rate of just 1.7% tends to affirm the relevance of the use of items chosen from the Alpha (7) vocabulary lists in providing materials of appropriate levels of frequency (familiarity). Brady et al. (1986) did not use a reading-age control group.

2.8.2. (b). Nonword repetition.

SRD group.

Two children in this group gave an error-free performance, the other four children made a total of eighteen errors (an overall error-rate of 7.5%). One error was of response omission. The Table below details seventeen of these eighteen errors. There was little evidence of consistency of erroneous repetitions of particular nonwords.

TABLE 8. Error-totals and error-responses by SRD children for certain items in the nonword repetition task.

<table>
<thead>
<tr>
<th>ITEM</th>
<th># ERRORS</th>
<th>ERROR RESPONSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>vuse</td>
<td>3</td>
<td>/vulaz/, /fuz/, /buz/</td>
</tr>
<tr>
<td>pirt</td>
<td>3</td>
<td>/hst/</td>
</tr>
<tr>
<td>fest</td>
<td>2</td>
<td>/set/</td>
</tr>
<tr>
<td>saft</td>
<td>2</td>
<td>/sef/</td>
</tr>
<tr>
<td>boll</td>
<td>2</td>
<td>/bul/</td>
</tr>
<tr>
<td>garl</td>
<td>1</td>
<td>/gal/</td>
</tr>
<tr>
<td>wut</td>
<td>1</td>
<td>/wut/</td>
</tr>
<tr>
<td>hile</td>
<td>1</td>
<td>/pail/</td>
</tr>
<tr>
<td>tull</td>
<td>1</td>
<td>/kal/</td>
</tr>
<tr>
<td>doy</td>
<td>1</td>
<td>/doli/</td>
</tr>
</tbody>
</table>

The error-corpus contained 5 substitutions involving both manner and place
features. Generally, the consonant mispronunciations found here followed the minimal-pair discrimination findings of, for instance, Mody (1993) and Cornelissen et al. (1996). This was that phonemically "close" errors predominate, i.e. that identification and discrimination errors made by reading-disabled subjects tend to concern phonemes which share two phonetic-features. In particular, confusions of /f/ with /v/, /f/ with /s/ and /t/ with /k/ were seen, but there were also confusions involving /p/ and /h/.

There was some evidence of final-cluster reduction in non-word repetition, as found with word-repetition, but, again, little indication that the majority of the SRD children tended to make the same types of production error. Therefore, the error-types noted probably relate to a source of difficulty for individual children, rather than fixed tendencies, or trends.

**Chronological-age controls.**

Four errors were made by these children, representing an overall rate of just 1.7 %. The nonwords "pirt" and "hile", produced in citation form, had highly-aspirated voiceless consonants in initial-position. Three of the groupwise errors involved confusions between /p/ and /h/, as suggested by the substitution-errors made, with one instance of vowel-change, where "wut" /wʌt/ was repeated as /wɒt/.

**Reading-age controls.**

The fifteen errors of repetition found for these younger children, represented an overall rate of 6.2 %. They showed an error-pattern largely consistent, in error-type and error-rate, with those made by the reading-disabled children for certain items. Some 33 % of the RA group's error-total was associated with the repetition of the item "pirt" /pɔt/, through substituting /h/ for /p/.

Given the low overall error-rate, there was no basis for noting error-trends in nonword repetition, for younger controls. However, there were five instances of the
/pət/-/hət/ confusion involving 4 individuals. It was noted above that this confusion also arose for both the experimental and the CA children.

**TABLE 9.** Error-responses, and totals, for RA control children for selected items in the nonword repetition task.

<table>
<thead>
<tr>
<th>ITEM</th>
<th># ERRORS</th>
<th>ERROR RESPONSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>pirt</td>
<td>5</td>
<td>/hət/</td>
</tr>
<tr>
<td>wut</td>
<td>3</td>
<td>/wɒt/, /mɒt/</td>
</tr>
<tr>
<td>boll</td>
<td>2</td>
<td>/bɔl/, /bul/</td>
</tr>
<tr>
<td>vuse</td>
<td>2</td>
<td>/vɔuz/, /fuz/</td>
</tr>
<tr>
<td>fest</td>
<td>1</td>
<td>/fes/</td>
</tr>
<tr>
<td>garl</td>
<td>1</td>
<td>/gəm/</td>
</tr>
<tr>
<td>doy</td>
<td>1</td>
<td>/dɔi/</td>
</tr>
</tbody>
</table>

When interpreting these results, it must be kept in mind that it is not possible to be sure whether any repetition-error is due exclusively to problems of perception or production, or whether both may be involved. Experimental children may differ widely in the extent to which their problems are productive / perceptual, and certain production-errors may not be detected by an experimenter due to the subtle expectations set up by knowledge of correct responses. The use of, and considerable reference to, response-recordings helped to minimise this danger.

Exactly half of the 18 errors made by the reading-disabled children involved substitution of the initial (consonant) phoneme, five resulting in lexicalisations. It is possible that any mis-repetitions on non-words which result in a lexicalisation response could relate to items in that child's individual spoken vocabulary, but, at least as far as written vocabulary is concerned, three of these five do not appear in the Alpha (7) list.

The reading-age (RA) controls did worse with monosyllabic nonword repetition than with monosyllabic real word repetition, whilst the chronological age (CA) controls were relatively accurate with both types of item. The SRD-group was not reliably less accurate at repeating nonwords than real words, but were significantly
worse than either control group at the repetition of monosyllabic real-words. The nonword repetition accuracy of the experimental and the RA groups was similar.

Perhaps a developmental factor is at work here, such that whilst the younger, normally-reading (RA) children can repeat familiar real words accurately, their overall use of acoustic-phonetic cues combined with their representation of phonology is still emerging. Certainly, Brady, Poggie and Merlo (1986) interpreted their pattern of results (of reduced repetition accuracy in poor readers compared to good readers for both monosyllabic nonwords and polysyllabic real words) as.... “measures of differences in phonetic processing efficiency”. Within the model of a limited-capacity working memory system (Baddeley and Hitch, 1974) the reading-impaired children would have weaker performance on such linguistic STM tasks as a result of less efficient encoding of the phonetic items, not on the rate-of-processing as such. The RA-controls used in this pilot test may have similarly less-efficient encoding skills specific to novel items as SRD-children, compared to older control children and normal adults, but only the SRD-children, as a whole, make little further progress with these skills. However, the broader significance of the SRD-children's relatively low repetition accuracy for both types of material is difficult to assess because the group size was small, with many of their errors being infrequent.

2.8.3. Initial-phoneme deletion.

Reading-disabled group.

The major features of their error-corpus seemed to be:

(1) to not attempt an average of about half of all deletions,

(2) to repeat the item as presented, and

(3) to "substitute" the initial consonant-phoneme to be deleted with a range of other consonant-phonemes.

The overall error-rate for this group was 56 % of trials. Of the 135 errors, 68 (or...
about half of the total) were refusals. Particular SRD listeners made more refusals. As can be seen in Table 5, two of the reading-impaired children, although they understood what was meant by "the first sound", did not make a single correct deletion response. A total of twelve repetitions of each stimulus word were presented to each subject-group. There were four vowel substitutions and one vowel deletion. One response was regarded as a semantic error (/kæt/ → /mæt/).

Thirty-nine errors (29% of the total) were due to non-deletion of the initial consonant phoneme but "substituting" it. One subject provided 24 of these initial-phoneme substitutions. Final consonant substitutions were comparatively rare, totalling only four. One subject substituted nasals /n/ and /l/ and the stop /t/ in item-initial position for many of his responses. For this subject, errors through simple repetition (e.g. stimulus = /dot/, response = /dot/) were entirely absent.

Chronological-age controls.

A total of only two errors (a rate of 0.7%) were associated with these listeners.

Reading-age controls.

Six groupwise errors were noted, making the overall rate 2.3%. Four of these related to substitution of the final phoneme. The remaining two errors were: one deletion of the final phoneme of "mean" /min/ to yield /mil/, and a combined vowel-substitution and cluster-reduction for the item "belt" /belt/ producing /aut/.

It is worth noting, though, that five of these six error-responses nevertheless incorporated deletion of the initial phoneme. The numbers of errors of any particular type were low, making it impossible to detect trends.

The low error-rates for both control groups indicate that this task, although somewhat lengthy in description, is not intrinsically difficult for children who have age-appropriate "phonological knowledge". The youngest children (RA group) made, individually, no more than 7.5% errors, and three of the six members of this group made no errors. Also apparent was the general enjoyment that all the control
children had in this task, it being treated as more of a game than a test. This was not true of the SRD-children, some of whom had prior experience of the procedure. Generally, they found it tedious, problematic and mildly stressful. The error-rate of 56 % for the SRD-group masks the fact that individual children in this small group varied greatly in their ability to delete an initial phoneme segment (10 % errors in one case and 100 % in two others). General statements are therefore impossible.

The average error rate on initial-phoneme deletion was far greater for the experimental group than for either control group (p = 0.0006). The control groups did not differ in their ability to perform this task. Some SRD-children find it hard to segment any of the sounds comprising a syllable, often perceiving a syllable as a single sound (Adams, 1990; Byrne and Fielding-Barnsley, 1989; Guthrie and Seifert, 1977; Mann and Brady, 1988; Treiman, 1985a, 1985b). Since individual SRD children varied widely in their ability to perform this task, the reading disability of some may not necessarily be related to the size of the phonological units that they are able to utilise, but to other aspects of phonological mediation.

The overall inaccuracy of decision-making, suggested by the mean error-rate of the SRD-group on this particular segmentation task, appears relevant to the findings of other studies (such as Pratt and Brady, 1988; Treiman, 1985b and Seymour and Evans, 1994). They considered whether the recognition and use of the smallest unit-size (a single "phoneme") is not always available, through mediation, to these children. Pratt and Brady found, using this procedure, that groups of 15 "poor" readers and 15 "good" readers aged from 8 to 10 years, and similar-sized adult groups of good and poor readers, performed significantly differently, according to reading-status. For the child groups in their study, good readers produced mean error-rates of 24 % whilst that of the poor readers was 74 %. Both of these mean scores are, respectively, considerably higher than either the CA or the RA control group, and somewhat higher than those found for the SRD children, in this pilot study.

Pratt and Brady's (1988) "poor" readers may have shown more uniform levels of
performance, with no one individual showing relative accuracy. Their use of items of increasing complexity, and of a cut-off criterion of 5 consecutive errors, would also be expected to contribute to the higher error rates of their groups. They concluded that there was..."an exceedingly strong relation between phonological awareness and reading ability in both adults and children". The persistence of weakness in initial-phoneme deletion in adults undermined the argument that such deficits are related largely to developmental delay. They also considered the possible effect of differences in reading instruction methods, principally the phonics approach compared to the whole-word. They found that the children tested showed considerable differences in reading skill and linguistic awareness despite having received the same type of instruction. Normally reading children who are familiar with the letter-sounds of the alphabet give every indication, by the age of 7-8 years, of being able to appreciate and use "phoneme"-length speech segments, through their performance on a variety of phoneme substitution, transposition, deletion and blending tasks.

2.8.4. Individual SRD-subjects' performance patterns.

The tasks in the pilot phase concerned phoneme discrimination, output phonology and phoneme segmentation. A main aim of this work is to assess whether some SRD-children are more likely than others to show problems with speech perception. Despite the small number of trials and their very differing requirements, the consistency of individual SRD-children's error-rates in pilot testing can be used as a guide to test-battery construction. Error-rates for one or more tests may show little variation across individuals, or there may be large within-subject variations across tests. Comparison of each SRD's performance across these tests also gives some indication of how broad their problems with "phonemic awareness" might be, and the data are provided in Table 10.

Across the SRD-group there was most variability in the ability to perform the initial phoneme deletion task, with two subjects (# 2 and # 5) showing a "floor" effect. With the possible exception of subject 6, there was little evidence of uniformity of
performance on the minimal-pair discrimination, nonword repetition or phoneme deletion tasks. Relatively few errors were made, within this group, on the word repetition task.

TABLE 10. Individual error-rates (%) for the SRD-children on the four tasks involved in pilot testing. The column headings are:- MP = minimal-pair discrimination (list 3), WR = word repetition, NWR = nonword repetition and IPD = initial-phoneme deletion. Error rates, means and standard deviations are given to the nearest integer.

<table>
<thead>
<tr>
<th>SUB</th>
<th>MP</th>
<th>WR</th>
<th>NWR</th>
<th>IPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38</td>
<td>8</td>
<td>8</td>
<td>35</td>
</tr>
<tr>
<td>2</td>
<td>19</td>
<td>8</td>
<td>15</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>5</td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>32</td>
</tr>
<tr>
<td>5</td>
<td>14</td>
<td>2</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Mean</td>
<td>17</td>
<td>6</td>
<td>8</td>
<td>56</td>
</tr>
<tr>
<td>S.D.</td>
<td>11</td>
<td>4</td>
<td>6</td>
<td>37</td>
</tr>
</tbody>
</table>

No SRD child in this sample found more than one pilot test particularly difficult, although subject 1 made errors on about one third of all trials in both the minimal-pairs and phoneme deletion tests. The children in this group who had obvious difficulty with phoneme deletion (subjects 2, 3 and 5) also had some difficulty with the discrimination of minimal-pairs. However, performance on one of these tests did not appear to be strongly related to that on the other. The evidence from the SRD performance patterns is that the minimal-pair discrimination and non-word repetition tests are likely to be sensitive measures of phonemic awareness, producing reliable individual differences in larger-scale experiments. Such measures are also likely to be accurate in that they do not induce undue stress in listeners. From close observation of SRD subjects, the same can not be said for the initial phoneme deletion task.
2.9. Conclusions.

2.9.1. Minimal-pair discrimination.

The following points, developing the pilot test for the main phase, are proposed:

1. The discrimination of naturally-produced minimal-pair stimuli allows an ecologically-valid evaluation of the speech-perceptual abilities of subjects differentiated by reading-status or by chronological age. The minimal-pair pilot indicated that SRD-children have occasional difficulties with the discrimination of certain phonemes in item-initial position under quiet listening conditions. The addition of low levels of background noise is apparently unnecessary for the generation of discrimination errors in SRD-children for certain types of phonemic contrast. Minimal-pair discrimination of naturally-produced real-word items will be included in the main test battery.

2. The procedure of having subjects repeat the word-pair before making their discrimination judgement was to be discontinued for the main phase experiments. Item-repetition may have entailed production as well as perceptual errors, and was considered capable of distracting attention from the discrimination task in subjects for whom the overall response-requirements might represent a heavy loading within "working STM".

3. Full-scale experiments in the main test battery will comprise "same" - "different" discrimination judgements expanded to cover a much wider range of phoneme-contrasts differing by only one feature, and recorded with a quiet background. The use of intervocalic (VCV) minimal-pairs will enable the study of a wider range of contrasts than would be possible if real-word stimuli were to be used, since the selection is free from vocabulary control. If, using VCV items, those consonants which prove to be accurately discriminated by the reading-impaired group are those which are relatively early-acquired, and these children are less accurate at discriminating those items which are mostly later-acquired, an
explanation based on "developmental delay" would be plausible.

4. Of further interest will be to examine whether, for SRD-children, there are circumstances in which perceptual confusion can be shown for contrasts differing by more than a single feature.

5. Since some consonant contrasts differing in only one feature were well discriminated by all reading-groups in the first pilot test (such as the /dai/-/gai/ plosive place contrast) contrasts will be presented in different vowel-contexts to examine the effect of this on discrimination accuracy. This will be referred to as the "natural minimal-pairs" test.

2.9.2. Real-word and nonword repetition.

As stated above, there is no estimate from the Alpha 7 (source) listings on the relative frequency of the words chosen for this test in the written vocabulary of language-normal children. Therefore it is not possible to control for differential effects of familiarity or frequency on the accuracy of their repetition. The fact that words such as "vase" and "lend", which would be of relatively low frequency even in the spoken vocabulary of adults, appear in the listings suggests that the errors associated with their repetition could be frequency-related, particularly for SRD children. They made several errors in the repetition of these two words, but the control groups did not. It was therefore decided not to ask subjects repeat real words in the main test-battery.

The nonword repetition test was, however, retained for items of greater syllabic length. The production of multi-syllabic nonsense words by different reading-groups will be studied in a replication of Gathercole et al's (1994) "CNRep" test. This will examine whether, as reported by the authors, dyslexic children make more errors in repeating the longer items (those of three syllables and more) than do CA- and RA-control children. Snowling and Hulme (1994) have emphasised that nonword repetition skills are related to learning the spelling and fluent
pronunciation of new words. Persistent problems with nonword repetition were regarded as tied to persistent difficulties with speech processing (phonological skills) in general. Developmental phonological dyslexics, such as Snowling and Hulme's subject JM, quite systematically mispronounce consonants. Although there is evidence that not all nonwords of a given length are equally difficult to decode (Treiman, Goswami and Bruck, 1990), it may be the case that children who are particularly weak at nonword reading may also be weaker than other SRD-children at nonword repetition. Therefore, the other main aim in using this test is to investigate this possibility. In other words, would the error pattern for the repetition of longer nonwords assist in the sub-grouping of the sample of reading-disabled children? That this may not prove to be demonstrable could be related, say, to the incidence of vowel digraphs in a sample of nonwords, which may present more consistent difficulties for groups of SRD children as a whole than the pronunciation of consonants.

2.9.3. Initial-phoneme deletion.

There was a very strong effect of group for the phoneme-deletion task, although individual experimental children differed widely in the extent to which they could execute this task. As it is so central to the difficulties of SRD-children with tasks involving some form of segmentation and/or blending of phonemes, phoneme deletion for such children becomes an operationally complex and potentially stressful task. This appears to be so whether or not a time limit for responding is imposed.

The conclusion could reasonably be drawn that problems arise because phoneme deletion is more closely related to these subjects' widespread difficulties with the representation of phonology (hence to decoding problems themselves) than to specific individual differences in speech perceptual acuity. In fact, the pilot test result did suggest that this procedure had little potential for distinguishing those SRD-children who, from the minimal-pair pilot data, had certain speech-discrimination problems from those who did not. The high refusal rate observed
for several children suggested the experience of stress, as was also clear from post-test comments. Phoneme deletion showed the largest degree of individual difference and the highest mean error rate of the three chosen pilot tests for the SRD children. It may have been possible to proceed with this measure in the main phase by considering a modification of the initial phoneme deletion task requiring no verbal response. The Lindamood Colour Blocks test (Lindamood and Lindamood, 1979) would have involved the removal of the first of a line (the leftmost) of differently coloured blocks said to represent the phonemic structure of items. This option was rejected because, although a verbal response would not be required, the need to mentally separate the first segment from each item heard would remain. However, the same perceptual decision is required, and it is this which creates the difficulty for SRD children, not the response mode. Based on the need to ensure the willingness of children to continue to participate in the entire test-battery, it was concluded that no further use should be made of this procedure.
CHAPTER 3.

THE MAIN TEST-BATTERY.

3.1. Introduction.

The overriding aim of the main phase is to obtain an extensive evaluation of any speech-perceptual difficulties for SRD-children, and to ascertain whether the performance of control children is uniformly more accurate throughout the range of tests. A further aim was to relate performances on speech tests to performance on reading-list tests which are intended to highlight specific "patterns" of reading-errors (based on Castles and Coltheart, 1993). Lastly, the intention is to try to discover whether a proportion of children within a reading-disabled group were performing outside normal limits in each of a range of speech discrimination and identification tests, which contain stimuli of varying levels of acoustic-phonetic complexity and of differing degrees of acoustic salience. In order to test previous findings that these relative deficits are at the level of phonemic processing rather than linked to general auditory deficits, psychoacoustic tests of temporal and spectral-frequency acuity will also be presented.

It was intended to produce an extensive test-battery. Perceptual errors which individual children might make over a range of speech-based tests would indicate different aspects of a recurring, if subtle, problem. Simultaneously, performance-profiles for each subject would provide a good index of heterogeneity with a group.

3.2. Rationale of Exclusion Criteria for Main-Phase Experiments.

The SRD-subjects in the pilot phase had been tested without tight control over the extent of their reading-delay or their chronological age. These variables were now more carefully limited in order to provide an experimental group which would be more homogeneous. The exclusionary criteria and the reasons for their application
were as follows:

i). Children were excluded from the main experimental battery if their reading-age was less than 18 months or more than 36 months below their chronological age. Combined with control of participants' chronological age, this would facilitate the exclusion of children with borderline SRD-status and of those with severe reading problems, without which the provision of a "matched" and fairly homogeneous reading-age control group would be difficult to achieve. Since the experiments frequently use words taken from a source related to the vocabulary of normally-developing 7-year-olds, it is clearly not possible to include in any group children who are younger than about seven;

ii). Although the chronological age-range of the SRD children who volunteered to participate in the pilot phase was not broad, control over this variable for the experimental children in this phase was desirable for CA-matching from within a restricted number of school classes. This also ensures that they have had similar opportunities for reading practice. An age-range of 9 to 12 years was set. A fairly narrow age-range was necessary, also, to control for the overall development of speech perception and yet allow a margin for possible individual differences in the rate of this development;

iii). The requirement that English be the child's mother-tongue arises to ensure that any difficulties a child may be showing with reading and the speech-based tests relate to the same language as that of testing, not to any aspect of learning of a second language (e.g. in a bilingual home). This would be particularly important if the second language did not happen to make one or more particular phonemic contrasts that feature prominently in English;

iv). The demands of a confining situation and the necessity of taking subjects away from their classmates and the familiar classroom surroundings might mean that an emotionally disturbed child becomes increasingly distressed. Teachers were consulted to ensure that no child with emotional problems was included in the
subject-group;

v). All subjects used in the main battery were to have hearing within normal limits as established by the results of previous standard audiometric tests. School records of these, usually comprising a single testing-session run between about 2 to 4 years previously, were consulted, together with more current information given by the notes of class and/or remedial teachers. It was not possible to provide suitable facilities for audiometric testing at the time of running these experiments in either the school or the home setting. Any child with a reported history of chronic hearing loss did not participate in this work. To minimise the risk of testing during a period of intermittent hearing loss, no child was tested on any day/s when s/he had a cold or other infection;

vi). Problems of speech production are not generally associated with reading-difficulty, but dyslexia can form part of a complex of expressive- and receptive-language problems which certain children appear to have from an early age. In order to avoid expressive language problems, mainly as a consequence of the need to measure nonword repetition skill as a function of general reading efficiency, it was decided to exclude from the study children who had production difficulty as regards age-appropriate conversational speech. The information provided by form teachers, remedial teachers and/or parents on this specific issue was used.

3.3. Selection of a Comparison Measure of Intelligence.

Children were not pre-screened for intelligence. Those children whose general intelligence was likely to be below the average range were not considered for the study as their reading-disability was not "specific", and probably associated with a number of other cognitive limitations which the IQ tasks have tapped. Reading-skills below those appropriate for the biological age of a child who is probably of below-average intelligence could, of course, be due at least partially to their performance- and/or verbal-limitations. In such a case the child is properly described as a "poor" reader, not "reading-disabled" or "dyslexic". Weaknesses of
abstract coding and/or short-term memory (STM), word-finding or attentive skills could be some of the major causes of low IQ scoring, and could impact crucially on a child's ability to read with age-appropriate fluency.

Clearly, the use of a verbal-IQ test would be far from ideal since the reading with full comprehension required for completion of such tests impacts with the disability under consideration. Picture vocabulary tests (such as the Peabody Test) are limited by the number of words which can be adequately represented, whilst sentence completion tasks would provide an obvious disadvantage to the SRD-child:— the growth of vocabulary is strongly positively correlated with reading ability (Aguiar and Brady, 1991). It is to be expected, therefore, that a reading-disabled child will score poorly on many verbal IQ measures through his/her reading disability rather than underlying intelligence. A fairly "clean" test, essentially free of written language, would be one of "non-verbal" intelligence, such as Raven's Progressive Matrices (Raven, Court and Raven, 1986). It was used here as an intelligence measure which could be independent of the degree of reading-delay a child suffers.

3.4. Organisation of Experimental Work in Main Phase.

The intentions of the test-battery were to provide experiments to test the suitability of the stimuli, and methods, in demonstrating possible differences in the speech-perceptual and speech-repetition abilities of individual SRD children, and to establish to what extent consistency of group effects would be shown. For several of the speech-based tests, a large number of phonemic contrasts was presented in order to estimate the generality of any group differences, and minimise the possibility of introducing effects which might prove to be "stimulus-bound" (i.e. applicable only, or mainly, to the particular stimuli selected for use). A set of psychoacoustic tests was included to assess whether any reading-group had more general difficulties of auditory discrimination.

Each test will be described in detail in Sections 7-9 of this chapter. The complete
experimental battery consisted of the following tasks, which all children were to complete:

**Reading tests.**

Neale Analysis of Reading Ability (revised) test of reading accuracy and comprehension.
Reading-lists of unconnected regular, irregular and nonword items.

**Intelligence test.**

The Raven's Progressive Matrices Test of non-verbal IQ.

**Discrimination tests.**

Intervocalic consonant (VCV).
Consonant cluster (omission) condition.
Consonant cluster (substitution) condition.
"Natural" minimal-pairs.

**Speech-pattern identification tests.**

Copy-synthesised continua as follows:

(a) "date"-"gate" test (/d/-/g/ stop place contrast), one "combined" and two "reduced-cues" versions;
(b) "Sue"-"zoo" test (/s/-/z/ fricative voicing contrast), one "combined" and one "reduced-cue" version.

**Nonword repetition.**

A set of forty 2- to 5-syllable legal nonwords.
Psychoacoustic tests.

The following tests of auditory acuity:

1. Gap detection.
2. Formant frequency discrimination.
3. Formant frequency-modulation detection.
4. Fundamental frequency (pitch) discrimination.

3.5. Subject Selection:- Chronological Age and Reading-Delay.

Reading-disabled children.

A group of 13 children with specific-reading-difficulty (SRD), and groups of 12 chronological-age (CA) controls and 12 reading-age (RA) controls who had satisfied all of the criteria, were selected. The RA controls were paired individually with SRD-children on the basis of their estimated reading-ages.

The experimental group comprised 9 boys and 4 girls aged between 9;3 and 11;7 years (mean: 10;4 years). The mean reading-delay of these thirteen reading-impaired children was 27 months, therefore the mean reading age was 8;1 years (s.d. = 11 months, range 6;10 to 10;1 years). Details of their RPM, Neale accuracy and comprehension scores are included in Table 11. Twelve of these children were right-handed (92 %), and one left-handed for writing.

Chronological-age controls.

The group of chronological-age matched (CA) control children was selected, using the same exclusion criteria except for reading-delay, generally from the same school classes as were the reading-disabled children. One CA control child took part in the first phase of pilot testing and in part of the second phase, but...
in this group were boys (67%). The mean age of this group was 10;1 years (s.d. = 8 months, range 9;3 to 11;2 years). Each child was reported as having reading skills which were at least age-appropriate, although, in practice, many were reading beyond their age-equivalent range (reading-age range 9;6 to 13+ years, mean = 11;9 years). Mean scores on standard tests are given in Table 12. Nine of these children were right-handed (75%) and three left-handed for writing.

Reading-age controls.

The selection of normally-reading children for the reading-age (RA) control group depended on the estimated reading-age of individual SRD-children as each RA child was pair-matched to an SRD-child. Since the number in the SRD-group was one greater than that in the RA-control group, one child from the latter group was exactly matched to two experimental children whose reading-ages were estimated to be identical. Wherever possible, the matches were to be to within 2 months of reading-age-difference, and this was achieved for each pairing except one, where the difference was three months.

The age of each of the younger controls was, in any event, to be a minimum of 7;0 years, because real-word materials for some of the pilot tests, and many of the proposed full-scale experiments, were based on the Alpha word-list for 7-year-olds. The chronological age-range for the RA-group was 7;7 years to 8;9 years, with a mean of 8;2 years (s.d. = 4 months). It comprised 6 boys and 6 girls. As with the CA controls, 9 were right-handed (75%) and 3 left-handed for writing. Mean scores on standard tests are given in Table 13.

All of the children selected participated in the entire test-battery. The reports of normal hearing, and of the incidence of otitis media, other clinical information and
the length and nature of remedial teaching sessions (where relevant) were noted by means of a medical-educational history questionnaire.

*Individual medical- and educational-history questionnaire.*

For each child, a questionnaire was completed which asked for information from teachers, parents and children themselves about relevant medical issues such as the incidence, now or in the past, of episodes of ear infection, otitis media ("glue ear"), and some details of any hearing loss experienced. Other questions concerned the nature and scope of any remedial teaching in respect of reading difficulties, how often given, the number of remedial-hours set aside per week, and how long received. Finally, there were brief questions concerning familial problems with reading, and handedness for writing. The point of noting handedness is to discount the possibility that it might be reliably correlated with speech perceptual difficulty. [A clear majority of the members of each listener group were right handed for writing, in fact only one SRD listener with speech perceptual weakness was left handed.] A copy of this questionnaire is given in Appendix B.

3.6. Main Test Battery.

3.6.1. Standardised test of reading ability.

a). Rationale.

The "Neale Analysis of Reading Ability" (1989, Revised) was chosen as this contained graded tests of accuracy and comprehension, each with standardised tables of scores (procedure to be described below). It is also noted for its provision of standardised scores for reading rate, although these were not used here. The use of the Neale Analysis is widely reported in research in the field of reading-impairment, and is commonly employed by in-service remedial teachers. It is also quoted and used by those concerned with research and teaching in both speech- and language-impairment (e.g. Stackhouse and Snowling, 1996).
b). Test description.

The Neale Analysis of Reading Ability (Revised) comprises two series of six prose passages increasing in range of vocabulary and overall length. These passages are presented in the same fixed order, and a set of comprehension questions follows the completion of each passage.

3.6.2. Standardised Non-Verbal Intelligence Test.

a). Rationale.

The "Raven's Progressive Matrices" (RPM) test (Raven, Court and Raven, 1986) was selected as it had been widely used in a variety of studies involving children (and/or adults), and scores have been standardised. It was used here as a "clean" intelligence measure which could be independent of the degree of reading-delay a child suffers. The requirements of the tasks are easily understood by children aged 7 years and above.

b). Test description.

The individual tests involved completing a sequence of patterns presented on each page by selecting one of a set of numbered alternative pattern-elements supplied at the foot of that page. There were 5 such sets of tasks, marked A to E, each consisting of 12 puzzles.

3.6.3. Regular, Irregular and Nonword Reading Lists.

a). Rationale.

Lists of regular, irregular and nonwords were presented in order to judge the ability of children to decode regular phonology, and to look particularly at within-subject
differences in performance between irregular and nonword reading. Although the nonword-reading deficit is a general feature of SRD children's difficulties with orthography (Rack, Snowling and Olson, 1992), when a child's nonword reading is noticeably weaker than his/her irregular word reading, this is seen as indicating developmental "phonological" dyslexia. Irregular word reading is weaker than that of nonwords in developmental "morphemic" (surface) dyslexics (Castles and Coltheart, 1993; Seymour, 1985). The intention is to compare each individual's "reading patterns" across these lists to his/her pattern of performance on the main test battery, in order to assess whether there may be evidence for a relationship between reading-pattern type and speech perceptual problems. The issue of word selection for the "regular" and "irregular" lists is not a straightforward one. Many of the items were taken from Castles and Coltheart (1993) and categorised in the same way. Close letter-sound correspondence of the consonant phonemes was regarded as the main criterion for regularity.

b). Test description.

All words used were present within an age-appropriate written vocabulary control:- the Alpha (7) list (Edwards and Gibbon, 1964). From the published lists of Castles and Coltheart (1993), 11 regular and 11 irregular words were drawn since they fulfilled the criterion of inclusion in the Alpha list; a further 9 words in each category were chosen from this Alpha list to provide 20 words in each list. There was no information of the relative frequency of occurrence of individual items from this written-vocabulary source.

The 20 nonwords employed were derived from the monosyllabic lists of two recently published sources: Castles and Coltheart, (1993) and Laxon, Masterson and Coltheart (1991). These three lists are presented in Appendix C.
3.6.4. Intervocalic consonant discrimination.

a). Rationale.

Several previous discrimination studies have involved either reading- or language-disabled groups tested on a comparatively small range of phonemic contrasts, such as /b/-/d/ and /d/-/g/ (Gregory et al., 1981), /b/-/p/ (Tallal and Stark, 1981), /s/-/ʃ/ (Mody, 1993; Nittroer and Studdert-Kennedy, 1987) and /l/-/v/ (Masterson et al., 1995), using nonsense-syllable (CV) discrimination stimuli. The possibility of lexical effects and of different vowel environments accompanying the use of real-word minimal pairs in the pilot test described in Chapter 2 indicated the need for the consonants to be discriminated in a more controlled environment. The aim of this test was to evaluate consonant discrimination for speech items having an "inter-vocalic" (VCV) structure (see Ohman, 1966). The use of this form of stimulus ensures that all consonants appear in a controlled vowel framework and that lexical information is eliminated. Following the finding in the pilot tests that discrimination problems arose for SRD-children only when minimal-pairs differed in one phonemic feature, the paired inter-vocalic consonants will have the same manner of articulation but differ in either voicing or place-of-articulation. A large range of natural VCV-stimuli had been recorded using a phonetically trained female speaker for other research purposes, and so were readily available.

b). Test description.

The fifteen minimal-pairs used, classified in terms of the features in which they vary and with their broad phonemic transcriptions, were as follows:-

<table>
<thead>
<tr>
<th>Feature Type</th>
<th>Minimal Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop place contrasts</td>
<td>/aba/ - /ada/ /ada/ - /aga/ /apa/ - /aka/</td>
</tr>
<tr>
<td>Stop voicing contrasts</td>
<td>/aba/ - /apa/ /ada/ - /ata/ /aga/ - /aka/</td>
</tr>
<tr>
<td>Fricative place contrasts</td>
<td>/aʃa/ - /aža/ /asa/ - /aʃa/</td>
</tr>
<tr>
<td>Fricative voicing contrasts</td>
<td>/afa/ - /ava/ /aʃa/ - /aʒa/</td>
</tr>
</tbody>
</table>
Nasal place contrasts /ama/-/ana/  
Approximant place contrasts /ara/-/awa/ /ara/-/aja/ /ara/-/ala/  
Fricative place/voicing contrast /asa/-/a\̆a/

The contrast /asa/-/a\̆a/ differed in both place-of-articulation and voicing. It was added to further test the finding in the pilot study that significant numbers of errors in discrimination occurred only for contrasts differing in one phonetic feature.

3.6.5. Consonant-cluster discrimination.

a). Rationale.

It was of interest to establish how accurately real words differing only in their initial two-consonant clusters could be discriminated by reading-disabled children. Even for the monosyllabic words in the Alpha-7 source-listings, often of presumably high frequency, many bore such clusters in either initial or final position. If it is assumed that language-impaired and SRD-children are weaker than language-normal children at processing and discriminating brief speech-sounds in rapid succession (e.g. Tallal and Stark, 1981), it might be hypothesised that such clusters are more difficult for them to discriminate than single consonants.

Word-initial changes are generally most easily perceived by language-normal populations (Bruce, 1964) and would be expected to provide, therefore, a relatively strong test of perceptual confusion. Two conditions of cluster-discrimination were provided, one of omission of the second consonant of the cluster in "different" pairs (e.g. "say"- "stay" /sei/-/stei/), the other of the "substitution" of the second consonant by another (e.g. "snow"-"slow" /snou/-/slou/). These stimulus conditions were presented separately, and designed to discover whether SRD children find, on "different" trials, a contrast between a single consonant and a 2-consonant cluster easier to perceive than one between two such clusters. A second
issue is whether they find both conditions of consonant cluster contrast more difficult to discriminate than contrasts between single inter-vocalic consonants, as determined by mean error rates. Consonant-cluster word-initial segments are defined here as "complex" because they involve two adjacent, and different, consonants, provide a concatenation of acoustic-phonetic cues of varying duration and spectral content within a narrow time frame, and might include subtle coarticulation effects between the first and second consonants.

b). Test description.

The source for these real-word minimal-pairs was again the Alpha (7) list, and only monosyllables were chosen. In the "substitution" condition, words containing clusters were chosen on the basis that all clusters began with the fricative /s/ in absolute initial position. A contrast was made by substituting, appropriately, only the second consonant of a given word to generate another word which was otherwise identical phonemically (for example, "start" - "smart" /stɑːt/-/sma:t/). In order to complete two of the eight minimal-pairs in this condition, two words not occurring in this list were used, namely "snack" and "scar" to pair with "smack" and "star" respectively. The youngest (RA control) children were asked simple definition-questions to prompt the use of these words. In each case it was clear that both items were present in their individual spoken-vocabularies.

In the "omission" condition, for "different" pairs, one word contained an initial two-consonant cluster (onset) whilst for the other word the second clustered-consonant was omitted (e.g. "pay"-"play", /peɪ/-/pleɪ/). The remaining portions of all items were phonemically identical.

An estimate was made of the relative frequency of occurrence of particular two-consonant clusters in the Alpha (7) listings, and the most frequent combinations found were used in the pairings under the above two conditions. The eight minimal-pairs chosen for each condition are as follows:-
CLUSTER SUBSTITUTION

"skip" - "slip" /skip/-/slip/
"star" - "scar" /sta/-/ska/
"smack" - "snack" /smæk/-/snæk/
"spill" - "still" /spil/-/stil/
"snow" - "slow" /snow/-/slou/
"spot" - "slot" /spat/-/slot/
"stick" - "sick" /stik/-/slik/
"start" - "smart" /stat/-/smat/

CLUSTER OMISSION

"pay" - "play" /pei/-/plei/
"fog" - "frog" /fog/-/frog/
"sell" - "spell" /sel/-/spel/
"tin" - "twin" /tin/-/twin/
"say" - "stay" /sei/-/stei/
"seat" - "sweet" /sit/-/swit/
"dive" - "drive" /davr/-/drearv/
"bow" - "blow" /bou/-/blou/

3.6.6. Natural minimal-pairs.

a). Rationale.

The minimal-pairs pilot test used naturally produced real-words and contrasted single phonemes in word-initial position. In the main phase, the same phoneme contrasts were used in different vocalic contexts, to explore whether SRD-children are more vulnerable than control subjects to changes in that context in making discrimination judgements. They were referred to as “natural” minimal pairs simply to distinguish them from the other word-based but fixed context discrimination tests. Changes in the identity of the following vowel can affect the position, extent and direction of F2 and F3 transitions cueing place-of-articulation in stops. They can also affect the extent of the F1 transition, which is associated with voicing (Borden, Harris and Raphael, 1994; Clark and Yallop, 1990; Denes and Pinson, 1993; Fourcin, 1978; Mann and Repp, 1980 and Nittrouer and Studdert-Kennedy, 1987). If these acoustic changes have particular perceptual significance for SRD listeners, one would expect to be able to demonstrate that a given phoneme contrast will be better discriminated by them when followed by some vowels than by others. There may also be an effect of vowel context for control children, in which case the main questions are whether such an effect is
stronger for SRD listeners than for controls, and whether a particular sub-set of stimulus-pairs are involved across listener-groups.

b). Test description.

The same design was employed for a different set of monosyllabic words, contained within the Alpha (7) list. The use of this list constrained the number of such changes in context for these contrasts, and the number of alternative contexts per contrast was not always equal. For instance, /n/ and /m/ pairings were followed by /e/, /eɪ/ or /æ/, whilst /f/ and /v/ pairings were followed by /æ/ or /aɪ/.

The presence, here, of some minimal-pairs which were also present in other sets of test materials should be explained. The Alpha list (vocabulary) control made it possible to present only a small number of new real-word minimal-pairs. For the same reason, it was not possible to explore the effect of the presence of different vowel environments on the discrimination of particular minimal-pairs with consonant clusters in initial position. Therefore, three of the word-pairs used in the cluster (substitution) test were included as an opportunity to examine the error-rates for the same three listener-groups following a change of speaker. They were "smack" - "snack", "spill" - "still" and "skip" - "slip". Two new cluster-bearing pairs ("grass"-"glass" and "clown"-"crown") were added to determine whether other instances of discrimination difficulty for the SRD children could be shown concerning the /r/-/l/ substitution. The list of pairs, with their broad phonemic transcriptions and indication of the features in which they vary (P = place-of-articulation, M = manner-of-articulation, V = voicing) was as follows:

<table>
<thead>
<tr>
<th>Pair</th>
<th>Transcription</th>
<th>Place-of-articulation</th>
<th>Manner-of-articulation</th>
<th>Voicing</th>
</tr>
</thead>
<tbody>
<tr>
<td>net-met</td>
<td>/net/-/met/</td>
<td>(P)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nail-mail</td>
<td>/neɪl/-/meɪl/</td>
<td>(P)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nan-man</td>
<td>/næn/-/mæn/</td>
<td>(P)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>date-gate</td>
<td>/deɪt/-/geɪt/</td>
<td>(P)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>clown-crown</td>
<td>/klaʊn/-/kraʊn/</td>
<td>(P)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>smack-snack</td>
<td>/smæk/-/snæk/</td>
<td>(P)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>spill-still</td>
<td>/spɪl/-/stɪl/</td>
<td>(P)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>buy-pie</td>
<td>/bai/-/paɪ/</td>
<td>(V)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.6.7. Speech-pattern identification tests.

a). Rationale.

Identification tasks evaluate a different level of processing to discrimination tasks as they test a listener’s ability to categorise sounds into phonemic categories. Speech pattern audiometry (SPA) tests, using high-quality synthesised stimuli in which acoustic cues can be manipulated individually, provide some information about a listener’s identification ability, and about the relative perceptual importance given to different acoustic cues to a contrast (Hazan, Wilson, Howells, Miller, Abberton and Fourcin, 1995). Such tests have been successfully used in the perceptual evaluation of deaf children (e.g. Hazan, Fourcin and Abberton, 1991) and dyslexic adults (Masterson et al., 1995).

Each test is based on a single minimal pair (e.g. “date-gate”) which assesses the perception of a specific phonemic contrast (e.g. initial stop place contrast). The acoustic cues marking the contrast are interpolated in controlled steps of equal size to create a 6-item stimulus continuum, which are presented individually to the listener in random order for labelling. Different test conditions were presented in which either a combination of acoustic cues to the contrast (“combined-cue condition”), or individual cues (“single-cue conditions”) were varied. A comparison of performance on these different tests can give an indication of the perceptual weighting given to each cue. Here, investigations focused on the use of cues to an initial stop place contrast (as in DATE-GATE) and a fricative voicing contrast (as in SUE-ZOO) as these have been shown to be problematic for some children with reading difficulties (Mody, Studdert-Kennedy and Brady, 1997). It has been shown that whilst, normatively, a range of durations of fricative noise,
independent of the spectral properties of that noise, are characteristic of different fricative consonants. Minimum-necessary noise durations also vary with changes in fricative identities (Jongman, 1989). Differences in friction duration will be used in the reduced-cues version of the above fricative continuum.

b). Test description.

Copy-synthesised (six-step) continua in the following "combined" and "reduced-cues" versions:

(1) "date"-"gate" test (/d/-/g/ stop place contrast)
   a). Combined-cue condition: cued by changes in burst frequency and F2 transition;
   b). Burst-alone condition: cued by changes in burst-frequency;
   c). Transition-alone condition: cued by changes in F2 transition.

In the 'combined-cue' condition, the cues that were varied were the spectral characteristics of the initial burst transient and the F2/F3 transitions into the following vowel. The F2 onset frequency varied between 1800 Hz in /d/ and 2522 Hz in /g/. F3 onset frequency varied between 2910 Hz in /d/ and 2925 Hz in /g/. The burst transient was synthesised using the parallel configuration of the synthesiser and differed in the frequency and amplitude of two poles. The main change was in the frequency of F5 which varied between 5950 Hz in /d/ and 3700 Hz in /g/ with a concomitant reduction in amplitude. In the 'Burst-cue' condition, F2 onset frequency was fixed at 2060 Hz and F3 frequency at 2916 Hz and the burst varied as above. In the 'Transition-cue' condition, the burst was fixed using intermediate values of frequency and amplitude and the F2/F3 transitions varied as in the 'Combined-cue' test.

(2) "Sue"-"zoo" test (/s/-/z/ fricative voicing contrast)
   a). Combined-cue condition: cued by changes in friction duration and
intensity of the voice bar;

b). Friction alone condition: cued by changes in friction duration.

Fricatives are typically acquired late in normal development and are characterised by bands of friction situated in the mid- to high-frequency range. The fricatives /s/ has most of its friction energy between 4000 and 8000 Hz and is therefore difficult for deaf listeners to perceive on the basis of auditory cues. The voicing contrast in fricatives is marked by two main cues: (1) the duration of the friction portion which will be longer in /s/ than in /z/, and (2) the presence in /z/ and absence in /s/ of a ‘voice bar’. That is to say, low-frequency voicing energy which is present during the friction (mixed voiced/voiceless excitation). In these stimuli the friction portion varied in duration from 210 ms in the /s/ endpoint to 110 ms in the /z/ endpoint, and there was no voicing excitation in the /s/ endpoint and this increased gradually to reach the same amplitude as the friction excitation in the /z/ endpoint.


a). Rationale.

A brief (40-item) nonword repetition test was included for two reasons. Firstly, to attempt to replicate the findings of Gathercole, Willis, Baddeley and Emslie (1994), using the modified “CNRep” (children's nonword repetition) test as listed. Their main findings were: (1) that dyslexic children have greater problems with repetition-accuracy as non-word items increase in length, and (2) that there are close developmental links between these repetition scores and the vocabulary, reading and comprehension skills of normal beginning readers. The monosyllabic nonword-repetition test in the pilot phase of this work had revealed errors from the SRD-group at a similar level to the younger (RA) controls, suggesting limited phonological awareness in the experimental children. Gathercole et al. had removed monosyllabic items from the CNRep test because they proved "less reliable" than the other stimuli for SRD-subjects. By this they meant that they had low test-retest reliability, were less highly correlated with total test scores than the
multi-syllable stimuli, and gave an unexpectedly low level of performance (see Gathercole, Willis, Emslie and Baddeley, 1991).

Secondly, there was an interest in whether SRD-children, showing a pattern of single-word reading errors held to relate to "developmental phonological dyslexia", might make more errors in nonword repetition than do children whose reading pattern corresponds to "developmental morphemic (surface) dyslexia." A trend in this direction might be expected if the marked sound-spelling correspondence difficulties of phonological dyslexics for nonwords affect pronunciation strategies for novel phonological items. Alternatively, to discover whether nonword repetition accuracy is reduced in SRD children with speech-perceptual problems irrespective of their patterns of reading-error.

b). Test description.

This test required the children to repeat a list of nonwords played from audiotape. The 2 to 5-syllable nonwords used were taken from those used by Gathercole and Baddeley (1989). Monosyllabic nonwords were not used since Gathercole et al. (1994) had reported that their repetition scores were less reliable than for the other stimuli. Forty nonwords were included and each item was presented once only. One of the nonwords ("confrantually" /kɔnfræntˈʃɔli/) listed by Gathercole et al. (1994) as being 5 syllables in length was re-classified here as of four syllables. The test thus comprised ten items containing 2 syllables, ten containing 3 syllables, 11 containing 4-syllables, and nine containing 5 syllables. The full list of stimulus items now follows:

- **barrazon** /bærazən/  
- **skiticult** /skitikɔlɪt/  
- **confrantually** /kɔnfræntˈʃɔli/  
- **glistow** /ɡlistɔʊ/  
- **glistering** /ɡlistərɪŋ/  
- **versatrationist** /vɜrsətretʃərənɪst/  
- **empliforvent** /ɪmplɪfɔrˈvɛnt/  
- **bannifer** /bænɪfa/  
- **blonterstaping** /blɒntəstæpɪŋ/  
- **brasterer** /bræstərə/
3.6.9. Psychoacoustic tests.

a). Rationale.

As was stated in the introductory chapter, Farmer and Klein (1995), in their review of the case for a temporal-processing deficit linked to "dyslexia", noted that many researchers regarded dyslexia as fundamentally a linguistic problem. All aspects of their auditory perceptual difficulties should therefore be related to speech-based stimuli. The question of whether SRD children (as a language-impaired group) have a perceptual deficit centred either on speech alone or on speech and non-speech was taken forward by Tallal's suggestion that a construct common to both would be a "temporal" deficit (e.g. Tallal, 1984). In this sense, it is a "general temporal deficit", relying heavily on evidence of more-frequent confusions of temporal-order judgement and stop-discrimination by dyslexic subjects. The study made of this evidence in the introductory chapter noted that, where it related
specifically to dyslexic subjects, it was confounded with issues of stimulus identification-time or "codeability". Therefore, there could be no clear attribution of such errors to "temporal processing" difficulties.

The presentation of general tests of auditory acuity is therefore required to discover whether SRD-children's confusion for speech discrimination and identification tasks can also be related to difficulties with processing the acoustic properties of simpler, non-speech, stimuli. If they made fewer errors with the discrimination of non-speech stimuli marked by certain temporal or spectral cues (such as gap detection and pitch discrimination) than with speech discrimination, the proposal that reading-disabled children have a general auditory (temporal) problem would be challenged. The four psychoacoustic tests described below were included specifically to enable such a demonstration.

b). Test description.

The "Early Auditory" test battery developed by Bailey is designed to be brief and easy to administer, and consists of four tests which investigate temporal and spectral processing (for a further description see Morris, Franklin, Ellis, Turner and Bailey, 1996). Each trial consisted of a pair of sounds, separated by a 500 ms silent interval; the inter-trial interval was 4 seconds. "Same" trials paired a reference stimulus with itself, whilst "different" trials paired the reference stimulus with one of a range of stimuli differing in various amounts of the parameter under investigation. The gap detection, formant frequency discrimination and pitch discrimination tests each comprised 5 blocks of twelve trials per block. In total, listeners heard 10 exemplars of each of the six stimulus-pairings. For the formant-frequency modulation test, 3 blocks of 24 trials per block were presented, with listeners hearing 12 exemplars of each of the six stimulus-pairings (modulation magnitudes).
Gap detection.

Stimuli consisted of a set of low-pass filtered noise bursts containing silent intervals. Each noise burst had a total duration of 400 ms, with an upper-frequency cut-off at 3.5 kHz. Gaps were temporally centred in the bursts. "Different" trials involved pairing the reference stimulus (no gap) with stimuli which had gaps in the noise of 4, 8, 12, 16 or 20 ms duration. There were two identical repetitions of each "same" pair, and two versions of each "different" pair (gap/no gap and no gap/gap).

Formant frequency discrimination.

This test was based on a periodic stimulus of 400 ms duration with a single steady-state formant-like peak in its spectrum envelope and a fundamental frequency of 125 Hz. The reference stimulus had a formant frequency of 1000 Hz; this stimulus was paired in the "different" trials with stimuli with formant centre-frequencies of 1040, 1080, 1120, 1160 or 1200 Hz.

Formant frequency modulation detection.

The stimulus developed for the formant frequency discrimination test used was a carrier for formant frequency modulation. The signal consisted of one cycle of a single frequency of 400 ms duration, modulated about the 1000 Hz central value. Half of the modulation trials, randomly assigned, started at the zero crossing point (positive going) and half from a point in the cycle pi-radians from the origin. "Same" trials in this test also used a 1000 Hz reference stimulus, pairing this on "different" trials with peak-to-peak formant frequency modulations of 60, 120, 180, 240 or 300 Hz.

Fundamental frequency (pitch) discrimination.

The stimulus with formant frequency set to 1 kHz described above was synthesised with the fundamental frequency set at 125 Hz in the reference stimulus, this being
paired, on "different" trials, with stimuli having fundamental frequency values of 129, 133, 137, 141 or 145 Hz.

3.7. Test Preparation.

3.7.1. Regular, irregular and nonword reading lists.

All lists were typed, double-spaced, in black ink, onto a single sheet of plain white A4 paper, giving a uniformly high-contrast finish. The items in each list were numbered. The regular- and irregular-word lists were typed in parallel columns onto the same side of the sheet, whilst the non-word list was typed onto the reverse side. The regular, irregular and non-word lists are reproduced in full, together with those pronunciations which were considered acceptable, in Appendix C.

3.7.2. Speech discrimination tests.

For all tests, recordings of the utterances were made in an anechoic chamber and stored onto separate DAT tapes. The stimuli were acquired on a “Sun Sparc” station at a sampling rate of 44.1 kHz, segmented (ensuring that extraneous noise was edited out), equalised for signal-intensity, and then stored into individual speech files. The signal intensities were equalised by calculating and adjusting the corresponding root mean square (RMS) values of the amplitude of the frequency envelope. All stimuli were re-sampled at a sampling rate of 20 kHz or above, except the “cluster substitution” stimuli which were re-sampled at 10 kHz. The rationale for this is as follows. A sampling standard of 44.1 kHz applies to audio CD production. This re-sampling halved the storage requirements and vastly reduced the processing time whilst not affecting the speech quality. The various speech discrimination tests were recorded onto separate audio-cassette tapes with an inter-stimulus interval (ISI) of about 1 second and an inter-trial interval (ITI) of about 5 seconds. The ITI value arose out of a consideration of the likely maximum period a child would need to select and output their response, and of one typically employed in psychophysical experiments.
i). Intervocalic (VCV) consonant discrimination.

Existing recordings of the RP voice of a phonetically trained adult female (GW) were selected. In these VCV recordings, stress had consistently been placed on the second syllable. Four repetitions of each of these 15 minimal-pairs were counterbalanced and presented with an equal number of catch ("same") trials. A total of 240 trials were thus derived, divided into 4 blocks of 60 trials each. The content of each of the blocks was fully randomised. The intended stimulus-pairs were created on the computer by combining, appropriately, the individual word-files into new pairs-files.


The test materials were recorded by a phonetically-trained adult male speaker with received pronunciation (JM). The order of presentation of items within each of the eight "different" pairs was counterbalanced (e.g. "spill"-"still" with "still"-"spill", and "frog"-"fog" with "fog"-"frog"), and each such pairing repeated 5 times (total of 80 trials). Each of the sixteen derivative "same" pairs were constructed by pairing an word with a physically-identical copy of itself (e.g. "spill"-"spill" and "frog"-"frog") and each pairing was repeated 5 times (total of 80 trials). Therefore, experimental and "catch" trials occurred with equal overall frequency, each test-condition consisting of a total of 160 trials. The order of all constituent pairings was fully randomised. Four blocks, each of 40 trials, were constructed.

iii). Natural minimal-pair discrimination.

The test materials were recorded by a phonetically trained female adult speaker with received pronunciation (EA). The order of tokens within each of the sixteen "different" pairings was counterbalanced (e.g. "fine"-"vine" and "vine"-"fine") and each such order presented twice for each pairing (16 pairs x 2 order x 2 presentation = 64 trials). "Same" pairs were constructed by pairing each of the 32
words forming the sixteen minimal-pairs with a physically-identical copy of itself, and each of these was presented twice (32 pairs x 2 presentation = 64 trials). Experimental and "catch" trials therefore occurred with equal frequency, with the test consisting of a total of 128 trials. The order of all constituent pairings was fully randomised.

3.7.3. Identification tests.

The combined-cues and reduced-cues versions of the "date"-"gate" (/deɪt/-/get/) and "Sue"-"zoo" (/su/-/zu/) continua had been prepared in the laboratory, using the copy-synthesis method, for other research purposes. The stimuli were incorporated into a software package for use with a DELL "laptop" computer. The software was developed internally (see Hazan et al, 1991), and known as the "Speech Pattern Audiometry" (or SPA) procedure. For this computer, stimuli were output with the use of a 16 bit “Soundblaster”-compatible sound card. The system specified an adaptive procedure and allowed storage of individual data sets in separate files for each test condition, but with the files linked automatically by a subject-identifier. From these, results in both graph and tabulated form were constructed on-screen.

3.7.4. Nonword repetition.

These test items were recorded by a phonetically-trained RP female speaker (EA).

3.7.5. Psychoacoustic tests.

A single audio tape containing all four of the non-speech tests described above was made available by the test developers (see Morris et al., 1996).
3.8. Test Procedure.

3.8.1. Organisation of test sessions.

The standardised test of reading (Neale Analysis) was presented first because of the need to estimate a child's reading age for participation in the main test battery. In the following session the RPM test of non-verbal intelligence was carried out. The amount of time taken by individual children to complete each of them varied between about 15 and 35 minutes.

The speech discrimination tests (VCV, cluster substitution, cluster omission and natural minimal pairs) were each presented on different audio-tapes, as were the psychoacoustic and nonword repetition test stimuli. In order to minimise possible effects of presentation order, these tests were presented to different children in different orders, using a batch structure and a staggered program. The batch structure (where a given child is presented with a long experiment divided into portions) enabled the ready "mixing" of different tasks within a given test session, and with ensuring that no session significantly overran the recommended time-allocation. Full counter-balancing of the order of presentation of the blocks was impractical using a pre-recorded audiotape, so any possible learning effect was minimised by presenting the blocks over the course of several (non-consecutive) days.

The identification tests, involving a total of five different continua, were also distributed within each of two of the later sessions, but with the order of their presentation within sessions varied for each child. These measures ensured a maximum of variety within each test session, an important factor given the need to retain a child's attention throughout.

The time-constraints enforced by the content and structure of any given school day meant that the optimal test-session duration, agreed with class teachers, was 30
minutes. In practice, this limit was almost invariably adhered to. On a limited number of occasions when other circumstances permitted, with the child's cooperation, it was seen to be convenient to finish a particular quota of batches over a 35-45 minute session. Brief rest periods were taken between tasks, and between batches of trials on the same task. Some tests, such as those of nonword repetition and natural minimal-pair discrimination, were shorter than those involving VCV or consonant-cluster discrimination. It was often possible to complete these within one session.

The number of sessions required for the completion of the test battery by an individual child varied between 8 and 10. It was also convenient on some occasions for a child to be tested over two sessions in the same day, separated by at least two hours, but one session on any one day was the norm. The need to test children at different schools on different days meant that the required number of sessions could not be completed within a set period, but over widely-varying time-spans. It was not uncommon for two consecutive test sessions with any one of the thirty-seven children involved to have been separated by about two weeks, so that his/her entire test period might span several months.

3.8.2. Standardised tests of reading and non-verbal intelligence.

To estimate reading delay, the Neale Analysis was presented to each subject in the recommended way. One of the two series of prose passages (Series 1) was selected. It was presented without including a formal measure of "rate" of reading. Children were tested individually. The Raven's Progressive Matrices test was presented to individual children in the standard way.

3.8.3. Reading tests using regular, irregular and nonword lists.

The three lists of items were presented first to each child in the following order: regular word, irregular word, nonword list, with the instruction that each word
should be read aloud in the order provided. The children could self-correct and their responses were tape-recorded. A refused attempt to pronounce an item was counted as an error and the correct pronunciation provided by the experimenter, after a suitable interval. Each child's reading aloud of each of the item-lists was timed. The reading rates for item-lists were obtained by timing the overall reading period and then calculating from this the mean number of seconds for a child to read each word. These measurements were reliable because timing was co-ordinated with a signal for a child to begin reading and with his/her final-item response. The purpose of this was to determine whether the SRD-group were slower as a whole than the younger (RA) controls who were matched with them in reading accuracy, using the criterion of at least 1 standard deviation above (slower than) the RA group mean rate. Throughout, general encouragement but not systematic feedback was given. Children were instructed that these were "nonsense words", so that they should not refer to the pronunciation of real words that some items might resemble (assuming adequate lexical knowledge). Nonword pronunciations were considered acceptable if regular letter-sound correspondences for consonants and single vowels and a monosyllabic structure were evident. Responses which were phonetically analogous to real words were also accepted, e.g. “toud” /taud/ by analogy with “loud” /laud/. Accepted pronunciations are transcribed alongside each list-item in Appendix C.

3.8.4. Speech-discrimination tests.

A fixed (and marked) volume-control setting, representing a comfortable listening level, was used for all audio-taped tests for each child, and using the same tape-recorder throughout. The presentation-levels for the various tests which corresponded to this setting was later measured in the laboratory using a Brueel and Kjaer Type 2231 hand-held sound level meter. Mean readings for samples of stimuli were found to vary little from 60 dB SPL. The same volume setting was also used throughout the running of the group of psychoacoustic tests.
Audiotape recordings were played via Sennheiser 414 headphones presented to the right ear only. The right ear was used because there is some evidence of a right-ear advantage for CV-syllables (e.g., Darwin, 1971). It was thought that monaural presentation would help to maintain the auditory attention of children throughout the listening period. A small set of simple practice trials was presented before testing in order to ensure that each task was understood. Listeners heard a pair of stimuli and gave an oral response of “same” or “different” after each trial. They were allowed to self-correct, the last attempt taken as their response. General encouragement was given but not systematic feedback. The same format was used for the natural minimal-pairs discrimination test. Since the running time was about 12 minutes, it could be completed within a single session.

3.8.5. Synthetic speech-pattern identification tests.

Children were tested using a computer-based test procedure. The child was seated in front of the portable PC, with pictures representing the two words placed on either side of the response pad. The child responded by pressing the left or right hand pad after each trial; this triggered the next trial within about 2 s of the previous response. Since an adaptive procedure was used (Hazan et al., 1991), test duration varied but each was no longer than about 4 minutes. Tests were presented in a pseudo-random order ensuring that no two conditions for the same minimal-pair occurred consecutively. Test administration was completed over at least two sessions usually separated by an interval of several days.


The items, of varying syllabic length, were presented once only in random order. Each child heard the items in the same order. Children were allowed to self-correct. Recordings were made of their productions for later analysis. All of an individual’s errors were noted on the original answer-sheets, using broad phonemic transcriptions.
3.8.7. Psychoacoustic tests.

Administration of each test was preceded by a familiarisation procedure in which identical stimulus-pairs and pairs with the largest difference on the relevant stimulus dimension were presented alternately. The test began when the experimenter was satisfied that a child understood the particular task. The experimenter noted a child's response to each trial by inserting either "S" for "same" or "D" for "different" decisions into prepared response sheets.

3.9. Results.

There were 13 subjects in the SRD-group but only 12 subjects in both the same-age and reading-age control groups. Therefore a one-way or two-way analysis-of-variance for "unbalanced" groups (General Linear Models procedure) was used to test, as appropriate, for simple main effects (such as those of subject-group, minimal-pair or consonant-category) for each of the tests described above for the main experimental battery.

3.9.1. Standardised tests.

In the event of the highest Neale-(R) Accuracy or Comprehension score of "13+" being achieved, this was recorded as 13:0 years for numerical accuracy. The scores obtained for the Neale Analysis and Raven's Progressive Matrices were analysed for a simple main effect of reading-group. The analysis of the Neale test was based on actual individual scores, but expressed, for comparative purposes, as age-equivalent values in the tables. The chronological age of the children is included for ease of interpretation. Since analysis was frequently required of proportionate data, the error rates found were converted where appropriate using an arc-sine transform expression. This allows scores near the extremes of a binary distribution to be expressed in radians and permits some orderly separation of clustered values.
Instances of zero proportions (no errors) were modified as recommended by Snedecor and Cochran (1978) before transforming to angles.

The difference in scores between groups for Raven’s test of non-verbal intelligence was not significant. A one-way ANOVA revealed that the subject groups did not differ in their performance on the non-verbal IQ test (Raven’s Progressive Matrices) \( F(2,34) = 2.018, p = 0.149 \). Tukey’s HSD post-hoc comparisons with control groups showed: SRD: CA \( p = 0.573 \), SRD: RA \( p = 0.561 \) and CA: RA \( p = 0.125 \).

TABLE 11. Summary data calculated for standardised tests for SRD listeners (n = 13) being the Neale (Revised) Accuracy and Comprehension tests with both scores expressed as an equivalent reading age, and Ravens’ Progressive Matrices (RPM) with the score expressed as a percentile. C.A. = chronological age. Delays refer to reading accuracy and are given in “years; months” format.

<table>
<thead>
<tr>
<th></th>
<th>CA</th>
<th>Accuracy</th>
<th>Comp.</th>
<th>RPM</th>
<th>Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>10;4</td>
<td>8;1</td>
<td>10;6</td>
<td>81</td>
<td>2;3</td>
</tr>
<tr>
<td>S.D.</td>
<td>0;8</td>
<td>0;11</td>
<td>1;6</td>
<td>14</td>
<td>0;6</td>
</tr>
</tbody>
</table>

The SRD children obtained significantly lower scores than the two control groups on the Neale reading-accuracy test \( F(2,34) = 35.374, p < 0.001 \), and on the Neale reading comprehension test \( F(2,34) = 10.835, p < 0.001 \). The lower percentile scores on the Neale reading-comprehension test for the reading-impaired group compared to those of same-age controls is in keeping with their lower accuracy scores. In fact, the EXP group mean comprehension score, expressed as standardised age-equivalents, is entirely appropriate to their mean chronological age. The high Neale comprehension scores, relative to their chronological age, of eight of the CA control group was the major source of difference between group-means. Individual details are given in correspondingly numbered Tables in Appendix A.
### TABLE 12. Summary data calculated for standardised tests for the chronological age (CA) control group (n=12), being Neale-(R) Accuracy and Comprehension, (scores expressed as an equivalent reading-age), and Raven’s Progressive Matrices, (scores given as a percentile).

<table>
<thead>
<tr>
<th>CA</th>
<th>Accuracy</th>
<th>Comp.</th>
<th>RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>10:1</td>
<td>11:9</td>
<td>12:7</td>
</tr>
<tr>
<td>S.D.</td>
<td>0:8</td>
<td>1:7</td>
<td>1:5</td>
</tr>
</tbody>
</table>

### TABLE 13. Summary data calculated for standardised tests for the Reading-Age (RA) matched control group (n=12), being Neale-(R) Accuracy and Comprehension (scores expressed as an equivalent reading-age), and Raven’s Progressive Matrices (scores given as a percentile).

<table>
<thead>
<tr>
<th>CA</th>
<th>Accuracy</th>
<th>Comp.</th>
<th>RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>8:2</td>
<td>8:1</td>
<td>9:5</td>
</tr>
<tr>
<td>S.D.</td>
<td>0:4</td>
<td>0:11</td>
<td>1:2</td>
</tr>
</tbody>
</table>

### 3.9.2. Reading list performance.

Individual error-rates were calculated by totalling the number, and converting to a percentage, of final attempts to decode items which did not correspond to an accurate pronunciation. Mean error-scores (%) for each of the lists are included in summary form in Tables 14, 15 and 16. Individual details are given in correspondingly numbered tables in Appendix A.

A two-way analysis of variance for unbalanced groups (General Linear Models procedure) was used to test the main effects of subject-group and list-type. The main effect of subject-group was significant \[F(2,34) = 20.42, p = 0.0001\]. Duncan's Multiple Range post-hoc test showed that all groups differed significantly from each other. The effect of word-list type according to a two-way ANOVA was also significant \[F(2,34) = 68.882, p < 0.001\], as was the group x word-list interaction \[F(2,34) = 3.943, p = 0.006\]. This indicated that both SRD children and RA controls made more errors on both irregular word and nonword lists than they...
did on regular words, whilst CA controls were relatively accurate at reading each type of item-list.

TABLE 14. Summary error scores (percent) for the SRD-children on the Regular (REG), Irregular (IRR) and Nonword (NW) reading list tests, the intervocalic (VCV) discrimination test, the consonant cluster "Substitution" (CC(S)) and "Omission" (CC(O)) discrimination tests. The estimated mean reading rate for each reading test (seconds per item) is given.

<table>
<thead>
<tr>
<th></th>
<th>REG rate</th>
<th>IRR rate</th>
<th>NW rate</th>
<th>VCV</th>
<th>CC(S)</th>
<th>CC(O)</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>18</td>
<td>41</td>
<td>58</td>
<td>6.2</td>
<td>6.4</td>
<td>5.6</td>
<td>10.4</td>
</tr>
<tr>
<td>S.D.</td>
<td>14</td>
<td>21</td>
<td>20</td>
<td>9.1</td>
<td>8.3</td>
<td>10.1</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Statistics were then run on the data obtained for each item list to examine further the difference across groups. The main effect of subject group for regular word reading was significant according to a one-way ANOVA [F(2,34) = 8.230, p = 0.001]. Tukey's HSD post-hoc test indicated that this was due only to the difference between the SRD and the CA group scores, since that between the SRD and RA groups just failed to reach significance (p = 0.056). However, Duncan's post hoc result did not agree with this, indicating that the SRD performance was reliably weaker than that of either control group.

The effect of subject group for irregular word reading was highly significant [F(2,34) = 12.704, p < 0.001], and here Tukey's HSD showed significantly weaker performance for the SRD group than for either group of controls. The RA controls also performed reliably less accurately than CA controls.

The effect of subject group for nonword reading was also highly significant [F(2,34) = 20.120, p < 0.001]. Tukey's HSD revealed significantly weaker SRD performance than CA controls (p < 0.001), and also weaker than for RA controls (p = 0.003). The control groups' performances also differed reliably from one another.
TABLE 15. Summary error scores (%) for the chronological-age control (CA) group for the Regular, Irregular and Nonword reading list tests and the consonant-cluster and VCV speech discrimination tests.

<table>
<thead>
<tr>
<th></th>
<th>REG rate</th>
<th>IRR rate</th>
<th>NW rate</th>
<th>VCV</th>
<th>CC(S)</th>
<th>CC(O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1 1.06</td>
<td>8 1.26</td>
<td>11 1.70</td>
<td>1.9</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>S.D.</td>
<td>2 0.36</td>
<td>5 0.23</td>
<td>13 0.92</td>
<td>1.6</td>
<td>1</td>
<td>0.6</td>
</tr>
</tbody>
</table>

The mean reading rates across subject-groups for each of the three item lists were compared. The main point was that SRD children read each of these item lists more slowly and less accurately than did same-age (CA) controls but at a similar rate to the reading-age matched (RA) controls. There was evidence that the younger controls read each list more accurately, however.

Table 16. Summary error scores (%) for the reading-age (RA) control group for the Regular, Irregular and Nonword reading list tests and the consonant cluster and VCV speech discrimination tests.

<table>
<thead>
<tr>
<th></th>
<th>REG rate</th>
<th>IRR rate</th>
<th>NW rate</th>
<th>VCV</th>
<th>CC(S)</th>
<th>CC(O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>8 1.85</td>
<td>25 2.47</td>
<td>33 3.33</td>
<td>1.8</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>S.D.</td>
<td>11 1.06</td>
<td>17 1.78</td>
<td>21 1.93</td>
<td>1.5</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

3.9.3. Speech discrimination tests.

The individual error-rates for the three subject-groups are given below in summary form for particular discrimination tests in Tables 17, 18 and 19.

i). Intervocalic consonant (VCV) discrimination.

The data was analysed in terms of the overall percentage of errors, and also to examine the number of errors within each consonant category (stops, fricatives, nasals and approximants). The errors could be in the perception of either the voicing or place-of-articulation feature. The main effect of subject group in a two-way ANOVA was not significant (p = 0.092), nor was the group by pair interaction (p =
0.490), but the effect of consonant pair was significant [F(14,476) = 6.189, p < 0.001]. Here, Tukey's HSD indicated that the contrasts /b/-/d/ and /d/-/g/ were reliably less accurately discriminated by the experimental group than by either control group, whose performance did not differ significantly from each other on any pairing. For each category, the experimental group made more discrimination errors than either control group, most notably in the case of stops. Post-hoc analyses carried out on the data for individual consonant categories (summarised in Table 17) revealed a rather complex situation. The mean error-rate for nasals was greater than that for either approximants or stops. The mean error-rate for stops, though lower, did not differ from that for fricatives or approximants.

TABLE 17. Mean error-rates (%) for the discrimination of intervocalic (VCV) consonant contrasts classified in terms of consonant categories. Standard deviations are given in parentheses.

<table>
<thead>
<tr>
<th>Group</th>
<th>STOPS</th>
<th>FRICATIVES</th>
<th>NASALS</th>
<th>APPROX</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXP</td>
<td>5.77 (9.4)</td>
<td>6.25 (8.1)</td>
<td>8.65 (15.2)</td>
<td>5.77 (8.8)</td>
</tr>
<tr>
<td>RA</td>
<td>0.43 (0.5)</td>
<td>2.39 (2.3)</td>
<td>4.17 (9.4)</td>
<td>2.78 (4.3)</td>
</tr>
<tr>
<td>CA</td>
<td>0.43 (0.7)</td>
<td>3.12 (2.8)</td>
<td>4.17 (6.7)</td>
<td>2.08 (2.9)</td>
</tr>
</tbody>
</table>

ii). Consonant cluster discrimination test (substitution condition).

Each of these Tables is in detailed form in Appendix A. The effect of listener group was significant in a two-way ANOVA [F(2,34) = 4.933, p = 0.013]. The effect of minimal pair was also reliable [F(7,238) = 3.305, p = 0.002]. The pair x group interaction was not significant (p = 0.695). Tukey's HSD indicated here that the SRD group was weaker than either control group for "star"-"scar" discrimination, but was weaker than only the CA controls for "spill"-"still", "snow"-"slow", "star"-"scar" and "skip"- "slip". Pairs "smack-snack" and "spill-still" were
TABLE 18. The six word-pairs associated with the 3 highest and 3 lowest mean error-rates (%) for the SRD-group, and the corresponding scores for control groups, on the cluster "substitution" task. The phonemic-features (F) by which the substituted second-consonants differ are given in parentheses, for which M = manner-of-articulation, V = voicing and P = place-of-articulation.

<table>
<thead>
<tr>
<th>PAIR</th>
<th>EXP</th>
<th>CA</th>
<th>RA</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>“smack” - “snack” /smæk/-/snæk/</td>
<td>10.0</td>
<td>1.2</td>
<td>5.8</td>
<td>(P)</td>
</tr>
<tr>
<td>“spill” - “still” /spil/-/stil/</td>
<td>7.7</td>
<td>1.2</td>
<td>3.8</td>
<td>(P)</td>
</tr>
<tr>
<td>“skip” - “slip” /skɪp/-/slɪp/</td>
<td>6.9</td>
<td>0.0</td>
<td>0.4</td>
<td>(P)</td>
</tr>
<tr>
<td>“stick” - “slick” /stɪk/-/slɪk/</td>
<td>5.8</td>
<td>0.8</td>
<td>2.0</td>
<td>(MV)</td>
</tr>
<tr>
<td>“start” - “smart” /stɑt/-/smɑt/</td>
<td>5.8</td>
<td>0.0</td>
<td>0.8</td>
<td>(MVP)</td>
</tr>
<tr>
<td>“spot” - “slot” /spɒt/-/slɒt/</td>
<td>2.7</td>
<td>0.8</td>
<td>0.8</td>
<td>(MVP)</td>
</tr>
</tbody>
</table>

associated with significantly higher error rates than all other pairs (a partial illustration of the data is given in Table 18 above). An examination of the ordering of minimal pairs in terms of their error rates revealed that the substituted consonant in the two pairs with the highest error rates differed in one feature only (place of articulation). The substituted consonant in the two pairs with the lowest error rates differed in three features (manner, voicing and place-of-articulation).

**iii. Consonant cluster discrimination test (omission condition).**

A two-way ANOVA for unbalanced groups (General Linear Models procedure) was carried out to test for main effects of listener-group and stimulus-pair. The effect of listener group was significant [F(2,34) = 3.651, p = 0.037]. Post hoc tests showed that the SRD group performed less accurately than either control group, which did not differ from each other. The effect of pair was also significant [F(7,238) = 2.210, p = 0.034], with Tukey's HSD revealing that the SRD listeners made reliably more errors than the RA controls on the “pay”-“play” pairing, whilst they made more errors than the CA controls on the “bow”-“blow” pairing. The group x pair interaction was not significant (p = 0.452). Only two SRD-subjects had clear problems with this task, and many experimental subjects performed at a similar level of accuracy as the control children.
TABLE 19. The six word-pairs associated with the 3 highest and 3 lowest mean error-rates (%) for the SRD-group, and the corresponding scores for control groups, on the cluster "omission" task.

<table>
<thead>
<tr>
<th>PAIR</th>
<th>EXP</th>
<th>CA</th>
<th>RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;bow&quot; - &quot;blow&quot; /bɔu/-/blɔu/</td>
<td>8.1</td>
<td>0.8</td>
<td>2.1</td>
</tr>
<tr>
<td>&quot;fog&quot; - &quot;frog&quot; /fɔɡ/-/fɔɡ/</td>
<td>6.9</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>&quot;sell&quot; - &quot;spell&quot; /sɛl/-/spɛl/</td>
<td>6.5</td>
<td>0.0</td>
<td>1.2</td>
</tr>
<tr>
<td>&quot;say&quot; - &quot;stay&quot; /sɛi/-/stei/</td>
<td>3.8</td>
<td>0.8</td>
<td>1.2</td>
</tr>
<tr>
<td>&quot;dive&quot; - &quot;drive&quot; /daɪv/-/draɪv/</td>
<td>3.5</td>
<td>0.0</td>
<td>0.4</td>
</tr>
<tr>
<td>&quot;tin&quot; - &quot;twin&quot; /tɪn/-/tɪn/</td>
<td>2.9</td>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

*iv). Natural minimal pairs.*

TABLE 20. Individual error-rates (%) for natural minimal-pair discrimination and nonword repetition for the SRD-group, and mean error-rates and standard deviations (in parentheses) for each listener-group.

<table>
<thead>
<tr>
<th>Sub.</th>
<th>Minimal Pair</th>
<th>Nonword repetition</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>8.6</td>
<td>15.0</td>
</tr>
<tr>
<td>E2</td>
<td>7.0</td>
<td>42.5</td>
</tr>
<tr>
<td>E3</td>
<td>4.6</td>
<td>42.5</td>
</tr>
<tr>
<td>E4</td>
<td>6.2</td>
<td>7.5</td>
</tr>
<tr>
<td>E5</td>
<td>3.1</td>
<td>7.5</td>
</tr>
<tr>
<td>E6</td>
<td>3.1</td>
<td>17.5</td>
</tr>
<tr>
<td>E7</td>
<td>3.1</td>
<td>25.0</td>
</tr>
<tr>
<td>E8</td>
<td>10.2</td>
<td>17.5</td>
</tr>
<tr>
<td>E9</td>
<td>10.2</td>
<td>47.5</td>
</tr>
<tr>
<td>E10</td>
<td>4.6</td>
<td>5.0</td>
</tr>
<tr>
<td>E11</td>
<td>5.5</td>
<td>12.5</td>
</tr>
<tr>
<td>E12</td>
<td>17.2</td>
<td>32.5</td>
</tr>
<tr>
<td>E13</td>
<td>9.4</td>
<td>32.5</td>
</tr>
<tr>
<td>Mn EXP</td>
<td>7.1 (4.0)</td>
<td>23.3 (14.7)</td>
</tr>
<tr>
<td>Mn RA</td>
<td>6.1 (3.6)</td>
<td>16.6 (10.7)</td>
</tr>
<tr>
<td>Mn CA</td>
<td>4.6 (2.3)</td>
<td>9.4 (6.0)</td>
</tr>
</tbody>
</table>
Mean error rates are presented in Table 20. The main effect of listener group, according to a two-way ANOVA, was not significant \[ F(2,34) = 1.668, p = 0.204 \]. However, there was a highly significant effect of minimal pair \[ F(15,510) = 15.811, p < 0.001 \], with Tukey’s HSD revealing no reliable differences in discrimination accuracy within subjects for fifteen of the sixteen pairings. The listener group x pair interaction was therefore not significant \( p = 0.989 \).

3.9.4. Synthetic speech-pattern identification tests.

The mean identification functions obtained for the three listener groups are presented in Figures 1 and 2. A maximum likelihood estimation (MLE) procedure (Bock & Jones, 1968) was used to fit a cumulative normal function (probit analysis) to each subject's set of data per test condition. From this, a measure was obtained of the gradient of the identification function fitted to the observed data. Gradients may be used as an indication of labelling consistency, a greater negative value corresponding to a steeper identification function. These measures were then used in a one-way analysis of variance to look at the effect of subject group on function gradient.

Individual data on identification functions is summarised in Table 30 by means of counts of the number of children in each group/sub-group labelling each of the 5 continua in a “categorical”, “progressive” or “random” fashion. Such a summary makes clearer the differences in performance obtaining within a listener group/sub­group than an exhaustive listing of individual gradient values could do.

Data was examined to see whether there was any significant difference between listener groups in the gradients obtained for the combined-cue conditions of the DATE-GATE and SUE-ZOO tests. The effect of listener groups was not significant for either the combined-cue DATE-GATE test \( p > 0.05 \) or the combined-cue SUE-ZOO test \( p > 0.05 \). On average, identification functions obtained for the single-cue conditions were less steep than for the combined-cue conditions. The difference between listener-groups only reached significance for the "friction-only" condition of
the SUE-ZOO test, \( F(2,33) = 3.34, p < 0.05 \), where the mean gradient for the experimental group was shallower than that for the chronological-age controls. Graphs representing these functions for both tests in combined- and reduced-cues versions are presented in Figures 1 and 2 which follow.
Figure 1: Mean identification functions for the combined-cue and reduced-cue conditions of the DATE-GATE test.
Figure 2: Mean identification functions for the combined-cue and reduced-cue conditions of the SUE-ZOO test.
3.9.5. Nonword repetition test.

The individual error-data for the SRD-group, together with group-means and standard deviations (in parentheses) are given above in Table 20. A summary of the mean error rates by nonword-item length (syllabic) for each reading-group is given in Table 21. In scoring this test, it should be noted that the re-classification of one nonword item (i.e. "confrantually") from 5 to 4 syllables in length resulted in error-totals being made here across 11 items for "Length 4" and 9 items for "Length 5". A two-way ANOVA showed that the main effect of listener group was significant \[F(2,34) = 5.155, p = 0.011\], with Tukey's HSD post hoc test indicating that the SRD children made reliably more errors than CA controls for lengths of 3 and 4 syllables. Duncan's post hoc test indicated that SRD listener group errors were reliably greater than either control group for items 3 syllables in length. The effect of syllabic length was also found to be significant \[F(3,102) = 39.003, p < 0.001\], but the listener group x length interaction was not significant \[F(6,102) = 1.935, p = 0.082\]. The error scores for the five-syllable words were significantly higher than those of the four-syllable words, which were themselves higher than those for the two- and three-syllable words (which did not differ from each other). The subject groups did not differ in their error rates for the two-syllable words, but the experimental group made more errors when repeating nonsense words of three syllables or longer.

<table>
<thead>
<tr>
<th># SYLL.</th>
<th>TWO</th>
<th>THREE</th>
<th>FOUR</th>
<th>FIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXP group</td>
<td>4.6 (7.8)</td>
<td>16.9 (13.1)</td>
<td>33.6 (25.3)</td>
<td>38.5 (28.6)</td>
</tr>
<tr>
<td>RA group</td>
<td>3.3 (6.5)</td>
<td>3.3 (4.9)</td>
<td>11.4 (11.0)</td>
<td>26.9 (21.4)</td>
</tr>
<tr>
<td>CA group</td>
<td>3.3 (4.9)</td>
<td>3.3 (6.5)</td>
<td>9.9 (8.2)</td>
<td>22.2 (15.7)</td>
</tr>
</tbody>
</table>
3.9.6. Psychoacoustic tests.

A summary of the mean error-rates over all stimulus pairs for each component of the psychoacoustic test-battery is given in Table 22. For each test, a two-way analysis of variance was carried out on the discrimination scores obtained, including those for the "same" trials, to test for main effects of subject-group and stimulus-pair. The gap detection, formant frequency discrimination and frequency modulation discrimination tests showed non-significant effects of subject group. The effect of group for fundamental (pitch) discrimination did reach significance, but the result was difficult to interpret since the multiple comparisons table revealed that it was due only to differences in performance for "same" pairs. The calculations for between subjects (group) figures were: gap detection \(F(2,34) = 1.361, p = 0.270\); formant frequency discrimination \(F(2,34) = 2.530, p = 0.095\); frequency modulation discrimination \(F(2,34) = 0.614, p = 0.547\) and fundamental (pitch) discrimination \(F(2,34) = 3.544, p = 0.040\). Post hoc comparisons using Tukey's HSD and Duncan's tests indicated that the SRD and RA groups performed similarly to each other and less accurately than the CA group in pitch discrimination. There was therefore no evidence that, for any psychoacoustic test, SRD children performed systematically worse than either group of controls.

The effect of stimulus pair was in all cases significant and in the expected direction; pairs differing by small steps were more difficult to discriminate than other stimulus pairs. These were:- gap detection \(F(5,170) = 40.798, p < 0.001\); formant frequency \(F(5,170) = 36.363, p < 0.001\); frequency modulation \(F(5,170) = 83.230, p < 0.001\) and fundamental (pitch) discrimination \(F(5,170) = 6.809, p = 0.001\). Only the group x pair interaction for fundamental (pitch) discrimination was significant:- gap detection \(F(10,170) = 0.806, p = 0.623\); formant frequency \(F(10,170) = 1.487, p = 0.148\); frequency modulation \(F(10,170) = 1.817, p = 0.061\) and fundamental (pitch) discrimination \(F(10,170) = 2.035, p = 0.033\).
TABLE 22. Mean error-rates (%) for four psychoacoustic tests by listener-group, excluding “same” trials. Standard deviation measures are given in parentheses.

<table>
<thead>
<tr>
<th>Listener group</th>
<th>Gap detection</th>
<th>F0 disc.</th>
<th>Frequency disc.</th>
<th>Frequency modulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXP</td>
<td>11.1 (7.3)</td>
<td>16.5 (11.9)</td>
<td>23.8 (16.4)</td>
<td>28.7 (15.3)</td>
</tr>
<tr>
<td>CA</td>
<td>6.8 (6.2)</td>
<td>10.5 (16.0)</td>
<td>21.3 (9.2)</td>
<td>26.9 (8.3)</td>
</tr>
<tr>
<td>RA</td>
<td>9.8 (8.9)</td>
<td>19.7 (17.8)</td>
<td>40.7 (38.1)</td>
<td>28.6 (8.1)</td>
</tr>
</tbody>
</table>

Also, mean-accuracy functions for each psychoacoustic test are given below in a composite Figure 3 for the three subject-groups.

Figure 3. Graphs showing mean error scores obtained by the two experimental sub-groups (NP = normal perception; PW = perceptual weakness), and the two control groups on the gap detection, formant frequency, frequency modulation and pitch discrimination (psychoacoustic) tests.
Formant frequency discrimination

Number correct

0 Hz 60 Hz 120 Hz 180 Hz 240 Hz 300 Hz
Stimulus

Frequency modulation test

Number correct

0 Hz 60 Hz 120 Hz 180 Hz 240 Hz 300 Hz
Stimulus
3.10. Medical-Educational History Questionnaire.

The results of this questionnaire are summarised below in Table 23. Under "other clinical information", the presence of such conditions as asthma were noted, as was whether their class and remedial teachers concurred in regarding them as having poor short-term memory, and such factors as whether they had received speech and/or language therapy. One report noted slightly abnormal tympanometry for a child (male) when younger, which had been related to an episode of middle-ear infection.

Five of the experimental children reported having previously worn grommets. None were still doing so at the time of testing. Grommets are surgically inserted into the eardrum (unilaterally or bilaterally) for the relief of pressure and the removal of fluid in the middle ear in treating cases of otitis media, when the Eustachian tube has become infected. This action is taken when OM is accompanied by effusion and...
there is evidence of some conductive hearing-loss (personal communication). In cases of "otitis externa" there is inflammation of the canal between the eardrum and the external opening of the ear (external auditory meatus), but this is a contra-indication for the fitting of grommets. One of these five children made more than the average number of perceptual errors on a range of speech-based tests. The remaining children who had previously worn grommets did not give evidence of any speech-perceptual difficulty, but all had a history of one or more episodes of otitis media in early childhood. This included one girl who had a history of severe infection, at the age of about 2 years, resulting in significant effusions and temporary deafness in one ear. One of the CA-control children reported having worn grommets in his right ear. None of the three children who had earlier undergone speech therapy had residual speech production problems at the time of testing. Two members of the experimental group were also considered to have poor short term memory, but measured in terms of sentence comprehension and question-setting.

TABLE 23. Summary of findings from the medical-educational history questionnaire collated from each member of the three listener-groups. The necessary information was gathered from class and head teachers, medical reports and the children themselves.

EXPERIMENTAL (SRD) GROUP (n=13). # %

Number considered with normal pure-tone thresholds:- 13 100
Number considered with normal tympanometry:- 12 92
Number having a history of otitis media:- 3 23
Of those with OM, number with discharge:- 2 15
Number having worn grommets for any reason:- 5 38
Number still wearing grommets:- 0 0
Number with history of hearing loss:- 0 0

Other clinical information:
  i). number with history of asthma:- 4 31
  ii). number with poor "fine" motor-control:- 1 8
### iii). Number having had speech therapy:

<table>
<thead>
<tr>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>23</td>
</tr>
</tbody>
</table>

### iv). History of severe and/or recurrent earaches:

<table>
<thead>
<tr>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>31</td>
</tr>
</tbody>
</table>

### v). Number having suffered from tinnitus:

<table>
<thead>
<tr>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### vi). Number considered to have poor STM:

<table>
<thead>
<tr>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>15</td>
</tr>
</tbody>
</table>

### Number having had remediation on school premises:

<table>
<thead>
<tr>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>100</td>
</tr>
</tbody>
</table>

### What areas/methods used?

- Phonics, spelling tests, spelling practice, precis, vocabulary, reading,
- "Speedreading" (computerised).
- Most typical: phonics, spelling, reading.

### What is total length of weekly sessions (hours)?

<table>
<thead>
<tr>
<th>Duration</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 hours</td>
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<tr>
<td>3 hours</td>
<td>1</td>
</tr>
<tr>
<td>2 hours</td>
<td>3</td>
</tr>
<tr>
<td>1.5 hours</td>
<td>1</td>
</tr>
<tr>
<td>3.5 hours</td>
<td>1</td>
</tr>
</tbody>
</table>

### How long receiving such training (yrs.)?

<table>
<thead>
<tr>
<th>Duration</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 yrs</td>
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</tr>
<tr>
<td>3 yrs</td>
<td>1</td>
</tr>
<tr>
<td>4 yrs</td>
<td>1</td>
</tr>
</tbody>
</table>

### Number reporting instances of familial dyslexia:

<table>
<thead>
<tr>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>54</td>
</tr>
</tbody>
</table>

### CA CONTROL GROUP (n=12).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number considered with normal pure-tone thresholds</td>
<td>12</td>
<td>100</td>
</tr>
<tr>
<td>Number considered with normal tympanometry</td>
<td>12</td>
<td>100</td>
</tr>
<tr>
<td>Number having a history of otitis media</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Of those with OM, number with discharge</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>Number having worn grommets for any reason</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Number still wearing grommets</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Number with history of hearing loss</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Other clinical information:

- i). Number with history of asthma: 0 0
- ii). Number with poor 'fine motor' control: 0 0
- iii). Number having had speech therapy: 0 0
| iv). history of severe and/or recurrent earaches: | 18 |
| v). number having suffered from tinnitus: | 00 |
| vi). number considered to have poor STM: | 00 |
| Number reporting instances of familial dyslexia: | 217 |

RA CONTROL GROUP (n=12).

| Number considered with normal pure-tone thresholds: | 12100 |
| Number considered with normal tympanometry: | 12100 |
| Number having a history of otitis media: | 00 |
| Of those with OM, number with discharge: | n.a. |
| Number having worn grommets for any reason: | 00 |
| Number still wearing grommets: | n.a. |
| Number with history of hearing loss: | 00 |

Other clinical information:

| i). number with history of asthma: | 18 |
| ii). number with poor 'fine motor' control: | 00 |
| iii). number having had speech therapy: | 00 |
| iv). history of severe and/or recurrent earaches: | 217 |
| v). number having suffered from tinnitus: | 1*8 |
| vi). number considered to have poor STM: | 00 |
| Number reporting instances of familial dyslexia: | 18 |

* This child had experienced one episode of unilateral tinnitus, but showed no evidence of speech-perceptual problems.

3.11. Heterogeneity of Performance Patterns.

Examination of the individual error-rates on the various tests was made to discover whether high rates for each applied to the same children, i.e. whether
TABLE 24. Individual error-rates (%) on the word and nonword reading-list tests and standardised tests for children in the experimental group, and group means for controls. Reading delay is given in years;months format. Standard deviation measures are given in parentheses. Asterisks mark error scores that are greater than one standard deviation above reading-age control means. The Neale (A=Accuracy) and (C = Comprehension), and Ravens percentiles are age-appropriate.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10;9</td>
<td>7;11</td>
<td>2;10</td>
<td>10</td>
<td>40</td>
<td>55</td>
<td>12</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>10;5</td>
<td>8;1</td>
<td>2;4</td>
<td>25 *</td>
<td>60 *</td>
<td>60 *</td>
<td>12</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>10;6</td>
<td>7;8</td>
<td>2;10</td>
<td>20 *</td>
<td>65 *</td>
<td>65 *</td>
<td>8</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
<td>10;1</td>
<td>9;5</td>
<td>1;6</td>
<td>5</td>
<td>10</td>
<td>35</td>
<td>26</td>
<td>94</td>
</tr>
<tr>
<td>5</td>
<td>10;9</td>
<td>9;3</td>
<td>1;6</td>
<td>5</td>
<td>15</td>
<td>30</td>
<td>26</td>
<td>85</td>
</tr>
<tr>
<td>6</td>
<td>9;5</td>
<td>7;4</td>
<td>2;1</td>
<td>30 *</td>
<td>50 *</td>
<td>60 *</td>
<td>13</td>
<td>51</td>
</tr>
<tr>
<td>8</td>
<td>10;6</td>
<td>7;10</td>
<td>2;8</td>
<td>10</td>
<td>30</td>
<td>55</td>
<td>10</td>
<td>34</td>
</tr>
<tr>
<td>10</td>
<td>9;10</td>
<td>7;9</td>
<td>2;1</td>
<td>5</td>
<td>35</td>
<td>30</td>
<td>21</td>
<td>51</td>
</tr>
<tr>
<td>13</td>
<td>9;11</td>
<td>7;7</td>
<td>2;4</td>
<td>30 *</td>
<td>65 *</td>
<td>85 *</td>
<td>18</td>
<td>64</td>
</tr>
<tr>
<td>7</td>
<td>9;8</td>
<td>7;4</td>
<td>2;4</td>
<td>25 *</td>
<td>65 *</td>
<td>60 *</td>
<td>13</td>
<td>27</td>
</tr>
<tr>
<td>9</td>
<td>9;3</td>
<td>6;10</td>
<td>2;5</td>
<td>50 *</td>
<td>35</td>
<td>95 *</td>
<td>8</td>
<td>64</td>
</tr>
<tr>
<td>11</td>
<td>11;7</td>
<td>10;1</td>
<td>1;6</td>
<td>0</td>
<td>5</td>
<td>60 *</td>
<td>23</td>
<td>85</td>
</tr>
<tr>
<td>12</td>
<td>10;4</td>
<td>7;7</td>
<td>2;9</td>
<td>20 *</td>
<td>55 *</td>
<td>75 *</td>
<td>6</td>
<td>31</td>
</tr>
<tr>
<td>Mn</td>
<td>10;4</td>
<td>8;1</td>
<td>2;3</td>
<td>18.1</td>
<td>40.8</td>
<td>58.5</td>
<td>15</td>
<td>58</td>
</tr>
<tr>
<td>EXP</td>
<td>(0;8)</td>
<td>(0;11)</td>
<td>(0;6)</td>
<td>(14)</td>
<td>(21)</td>
<td>(20)</td>
<td>(7)</td>
<td>(23)</td>
</tr>
<tr>
<td>Mn</td>
<td>8;2</td>
<td>8;2</td>
<td>8.6</td>
<td>24.1</td>
<td>35.9</td>
<td>50</td>
<td>73</td>
<td>75</td>
</tr>
<tr>
<td>RA</td>
<td>(0;4)</td>
<td>(0;11)</td>
<td>(11)</td>
<td>(18)</td>
<td>(20)</td>
<td>(20)</td>
<td>(17)</td>
<td>(22)</td>
</tr>
<tr>
<td>Mn</td>
<td>10;1</td>
<td>11;9</td>
<td>0.8</td>
<td>7.9</td>
<td>12.5</td>
<td>69</td>
<td>80</td>
<td>88</td>
</tr>
<tr>
<td>CA</td>
<td>(0;8)</td>
<td>(1;7)</td>
<td>(2)</td>
<td>(5)</td>
<td>(13)</td>
<td>(20)</td>
<td>(21)</td>
<td>(9)</td>
</tr>
</tbody>
</table>

Performance-heterogeneity was consistent. Reliable evidence of poor performance on a range of tests by some SRD-subjects would only be of theoretical interest if the same SRD children were involved. If so, there would be a prima facie case for the formation of a "sub-group" of SRD children. An investigation would then be possible of whether these children have in common any particular pattern of reading-list errors. In order to be able to relate the following account to the individual results on the main test battery, comprehensive tables are presented here for each of the three subject-groups. They form a
retrospective of all of the test-results in the battery, plus the standardised tests, from the point of view of individual error-scores. Performance within "normal range" was defined as being within one standard deviation of reading-age control means (see Morris, 1988). This is a stringent criterion when applied to the speech discrimination tests, because the RA control children were about 2 years younger than the experimental children, and therefore would be expected to be at an earlier stage of perceptual maturity. It is one previously used in similar experiments (Watson, 1992). Examination of the individual error-rates for the experimental children across a range of perceptual and item-repetition tests shows that there is, potentially, a clear difference in their patterns of performance. Applying this criterion to the data-sets given in Tables 24 and 25, and using asterisks to indicate values which exceed it, shows that higher error-scores seem to occur fairly consistently on a range of tasks only for certain SRD children, particularly those of nonword reading, and VCV and consonant-cluster discrimination. In fact, this heterogeneity was very marked; several of the individual error-rates are many standard deviations above the mean error-rate for RA control children.

There would appear to be a prima facie case for proposing that the test-battery performance profiles of the SRD-children are different. It is proposed that these 13 SRD-children should be regarded as a "composite" group as regards their speech-perceptual skills, and be appropriately partitioned into two sub-groups. One subgroup consists of four children who show a (relative) perceptual "weakness" on at least three of the four natural-speech discrimination tests in the main battery; these are subjects E7, E9, E11 and E12. This pattern of performance was seen for only R4, one of twenty-four control children. The remaining nine SRD-children generally performed with an accuracy very similar to that achieved by the CA and RA controls.
TABLE 25. Individual error-rates (%) on the speech discrimination and nonword repetition tests for children in the experimental group, with group means for controls. Standard deviation measures are given in parentheses. Asterisks indicate those scores which are greater than one standard deviation above the corresponding reading-age control means.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Minimal Pair % errors</th>
<th>Cluster omission % errors</th>
<th>Cluster substitution % errors</th>
<th>VCV % errors</th>
<th>Nonword Repetition % errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.6</td>
<td>0.6</td>
<td>5.0</td>
<td>2.1</td>
<td>15.0</td>
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<td>2</td>
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<td>1.2</td>
<td>0.4</td>
<td>42.5 *</td>
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<td>3</td>
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<td>4</td>
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<td>1.2</td>
<td>1.3</td>
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<td>6.9 *</td>
<td>5.0 *</td>
<td>25.0</td>
</tr>
<tr>
<td>9</td>
<td>10.2 *</td>
<td>2.5</td>
<td>13.0 *</td>
<td>13.8 *</td>
<td>47.5 *</td>
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<td>14.0 *</td>
<td>17.5 *</td>
<td>21.7 *</td>
<td>12.5</td>
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<td>37.0 *</td>
<td>28.0 *</td>
<td>28.0 *</td>
<td>32.5 *</td>
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<tr>
<td>Mean</td>
<td>7.14</td>
<td>5.59</td>
<td>6.41</td>
<td>6.15</td>
<td>23.3</td>
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<tr>
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<td>(4.0)</td>
<td>(10.1)</td>
<td>(8.3)</td>
<td>(9.1)</td>
<td>(14.7)</td>
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<tr>
<td>Mean</td>
<td>6.13</td>
<td>1.08</td>
<td>2.14</td>
<td>1.98</td>
<td>16.6</td>
</tr>
<tr>
<td>RA</td>
<td>(3.0)</td>
<td>(2.1)</td>
<td>(3.0)</td>
<td>(1.5)</td>
<td>(10.7)</td>
</tr>
<tr>
<td>Mean</td>
<td>4.61</td>
<td>0.51</td>
<td>0.77</td>
<td>1.92</td>
<td>9.4</td>
</tr>
<tr>
<td>CA</td>
<td>(2.3)</td>
<td>(0.6)</td>
<td>(1.0)</td>
<td>(1.6)</td>
<td>(6.0)</td>
</tr>
</tbody>
</table>

They are therefore proposed to have shown "normal" speech perception. For convenience, the perceptual-weakness sub-group of SRD-children will be referred to by the abbreviation "PW", whilst the normally perceiving SRD sub-group will be abbreviated "NP". The number of children in the "PW" sub-group was small, therefore parametric statistical testing of any differences in performance was not possible. To facilitate immediate reference and comparison of each individual’s data, several tables below are presented in full rather than summary form.
By comparing the performance pattern of individual SRD- and control-children with their medical-educational questionnaire data, an indication could be made of the potential effect of such factors as otitis media and familial dyslexia on reading accuracy and speech-perceptual development.

3.12. Medical-Educational History Questionnaire and Heterogeneity.

The first question to be addressed is whether the children in the "PW" sub-group of SRD-children are more likely than the "NP" sub-group to also have a first-degree relative (i.e. parents and siblings) who has/had problems of the dyslexic type. Seven of the SRD-group reported at least one case of familial dyslexia. Of these seven children, three were classified as members of the "PW" sub-group. Therefore, 75% of the "PW" children had reported familial dyslexia but this was also true of 44% of the "NP" sub-group. Although the sample-sizes are small, the implication is that incidence of familial dyslexia per se does not predict the development of speech-perceptual weakness. This lack of "exclusivity" was emphasised by the fact that two of the twelve CA-control children and one of the twelve RA-control children also reported cases of familial dyslexia. It does appear, though, that specific reading difficulties in first-degree relatives can pre-dispose children to similar difficulties.

The next question is whether children in the "PW" sub-group are more likely than "NP" SRD children and controls to have had a history of otitis media (OM). Familial dyslexia combined with having some history (one or more episodes) of otitis media (or "glue ear") was reported for two "experimental" children, one of whom was a member of the "PW" sub-group. For one further SRD child, otitis media without known cases of familial dyslexia was reported. Otitis media was therefore associated with 25% of the "PW" sub-group and 22% of the "NP" sub-group. On the basis of this limited sample, otitis media does not seem to be strongly associated with cases of relative speech-perceptual difficulty. All four "PW" children reported pure-tone thresholds within the normal range (confirmed by current school records). Since audiometric tests were not carried out independently, it was uncertain as to whether any of the children who were later regarded as "perceptually weak" had, in fact, been
suffering some temporary hearing loss at the time of the first speech-perceptual tests. The typically long overall time span of such testing, and the fact that children were never tested when suffering (or recovering) from an upper-respiratory infection, served to minimise this risk. Other evidence for hearing loss following the effects of recurrent earache or tinnitus was based partly on school reports, and on children's self-reports for their pre-school years. As such, it is regarded as incomplete, circumstantial and probably unreliable.

To what extent could otitis media per se affect early reading development? The issue remains controversial, largely because early episodes of otitis media rarely occur as a single factor in the histories of children who have subsequently presented with reading problems (see e.g. Friel-Patti and Finitzo, 1990; Roberts et al., 1985 and Teele et al., 1984). There is evidence that early (pre-school) otitis media is most often associated with reading failure when one or more of a child's immediate family members (first-degree relatives) also have a history of language- or reading-impairment (see e.g. Bishop and Edmundson, 1986). From the demographic evidence gathered in this section of the questionnaire, it seems that the OM + familial dyslexia combination may be potent as regards predicting reading-failure in children (see also Scarborough, 1989).

Other issues from these questionnaires deserve mention in respect of their relevance to speech-perceptual weakness in SRD-children. One "PW" child had a history of asthma. Another had received speech-and-language therapy, and the same child had what were described as auditory short-term memory problems relating to the recall of word-lists. Problems with the recall of word-lists preserving the order of presentation are well-known in SRD-subjects, having been widely studied in the literature involving short-term memory (see e.g. Dempster, 1981 for review; Hulme, Thomson, Muir and Lawrence, 1984; Mann, Liberman and Shankweiler, 1980). Similar effects have been shown in SRD's recall of digit-sequences (e.g. Sipe and Engle, 1986). They appear not to be linked to particular aspects of developmental dyslexia.

In order to develop the case for the proposed distinction between "PW" and "NP"
sub-groups of SRD children, the experimental group's test-data were re-analysed and illustrated by the use of figures. One of the most important factors is the proportion of groupwise variance on a particular test which can be accounted for by the performance of these children taken alone, and the presentation makes these proportions clear.


Using the performance-difference criterion described in Section 3.9, the subjects in the proposed "PW" sub-group are: E7, E9, E11 and E12. What is also evident is that the performances of the remaining 9 SRD children are within RA-group norms, and do not, generally, show a gradual increase in the magnitude of error-rates up to the level shown by the “PW” children. The subjects in the proposed "NP" sub-group of SRD-children are: E1, E2, E3, E4, E5, E6, E8, E10 and E13. The error-data presented here is partitioned according to these sub-groupings.


Reading errors (rounded) for the two proposed experimental sub-groups and two control groups are presented in Figure 4. It appears that children in the partitioned SRD-group produced similar error-rates on the reading of regular (mean PW = 24 %, mean NP = 16 %) and irregular words (mean PW = 40 %, mean NP = 41 %).

The children in the PW sub-group performed below RA norms on their reading of nonwords, whilst the difference in scores between the two sub-groups (mean PW = 72 %, mean NP = 53 %) was significant [t (11) = 1.85, p< 0.05] (1-tailed). As to the reading-rates, there was no evidence of the SRD-children being generally slower than the RA controls on any of the three list-types. Neither was there evidence of the SRD-children who made most of the speech-discrimination errors also reading consistently more slowly than other SRD children or the RA children. A criterion of 30 percentage points difference between error-rates on the irregular and
nonword lists was used to ascribe "phonological" and "surface/morphemic" dyslexic reading patterns. With reference to Table 24, this criterion relates to more than 1 standard deviation from the RA group mean for both lists.

Figure 4. Bar charts showing mean error scores obtained by the two experimental sub-groups (PW = perceptual weakness; NP = normal perception), and the two control groups on the reading and speech repetition tasks.

3.13.2. Standardised tests of reading and non-verbal intelligence.

The mean reading-delay for accuracy (estimated using the Neale Analysis) for subjects E7, E9, E11 and E12 was 27 months, and that for the remainder of the SRD-group was also 27 months. Comprehension age-equivalents, also estimated using the Neale Analysis, for the proposed "PW" and "NP" sub-groups did not obviously differ; the mean values were 10;1 years and 10;8 years respectively. There appeared to be no difference between sub-groups of experimental children in terms of their non-verbal intelligence as shown by percentile scores on the Raven's Progressive Matrices test. The "PW" mean was 80, that for the remaining nine children was 82. Any differences in the pattern of performance on the main test-battery by these particular children can not, therefore, be attributed to basic quantitative differences in reading accuracy, reading comprehension or non-verbal intelligence.
3.13.3. Speech discrimination tests.

In Figure 5, mean error-rates are plotted separately for subjects E7, E9, E11 and E12 from the SRD-group, that of the remaining subjects in the SRD-group, plus the mean error-rates of the two control groups, for the VCV discrimination test and for both consonant-cluster discrimination tests.

i). Intervocalic consonants (VCV).

For this discrimination test, the mean error rate for the four children in the proposed "PW" sub-group was 17.1 % and that for the proposed "NP" sub-group was 1.2 %.

Error scores obtained for the VCV test were examined in more detail. As can be seen from Table 14, a large number of SRD children performed entirely within the normal range of accuracy, whilst 4 other children from the same group appeared to produce higher error-rates. This shows that the speech-perceptual acuity of a majority of SRD children could be regarded as consistent with those of control children across the different types of consonant used, but that a minority could be regarded as showing weaker performance. Bar charts showing the percentage of errors obtained for stop, fricative, nasal and approximant contrasts are presented in Figure 5.

To further examine the significance of the apparent difference in performance level within the SRD group, Table 26 below shows the proportion of experimental group errors which are attributable only to these four children, for each of the types of contrast involved in this test. It indicates, for instance, that the putative "PW" sub-group would account for 85 % of the 41 stop place discrimination errors made by the SRD-group. These four children could not distinguish items in this type of speech contrast on 18 % of all presentations. It is clear that the SRD-children did not find the discrimination of stop contrasts to be the only difficult task. Errors of fricative place and fricative voice, and those of approximant place, were associated with
similar error-rates to that for stop contrasts. The error rates do, however, relate to a necessarily smaller number of trials for the nasal place contrast than for most other types of contrast.

Figure 5. Bar charts showing mean error scores obtained by the two experimental sub-groups (PW = perceptual weakness; NP = normal perception), and the two control groups on the VCV discrimination task.

The two control groups made rather more errors with the discrimination of fricative voice and approximant place contrasts, but both the CA and RA groups were remarkably accurate on stop discrimination. For the fricative contrast differing in both place-of-articulation and voicing (added as a check on the need for single-feature differences within contrasts) there were very few (5) discrimination errors, but all of these were made by the proposed "PW" sub-group.
TABLE 26. Number of discrimination errors for the three listener groups on each type of minimal-pair in the intervocalic (VCV) task, the proportion (%) of the EXPERIMENTAL group errors made by the "PW" and "NP" sub-groups of SRD children, and the error-rates (%) for the "PW" sub-group and the two control groups for each contrast-type.

<table>
<thead>
<tr>
<th>CONTRAST</th>
<th># GROUP ERRORS</th>
<th>PROPN^</th>
<th>ERROR RATE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EXP^</td>
<td>CA</td>
<td>RA</td>
</tr>
<tr>
<td>Stop place</td>
<td>41</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Stop voice</td>
<td>31</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Fricative place</td>
<td>25</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>Fricative voice</td>
<td>35</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>Nasal place</td>
<td>18</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Approx'nt place</td>
<td>36</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Fric. Place/voice</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>191</td>
<td>55</td>
<td>52</td>
</tr>
</tbody>
</table>

This suggests that children with normal speech-perceptual acuity, whether they have reading problems or not, are easily able to discriminate contrasts differing in more than one phonetic feature (i.e. those which are relatively high in perceptual "salience" or distinctiveness). Even the SRD-children who show consistent evidence of speech-perceptual weakness in other speech-based tests were also generally able to discriminate speech contrasts which incorporate several acoustic-phonetic differences.

ii). Consonant cluster (substitution).

The number of errors made by the EXP group and the proportion of errors for each component minimal-pair by these 4 "PW" children was tabulated against the proportion made by the 9 remaining reading-disabled children. The number of errors made by the CA and RA controls was also included for comparison in Table 27 below, whilst Table 28 shows the same pairwise breakdown of errors for the consonant-cluster "omission" condition and Table 29 does likewise for the "natural minimal pairs test". Again, for each of the eight contrasts in this test the "PW" sub-group made a majority of the SRD-group errors (mean = 81 %), although the error-
rate for all subject-groups for the \(/sp/-/sl/\) contrast was low. The same-age (CA) controls had no difficulties with any contrast, and the younger (RA) controls made most discrimination errors on the \(/sm/-/sn/\) and \(/sp/-/st/\) contrasts, which differed only in place-of-articulation.

### TABLE 27. Number of discrimination errors for the three listener groups on the 8 minimal-pairs in the consonant cluster (substitution) task, the proportion (%) of the EXPERIMENTAL group errors made by the "PW" and "NP" sub-groups of SRD-children, and the error-rates (%) for the "PW" sub-group and the two control groups for each contrast.

<table>
<thead>
<tr>
<th>CONTRAST</th>
<th># GROUP ERRORS</th>
<th>PROP'N^</th>
<th>ERROR RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>/sk/-/sl/</td>
<td>18</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>/st/-/sk/</td>
<td>18</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>/sm/-/sn/</td>
<td>26</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>/sp/-/st/</td>
<td>20</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>/sp/-/sl/</td>
<td>16</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>/sn/-/sl/</td>
<td>7</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>/st/-/sl/</td>
<td>15</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>/st/-/sm/</td>
<td>14</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>134</td>
<td>15</td>
<td>38</td>
</tr>
</tbody>
</table>

**iii). Consonant cluster (omission).**

For each of these eight contrasts it was clear that the "PW" sub-group made a majority of the experimental group errors (mean = 79 %), whilst neither control group found any of them difficult to discriminate. Contrasts associated with lower error-totals for the EXP group did not relate to particular phoneme-categories in second-consonant position.
iv). Natural minimal-pairs.

The "natural minimal-pairs" test was based on 16 word-pairings and a total of 128 trials. This meant that it comprised only 8 trials per contrast, compared to 16 per contrast in VCV-discrimination and 20 per contrast for both conditions of consonant-cluster discrimination. A study of the effect of vowel context on consonant discrimination in naturally-produced real-words with, say, four such contexts per contrast would have been more thorough, but the constraint of having to derive stimuli from the Alpha (7) vocabulary control made this impossible.

All single-consonant contrasts differed in only one phonemic-feature (either place-of-articulation or voice). For all three subject-groups, the first four of these pairings, as listed in Table 29, produced "significant" error-rates between 9 and 28 %. At first sight, the proportion of errors made by the control children appears to be lower for those pairs where "PW" SRD-children were responsible for a greater proportion of

---

TABLE 28. Number of discrimination errors for the three listener groups on the 8 minimal-pairs in the consonant cluster (omission) task, the proportion (%) of the EXPERIMENTAL group errors made by the "PW" and "NP" sub-groups of SRD-children, and the error-rates (%) for the "PW" sub-group and the two control groups for each contrast.

<table>
<thead>
<tr>
<th>CONTRAST</th>
<th>#GROUP ERRORS</th>
<th>PROP'N</th>
<th>ERROR RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EXP^</td>
<td>CA</td>
<td>RA</td>
</tr>
<tr>
<td>/p/-/pl/</td>
<td>17</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>/f/-/fr/</td>
<td>18</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>/s/-/sp/</td>
<td>16</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>/t/-/tw/</td>
<td>10</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>/s/-/st/</td>
<td>10</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>/s/-/sw/</td>
<td>15</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>/d/-/dr/</td>
<td>10</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>/b/-/bl/</td>
<td>20</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>116</td>
<td>8</td>
<td>19</td>
</tr>
</tbody>
</table>
SRD group errors. This is an insignificant trend, however, because of each subject-group's very low error-rates for discrimination of ten of the sixteen contrasts presented. A perceptual developmental effect may apply to the RA controls for a discrimination task involving change of speaker identity, and have also interacted with the smaller number of presentations of each contrast.

TABLE 29. Number of discrimination errors made by the three listener groups on the 16 contrasts comprising the natural minimal-pairs task; the proportion (%) of the EXPERIMENTAL group errors made by the "PW" and "NP" sub-groups of SRD children; the error-rates (%) for the "PW" and "NP" sub-groups, and the control groups, for each contrast.

<table>
<thead>
<tr>
<th>CONTRAST</th>
<th># GROUP ERRORS</th>
<th>PROP^N^</th>
<th>ERROR RATE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>met-net *</td>
<td>25</td>
<td>22</td>
<td>25</td>
</tr>
<tr>
<td>mail-nail *</td>
<td>11</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>man-nan</td>
<td>4</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>smack-snack *</td>
<td>13</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Sue-shoe *</td>
<td>17</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>sign-shine</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>fan-van *</td>
<td>6</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>fine-vine *</td>
<td>9</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>done-gun</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>date-gate</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>buy-pie</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>bin-pin</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>skip-slip</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>clown-crown</td>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>grass-glass</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>spill-still</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>119</td>
<td>71</td>
<td>91</td>
</tr>
</tbody>
</table>

For the contrast-groups of nasal place, fricative place and fricative voicing performance-differences within listener groups were evident. Both groups of controls, and the "remainder" (9 "NP" children) of the SRD-group, also showed
relative difficulty in discriminating essentially the same contrasts as the four "PW" children, including most of the nasal contrasts. Indeed, with the exception of the evident difficulties which some RA-control children had with the "fan"-"van" (/fæn/-/væn/) and "fine"-"vine" (/fain/-/vain/) contrasts, it can be seen that the distribution of errors across pairs was similar for all three subject-groups. The effect of subject-group was not significant. In terms of percentage errors, the rightmost 4 columns indicate that listener-groups show generally similar patterns for six pairs (marked by an asterisk) for which error-rates were not minimal.

3.13.4. Speech pattern identification tests.

The individual identification functions obtained for the four members of the proposed "PW" sub-group were classified according to three configurations, being "categorical", "progressive" or "random". The criteria defining these configurations were as noted in Hazan, Fourcin and Abberton (1991). To achieve "categorical" status four steps of the continuum, including endpoints, needed to be labelled with 100 % consistency. If the endpoints were labelled with a consistency of at least 87 % a function was "progressive", but if neither of these criteria were met a function was classified as "random".

For the DATE-GATE test, two of the four children (E9 and E12) labelled the contrast categorically in the combined-cue condition. In the "burst cue" condition, none of these four children were able to label the endpoints of the continuum appropriately, which indicates that their good "combined-cue" performance was relatively dependent on formant transition information. However, 6 of the other experimental children, 8 of the reading age controls and no less than 11 of the chronological-age controls also showed a similar pattern of performance. In the "F2 transition" condition, two of the "PW" children (E9 and E12) were labelling the contrast either categorically or progressively. This is similar to performance in the two control groups, where half the children could label the contrast on the basis of formant transition information alone, whilst the other half showed evidence of poor
These four children also performed very poorly on the SUE-ZOO contrast. For all of them, 'random' configurations were obtained both when the contrast was cued by friction duration and intensity of the voice bar, or when it was cued by friction duration alone. This type of performance was not unique to children in the "PW" subgroup however. Four children in the remainder of the experimental group showed similar performance, as did 2 of the 24 control children.

The following table lists the number of individuals in each subject-group who labelled each of the five continua in different ways.

TABLE 30. The number of children in each listener group judged to have labelled each of five copy-synthesised speech-continua in a "categorical" (C), "progressive" (P) or "random" (R) fashion. The data for the experimental children has been divided between "PW" (n = 4) and "NP" (n = 9) subgroups.

<table>
<thead>
<tr>
<th>GROUP/SUB-GRP</th>
<th>PW</th>
<th>NP</th>
<th>CA</th>
<th>RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATE-GATE comb.</td>
<td>2 1 1 3 4 2 6 4 2 6 4 2 2 1 1 3 4 2 6 4 2 6 4 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DATE-GATE burst</td>
<td>0 0 4 1 2 6 1 0 11 1 3 8 0 0 4 1 2 6 1 0 11 1 3 8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DATE-GATE trans.</td>
<td>0 2 2 3 3 3 1 3 8 3 5 4 0 2 2 3 3 3 1 3 8 3 5 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUE-ZOO comb.</td>
<td>0 0 4 1 4 3 7 2 5 7 0 0 0 4 1 4 3 7 2 5 7 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUE-ZOO friction *</td>
<td>0 0 4 0 1 8 0 3 8 0 2 10 0 0 4 0 1 8 0 3 8 0 2 10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* No data recoverable for one CA-control child on this continuum.

The criteria listed above are arbitrary (see Hazan, Fourcin and Abberton, 1991) and attend strongly to subjects' labelling consistency for end-points. Small percentage-differences in certain data-points can therefore result in two otherwise-similar identification functions being classified differently. This is particularly so for the difference in criteria between configurations defined as "categorical" and "progressive". Therefore, with regard to Table 30 above, the potential effect of these criteria on the proportions of the three classifications for each subject-group should be borne in mind.
The uncertain fashion in which even the language-normal 10 year-old CA controls labelled the reduced-cue continua provides a striking illustration that there is considerable individual variation within groups in the perceptual weighting that children give to individual acoustic cues. It has been shown that, even for language-normal adult listeners, there can be marked individual variability in the perception of cues for labelling place contrasts (Hazan and Rosen, 1991). The small sample of untrained adults who were tested on these continua labelled the full- and reduced-cues versions of both contrasts in a clearly categorical fashion, suggesting that the quality of the tokens within each was adequate for the task. There is even evidence that normal adults are quite able to distinguish stimuli "within" certain categories, such as Miller's "goodness judgements" for /bi/-/pi/ and /gi/-/ki/ VOT-series (Miller, 1994). The fact that some CA control children in the current study labelled the combined-cues versions of both contrasts in a "random" fashion required closer examination of the data.²


It was reported above that the mean number of repetition errors made by the entire experimental group was significantly higher than that made by either control group. An analysis was made of the nonwords incorrectly repeated and scores were classified according to word-length (see Table 21). It was not possible to relate the subject-group mean error rates to corresponding percentile scores as supplied by Gathercole et al., as no such percentiles (Version 2) were available for subjects over the age of 9;11 years (Gathercole, Willis, Baddeley and Emslie, 1994). The mean performance of the RA group in the current study corresponded to a score between the 50th and 75th centiles of the published "CNRep." test norms for children whose chronological age was 8;01 to 8;11 years. In this study, the experimental children made considerably more errors with nonwords of four compared to those of three

² A check on the data of CA controls revealed that the reason some were regarded as having the full-cues continua in only a "random" fashion was due to the fact that, in each case, they showed 78 % consistency at one of the end-points. The criterion, here, for "progressive" labelling according to Hazan et al. (1991) was 87 % consistency.
syllables, in agreement with the Gathercole et al. (1994) results.

The table below compares the error-rates and standard deviations of children in the proposed SRD sub-groups and the control groups for each of the nonword (syllabic) lengths. The increase in error-rate for items of four compared to those of three syllables appears more pronounced for the "PW" than for the "NP" sub-group of SRD listeners. However, a small-sample-modified t-test on the distribution of error-scores for the children in the reading-disabled "sub-groups" showed that there was no reliable difference in nonword repetition accuracy \[t (11) = 1.639, p > 0.05, one-tailed\], although the larger mean error rate for the "PW" children approached significance.

TABLE 31. Means of the overall nonword repetition error-rates (%) for items of different syllabic length for the "PW" and "NP" sub-groups of SRD children, and for the two groups of control children.

<table>
<thead>
<tr>
<th>No. syllables</th>
<th>Two</th>
<th>Three</th>
<th>Four</th>
<th>Five</th>
</tr>
</thead>
<tbody>
<tr>
<td>PW</td>
<td>10</td>
<td>17.5</td>
<td>41.7</td>
<td>41.7</td>
</tr>
<tr>
<td>NP</td>
<td>2.2</td>
<td>16.7</td>
<td>27.3</td>
<td>27.3</td>
</tr>
<tr>
<td>RA</td>
<td>3.3</td>
<td>3.3</td>
<td>11.4</td>
<td>26.9</td>
</tr>
<tr>
<td>CA</td>
<td>3.3</td>
<td>3.3</td>
<td>9.9</td>
<td>22.2</td>
</tr>
</tbody>
</table>

3.13.6. Psychoacoustic tests.

There was no evidence of systematically poorer performance on any of the psychoacoustic tests by any experimental child, or by any child in either control group. It may be necessary to determine whether the step-sizes for "different" stimuli chosen for this set of psychoacoustic tests may have been generally too large to reflect possible discrimination difficulties for SRD compared to language-normal children. However, previous work has suggested that there may be absolute limits to the abilities of language-normal children to detect gaps between paired acoustic events.

Davis and McCroskey (1980) used paired brief tone-pulses to estimate the "auditory
fusion" of children aged 3 - 12 years. After controlling tone frequency, intensity and duration, the minimum silent gap necessary to maintain a perception of successive presentation was 10 ms in 6 year-olds and 4 ms in 10 year-olds for 60 dB SPL pulses. The fusion-point was independent of stimulus-frequency within the range 250 - 4000 Hz. Older children were unable to "perceive" briefer gaps than this. Very similar results were obtained for auditory temporal acuity in children aged from 6 to 12 years, and young adults by Irwin, Ball, Kay, Stillman and Rosser (1985) on the cessation of noise in a noise band at 60 dB SPL. This was not matched by estimations that the width of the auditory filter in 6 year-olds is wider than that of 10 and 19 year-olds (Irwin, Stillman and Schade, 1986).

The younger control children used here were already potentially old enough to have achieved the temporal acuity limit shown by Irwin et al. (1985), and Davis and McCroskey. There is also the possibility that the performance of RA control children, and that of SRD-children, on the frequency- and modulation-discrimination tasks for smaller "step" sizes would also be indistinguishable from those of older subjects if they approached the performance limits for 8-12 year-olds. Nevertheless, experiments using smaller steps on each of the four tests do need to be run on different reading-groups of children, and on normally reading adults, even if only to estimate performance-limits.

Some lack of consistency is evident in the performance of the "PW" children on the formant frequency and frequency modulation sub-tests in that they appeared less affected by the smallest difference-conditions than were the "NP" or control children (see Fig. 3). In the frequency modulation test they also appeared to benefit less than other groups from increases in modulation depth, save for the largest difference (300 Hz). For the gap detection and fundamental-pitch discrimination sub-tests, however, no such differences between overall performance trends were found across listener-groups.

Next, in order to achieve some meaningful comparison across tests of the performance of the two SRD sub-groups and the two control groups, an illustration
of the "relative order of difficulty" for a number of tests is attempted. This is complicated by the number of dimensions of difference between the stimuli and the absolute (individual) error-scores, but is valid since each of the children act as their own controls and there are no differences across tests in the composition of groups. A cross-correlation of results for the main test battery with those of other relevant studies will be included in the discussion section of Chapter 4.


A rank ordering of the mean error-rate for the discrimination tasks for each subject-group (or sub-group) provides an approximate indication of their relative difficulty. In Table 32 below, error-means for five tasks are given separately for the "PW" and "NP" sub-groups, as well as for the control groups, with the lowest error-rate ranked I (1) and the highest ranked V (5). Although the nonword repetition task is of a different nature to that of speech discrimination, the mean error-rates are included to emphasize its relative difficulty for all groups.

However, the ranks represent an "ordinal" scale only, and the differences between them do not reflect the differences in perceptual difficulty either by task or by subject-group (sub-group). This is particularly evident in the first four columns, where large differences in rank seem to be associated with quite similar error-rates, given the overall range. To illustrate more quantitatively the difference in performance of the "PW" sub-group from all others, an appropriate "interval" scale, where each of the intervals is suitably small as well as equal in size, is required. The lowest and highest error-rates obtained in the above tests are 0.5 and 29.4 percent respectively. Therefore, taking 3 percentage points for each interval, the relevant range of error-rates from 0 to 30 percentage points would provide ten equal intervals. This means that error rates between 0.0 and 3.0 % inclusive fall within interval 1, those between 3.1 and 6.0 % fall within interval 2, between 6.1 and 9.0 % = interval 3, and between 27.1 and 30.0 % = interval 10).

This interval scale is applied to the data in Table 32 to enable direct comparison with
rank ordering. The differences in the interval "level" across groups more accurately represent the various differences in performance accuracy. Clearly, the patterns of discrimination performance of the "NP" sub-group, the RA and the CA control groups are very similar, whilst that of the "PW" sub-group, except for natural minimal-pairs, appears to be deviant. That is, the "NP" sub-group and both control groups found the easiest tasks to be those of VCV, cluster-substitution and cluster-omission discrimination, which was not the case for the "PW" sub-group. On the natural minimal-pair discrimination and nonword repetition tests, the SRD-children performed similarly to the younger (RA) controls.

The evidence assembled here for the existence of a "perceptually-weak" sub-group within a sample of thirteen SRD children would be of limited value if similar patterns of difficulty could not be reproduced, using some of the original tests, for an independent sample of reading-disabled children. Theoretically, speech-perceptual
weakness in SRD children should not apply only to those whose delay for reading accuracy and/or chronological age falls within certain limits. Evidence has been provided in other studies of the persistence, at least into early adulthood, of speech-perceptual problems (Bruck, 1992; Masterson et al., 1995). In both of these studies, subjects had often substantially overcome their reading problems.

Children with reading delays larger than 36 months may, or may not, have underlying problems with speech perception. Relaxation of the reading-delay limit would allow study of the speech-perceptual acuity of several such children, but would also involve the inclusion of one child whose estimated delay (accuracy) was only 15 months. It should, then, be possible to demonstrate heterogeneity of performance in SRD-groups whether or not they have been screened in respect of these variables. The following section in this chapter concerns the details of testing such a group, together with a tabulation of their questionnaire data.

3.15. Speech-Perceptual Data from a Further SRD Group.

Rationale.

A second group of sixteen experimental (SRD) children was found in order to test the replicability of the original pattern of results on the discrimination of VCV and consonant-cluster contrasts (omission and substitution). These three discrimination tests were apparently the most consistent and sensitive in showing differences in speech-perceptual acuity for the original sample of SRD children, and were used to test this further group. Ideally, analysis of the individual sets of error-rates would need to show that some children were clearly weak on a majority of the speech-discrimination tasks, whilst the remainder of the SRD group could be regarded as perceptually-normal. The pattern of word and non word reading accuracy would also be related, as before, to performance on the speech-discrimination tests. This will enable an estimate of to what extent speech-perceptual weakness is associated with the "pattern" for developmental phonological dyslexia (i.e. weaker nonword than irregular word reading).
Subjects.

Each of these children had been given written parental permission to take part. Some were tested privately at home, but most were the classmates of children who had formed, from a number of schools, the original SRD group. They were not screened by chronological age or by reading-delay, and the range of these two variables for this second SRD group made it impossible to find "reading-age matches" for statistical comparison with the original RA control-group. Furthermore, the numbers of subjects in this SRD group and the original RA-group were unequal (i.e. 16 and 12 respectively). Their mean reading age was less than that of the RA control-children, with a mean reading delay (accuracy) of 42 months (s.d. = 16 months). Their mean chronological age was 11; 04 years, which is about 1 year older than that of the original SRD group. Nevertheless, it was necessary to provide some criterion against which to compare the individual test results. The criterion of "normal / abnormal perception" for the three speech discrimination tasks was again that error rates should be at least one standard deviation greater than that of the RA-group mean, so as to be able to compare the performances of the two SRD groups.

Test materials.

These were exactly the same materials as for the corresponding discrimination tests described above for the main test battery.

Test preparation.

As described above.

Test procedure.

As described above.
Results.

Comprehensive data on the experimental group for various tests are provided in certain tables below to enable direct reference and facilitate comparisons. The individual scores for the further group of SRD children on the standardised tests of reading accuracy and comprehension and non-verbal intelligence are given below in Table 33. This shows that, in fact, the means for the RA group on reading accuracy, reading comprehension and non-verbal intelligence are well matched with the corresponding means for this new group of SRD children. Also, the corresponding standard deviations are similar. By definition, however, the CA and RA control groups were not closely matched to this subsequent (unselected) SRD child sample. This should not be overlooked when considering the following statistical findings.

Non-verbal IQ (Ravens Progressive Matrices).

The non-verbal intelligence scores of the three subject groups were compared (as for the “selected” SRD group). A one-way analysis-of-variance (ANOVA) indicated that the main effect of group approached but did not reach significance \[ F(2,37) = 3.125, \ p = 0.056 \]. Tukey’s HSD and Duncan’s post hoc tests showed that the IQ estimate of this SRD group was reliably weaker than that of the CA control children but did not differ from that of the RA controls, whilst that of the control groups did not differ.

Neale Reading Accuracy.

A one-way ANOVA revealed a highly significant effect of reading accuracy by group on the Neale standardised test \[ F(2,37) = 33.677, \ p < 0.001 \] and also of Neale reading comprehension \[ F(2,37) = 17.120, \ p < 0.001 \]. Tukey’s HSD and Duncan’s post hoc tests agreed that the SRD children’s accuracy and comprehension scores were reliably lower than that of the CA controls but did not differ from that of the RA controls.
Reading list tests.

For comparison, the data on the reading accuracy of the three item-lists for the unselected group of 16 SRD children was analysed in the same way. A one-way ANOVA showed that there was a reliable effect of subject group for regular word reading \([F(2,37) = 10.974, p < 0.001]\), with post hoc tests revealing that the SRD children were weaker than either control group. The performance of the two control groups did not differ. A similar test of irregular word reading indicated that there was a highly reliable effect of subject group \([F(2,37) = 12.414, p < 0.001]\). Again, post hoc tests revealed that the performance of the SRD children was weaker than that of either control group. Tukey’s post hoc test indicated that the performance of the control groups did not differ, whilst Duncan’s test estimated that that of the RA controls was reliably weaker than that of the CA controls. A one-way ANOVA showed that there was a highly significant effect of subject group for nonword reading \([F(2,37) = 20.381, p < 0.001]\). Both Tukey’s and Duncan’s post hoc tests indicated that the SRD group performance was weakest, and that that of the RA controls was reliably weaker than that of the CA controls.

The data in Table 34 provides individual error-rates (%) for the second (unselected) group of SRD children on the reading-list tests, including mean reading rates as the number of seconds per word, the VCV-discrimination test and the two cluster discrimination tests. There was no consistent pattern of performance-heterogeneity in the reading accuracy or reading rate data across the three reading lists. Relative slowness in selecting a pronunciation therefore does not appear causally related for this SRD group (as it also was not for the original SRD group) to the simultaneous presence, in certain individuals, of speech-discrimination difficulties. Irregular word reading involves the mastery of orthographic (exception) rules (Frith, 1985). Nonword reading involves the ability to generalise regular letter-sound correspondences and orthographic structures in lexical material to those of non-
TABLE 33. Data calculated in respect of standardised tests for 16 unselected (U) SRD subjects, whose chronological age (Ch.A) is listed. Both Neale scores given as an equivalent reading age (years; months), that of Ravens' Progressive Matrices is given as a percentile. The delay given (in months) refers to Neale accuracy.

<table>
<thead>
<tr>
<th>Sub.</th>
<th>Ch.A</th>
<th>Neale (A)</th>
<th>Delay</th>
<th>Neale (C)</th>
<th>RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>13;8</td>
<td>8;4</td>
<td>52</td>
<td>9;5</td>
<td>28</td>
</tr>
<tr>
<td>U2</td>
<td>13;5</td>
<td>8;10</td>
<td>55</td>
<td>12;3</td>
<td>20</td>
</tr>
<tr>
<td>U3</td>
<td>12;8</td>
<td>6;7</td>
<td>73</td>
<td>7;5</td>
<td>82</td>
</tr>
<tr>
<td>U4</td>
<td>11;7</td>
<td>7;9</td>
<td>46</td>
<td>10;2</td>
<td>95</td>
</tr>
<tr>
<td>U5</td>
<td>11;11</td>
<td>8;7</td>
<td>40</td>
<td>12;3</td>
<td>71</td>
</tr>
<tr>
<td>U6</td>
<td>9;5</td>
<td>8;2</td>
<td>15</td>
<td>10;6</td>
<td>87</td>
</tr>
<tr>
<td>U7</td>
<td>11;9</td>
<td>7;11</td>
<td>46</td>
<td>10;2</td>
<td>71</td>
</tr>
<tr>
<td>U8</td>
<td>10;2</td>
<td>6;9</td>
<td>41</td>
<td>8;11</td>
<td>95</td>
</tr>
<tr>
<td>U9</td>
<td>9;6</td>
<td>7;11</td>
<td>19</td>
<td>11;1</td>
<td>91</td>
</tr>
<tr>
<td>U10</td>
<td>8;7</td>
<td>6;11</td>
<td>20</td>
<td>8;11</td>
<td>79</td>
</tr>
<tr>
<td>U11</td>
<td>11;2</td>
<td>7;5</td>
<td>45</td>
<td>9;2</td>
<td>60</td>
</tr>
<tr>
<td>U12</td>
<td>11;5</td>
<td>8;1</td>
<td>40</td>
<td>9;2</td>
<td>54</td>
</tr>
<tr>
<td>U13</td>
<td>11;5</td>
<td>6;0</td>
<td>65</td>
<td>8;8</td>
<td>84</td>
</tr>
<tr>
<td>U14</td>
<td>10;9</td>
<td>7;4</td>
<td>41</td>
<td>9;11</td>
<td>83</td>
</tr>
<tr>
<td>U15</td>
<td>10;7</td>
<td>6;5</td>
<td>50</td>
<td>6;9</td>
<td>42</td>
</tr>
<tr>
<td>U16</td>
<td>13;10</td>
<td>11;8</td>
<td>26</td>
<td>12;10</td>
<td>65</td>
</tr>
<tr>
<td>Mn</td>
<td>11;4</td>
<td>7;9</td>
<td>42</td>
<td>9;10</td>
<td>69</td>
</tr>
<tr>
<td>S.D.</td>
<td>1;6</td>
<td>1;4</td>
<td>16</td>
<td>1;8</td>
<td>23</td>
</tr>
<tr>
<td>Mn. RA</td>
<td>8;2</td>
<td>8;1</td>
<td>-</td>
<td>9;5</td>
<td>75</td>
</tr>
<tr>
<td>S.D.</td>
<td>0;4</td>
<td>0;11</td>
<td>-</td>
<td>1;2</td>
<td>22</td>
</tr>
<tr>
<td>Mn. CA</td>
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<td>11;9</td>
<td>-</td>
<td>12;7</td>
<td>88</td>
</tr>
<tr>
<td>S.D.</td>
<td>0;8</td>
<td>1;7</td>
<td>-</td>
<td>1;5</td>
<td>9</td>
</tr>
</tbody>
</table>
TABLE 34. Individual error-scores (%) for the group of 16 (U) SRD-children and controls on the consonant cluster and intervocalic discrimination tests, and the reading list tests. Rate = seconds/item. C. Age=chronological age.

<table>
<thead>
<tr>
<th>SUB.</th>
<th>CC(S)</th>
<th>CC(O)</th>
<th>VCV</th>
<th>REG</th>
<th>rate</th>
<th>IRR</th>
<th>rate</th>
<th>NW</th>
<th>rate</th>
<th>C.Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>8.1*</td>
<td>8.1*</td>
<td>3.8*</td>
<td>0</td>
<td>0.75</td>
<td>10</td>
<td>1.18</td>
<td>35</td>
<td>1.43</td>
<td>13;8</td>
</tr>
<tr>
<td>U2</td>
<td>5.6*</td>
<td>1.9</td>
<td>0.8</td>
<td>5</td>
<td>1.17</td>
<td>15</td>
<td>1.44</td>
<td>65</td>
<td>1.81</td>
<td>13;5</td>
</tr>
<tr>
<td>U3</td>
<td>0.6</td>
<td>0.0</td>
<td>0.4</td>
<td>0</td>
<td>1.59</td>
<td>30</td>
<td>2.44</td>
<td>15</td>
<td>2.53</td>
<td>11;5</td>
</tr>
<tr>
<td>U4</td>
<td>0.6</td>
<td>0.6</td>
<td>5.4*</td>
<td>55</td>
<td>5.45</td>
<td>75</td>
<td>6.00</td>
<td>85</td>
<td>6.35</td>
<td>10;2</td>
</tr>
<tr>
<td>U5</td>
<td>0.0</td>
<td>1.2</td>
<td>0.4</td>
<td>55</td>
<td>15.95</td>
<td>85</td>
<td>11.15</td>
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<td>5.68</td>
<td>12;8</td>
</tr>
<tr>
<td>U6</td>
<td>0.0</td>
<td>0.0</td>
<td>0.4</td>
<td>15</td>
<td>2.25</td>
<td>30</td>
<td>2.45</td>
<td>60</td>
<td>5.50</td>
<td>11;7</td>
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<td>3.1</td>
<td>2.5</td>
<td>2.1</td>
<td>5</td>
<td>1.07</td>
<td>10</td>
<td>1.27</td>
<td>60</td>
<td>2.08</td>
<td>9;5</td>
</tr>
<tr>
<td>U8</td>
<td>0.6</td>
<td>0.0</td>
<td>1.2</td>
<td>20</td>
<td>6.20</td>
<td>35</td>
<td>7.90</td>
<td>70</td>
<td>9.20</td>
<td>9;6</td>
</tr>
<tr>
<td>U9</td>
<td>5.6*</td>
<td>4.4*</td>
<td>6.2*</td>
<td>5</td>
<td>1.00</td>
<td>10</td>
<td>1.10</td>
<td>20</td>
<td>2.10</td>
<td>13;10</td>
</tr>
<tr>
<td>U10</td>
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<td>0.0</td>
<td>0.8</td>
<td>5</td>
<td>1.40</td>
<td>20</td>
<td>1.25</td>
<td>85</td>
<td>1.80</td>
<td>11;9</td>
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<td>U11</td>
<td>0.0</td>
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<td>0.8</td>
<td>20</td>
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<td>60</td>
<td>4.65</td>
<td>40</td>
<td>2.47</td>
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<td>7.5*</td>
<td>4.0*</td>
<td>9.2*</td>
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<td>35</td>
<td>2.20</td>
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<td>5.70</td>
<td>85</td>
<td>11.00</td>
<td>10;7</td>
</tr>
<tr>
<td>U14</td>
<td>8.1*</td>
<td>8.8*</td>
<td>5.0*</td>
<td>55</td>
<td>16.88</td>
<td>80</td>
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<td>14.55</td>
<td>10;9</td>
</tr>
<tr>
<td>U15</td>
<td>0.6</td>
<td>0.6</td>
<td>2.5</td>
<td>45</td>
<td>18.00</td>
<td>70</td>
<td>43.75</td>
<td>75</td>
<td>10.86</td>
<td>11;2</td>
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<td>14.0*</td>
<td>26.0*</td>
<td>25.0*</td>
<td>75</td>
<td>17.20</td>
<td>90</td>
<td>16.65</td>
<td>85</td>
<td>13.05</td>
<td>11;5</td>
</tr>
<tr>
<td>Mn (U)</td>
<td>4.9</td>
<td>5.0</td>
<td>5.0</td>
<td>29</td>
<td>6.30</td>
<td>46</td>
<td>8.11</td>
<td>60</td>
<td>5.97</td>
<td>11;4</td>
</tr>
<tr>
<td>S.D.</td>
<td>6.6</td>
<td>7.8</td>
<td>6.7</td>
<td>26</td>
<td>6.65</td>
<td>31</td>
<td>11.16</td>
<td>24</td>
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<td>1;6</td>
</tr>
<tr>
<td>Mn (S)</td>
<td>6.4</td>
<td>5.6</td>
<td>6.2</td>
<td>18</td>
<td>2.43</td>
<td>41</td>
<td>2.92</td>
<td>58</td>
<td>3.04</td>
<td>10;4</td>
</tr>
<tr>
<td>S.D.</td>
<td>8.3</td>
<td>10.1</td>
<td>9.1</td>
<td>14</td>
<td>1.28</td>
<td>21</td>
<td>1.29</td>
<td>20</td>
<td>1.11</td>
<td>0;8</td>
</tr>
<tr>
<td>Mn RA</td>
<td>2.0</td>
<td>1.0</td>
<td>1.8</td>
<td>8</td>
<td>1.85</td>
<td>25</td>
<td>2.47</td>
<td>33</td>
<td>3.33</td>
<td>8;2</td>
</tr>
<tr>
<td>S.D.</td>
<td>3.0</td>
<td>2.0</td>
<td>1.5</td>
<td>11</td>
<td>1.06</td>
<td>17</td>
<td>1.78</td>
<td>21</td>
<td>1.93</td>
<td>0;4</td>
</tr>
<tr>
<td>Mn CA</td>
<td>0.8</td>
<td>0.5</td>
<td>1.9</td>
<td>1</td>
<td>1.06</td>
<td>8</td>
<td>1.26</td>
<td>11</td>
<td>1.70</td>
<td>10;1</td>
</tr>
<tr>
<td>S.D.</td>
<td>1.0</td>
<td>0.6</td>
<td>1.6</td>
<td>2</td>
<td>0.36</td>
<td>5</td>
<td>0.63</td>
<td>13</td>
<td>0.92</td>
<td>0;8</td>
</tr>
</tbody>
</table>

lexical items. The weaker performance of RA than CA controls on both of these word-list types suggests that normal developmental increments in those skills occur only gradually, compared to those for familiar, regular words.
VCV-discrimination.

A two-way ANOVA was carried out and revealed a non-significant effect of listener group \([F(2,37) = 2.446, p = 0.101]\). However, the effect of minimal pair was significant \([F(14,518) = 7.540, p < 0.001]\). The listener group x pair interaction was not significant \((p = 0.652)\), suggesting that the effect of pair was confined strictly to the performance of the SRD listeners.

Consonant-cluster substitution.

A two-way ANOVA indicated a significant effect of listener group \([F(2,37) = 3.577, p = 0.038]\) together with a significant effect of pair \([F(7,259) = 3.404, p = 0.002]\). The listener group x pair interaction was not significant \((p = 0.962)\), again suggesting that the SRD group alone showed variation in the accuracy with which they could discriminate particular pairings.

Consonant-cluster omission.

A two-way ANOVA was carried out on this data, which showed a significant main effect of listener group \([F(2,37) = 3.933, p = 0.028]\). Post hoc tests revealed that this was due to the SRD listeners’ performance being weaker than that of either of the two control groups, whose performance did not differ. There was no effect either of minimal pair \((p = 0.794)\) or of the group x pair interaction \((p = 0.334)\).

Medical- and educational-history questionnaire.

The same questionnaire was completed for these children as had been originally used, and the collated data is summarised in Table 35 below.
TABLE 35. Summary of findings from the medical-educational history questionnaire for members of the unselected (U) SRD group. As before, the necessary information was gathered from class and head teachers, medical reports, parents and the children themselves.

EXPERIMENTAL GROUP (n=16).

<table>
<thead>
<tr>
<th>Category</th>
<th>#</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number considered with normal pure-tone thresholds:</td>
<td>16</td>
<td>100</td>
</tr>
<tr>
<td>Number considered with normal tympanometry:</td>
<td>14</td>
<td>88</td>
</tr>
<tr>
<td>Number having a history of otitis media:</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>Of those with OM, number with discharge:</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Number having worn grommets for any reason:</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>Number still wearing grommets:</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Number with history of hearing loss:</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

Other clinical information:

- i). number with history of asthma:                           | 4   | 25  |
- ii). number with poor "fine" motor-control:                 | 0   | -   |
- iii). number having had speech therapy:                     | 2   | 12  |
- iv). history of severe and/or recurrent earaches:           | 2   | 12  |
- v). number having suffered from tinnitus:                   | 0   | -   |
- vi). number considered to have poor STM:                    | 0   | -   |

Number having had remediation on school premises:             | 14  | 88  |

What areas/methods used?

- Phonics, spelling tests, spelling practice, precis, vocabulary, reading, comprehension and writing practice.
- Most typical:- phonics, spelling, reading.

What is total length of weekly sessions (hours)? *

- (0.5):- 2, (1):- 8, (1.5):- 1, (2):- 1, (2.5):- 1, (5.5):- 1.

How long receiving such training (years.)? *


Number reporting instances of familial dyslexia: 8 (50 %).

* Two children in this group had received no remedial training.
Evidence for the presence of a further "perceptually-weak" SRD sub-group.

Applying the criterion of error-scores at least one standard deviation higher than the mean of the equivalent RA control group score to the individual data in each of the discrimination tests listed in Table 34 above revealed heterogeneity in the new SRD group. The consistency of this group-variance is illustrated in Table 36. From this it is clear that six subjects are performing below "norm" on all three tasks, namely: U1, U9, U12, U13, U14 and U16. As all six of these SRD-subjects performed substantially more than one standard deviation below the RA-mean on each of these three measures, it is proposed that they form a second "PW" (perceptually weak) sub-group which will be designated "PW2". They comprise 37% of the SRD-group. The remaining 10 subjects, for whom most error-rates were below 3% on any test, have essentially no speech-perceptual problems, as far as these tests were concerned. Therefore, subjects U2, U3, U4, U5, U6, U7, U8, U10, U11 and U15 will be regarded as "normally-perceiving" SRD children, and assigned to the "NP2" sub-group.

TABLE 36. Identification, by reference-code, from within the unselected (U) group of SRD subjects of those individuals whose performance on the named tasks was below criterion. The abbreviations VCV, CC(S) and CC(O) refer to intervocalic discrimination, discrimination of consonant-cluster substitution and consonant-cluster omission respectively.

<table>
<thead>
<tr>
<th>TEST</th>
<th>SUBJECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCV:</td>
<td>U1, U4, U9, U12, U13, U14, U16.</td>
</tr>
<tr>
<td>CC (S):</td>
<td>U1, U2, U9, U12, U13, U14, U16.</td>
</tr>
<tr>
<td>CC (O):</td>
<td>U1, U9, U12, U13, U14, U16.</td>
</tr>
</tbody>
</table>
The pattern of this performance-heterogeneity did not apply to the reading-accuracy or the reading-rate data for the three item lists. Three children from this SRD sub-group did, however, show both speech-perceptual weakness and slowness (at least 1 s.d. below RA-mean) in reading the regular, irregular and nonword item-lists (U13, U14 and U16). Equally, the other three children in the "PW2" sub-group (U1, U9 and U12) performed comfortably within reading-rate norms. Oral reading that is inaccurate and slow might relate more consistently to selection and sequencing problems at the level of segmental phonology.

3.16. Re-analysis of Data in respect of the Proposed "PW2" and "NP2" Sub-groups of SRD Children.

To reiterate, the subjects comprising the proposed "PW2" sub-group are: U1, U9, U12, U13, U14 and U16. The remaining ten SRD-children thus comprise the "NP2" sub-group. In order to determine, retrospectively, whether the children with speech-perceptual problems had also performed more weakly on the Neale Analysis of Reading (accuracy and comprehension) than the normally perceiving remainder of the "unselected" SRD group, a calculation was made of the mean error-scores and standard deviations of the relevant scores. Comparison was also made of their reading delays (accuracy) and non-verbal IQ scores. These are presented in Table 37.

For none of these four measures did the SRD children who were later assigned to the "PW2" sub-group obviously differ, with respect to the mean values, from the normally perceiving ("NP2") remainder of the group. The error-data presented in Table 38 (below) for the three speech-based tests is partitioned according to the proposed sub-grouping, and shows clearly that a large proportion of the listener-group variance in each case is accounted for by the performance of the six "PW2" children.
TABLE 37. Comparison of the means and standard deviations (in parentheses) for the proposed “PW2” and “NP2” sub-groups of SRD children on their Neale (accuracy), Neale (comprehension) age-equivalents, reading-delay (accuracy) in months, and RPM percentile scores.

<table>
<thead>
<tr>
<th>SUB-GROUP</th>
<th>&quot;PW2&quot;</th>
<th>&quot;NP2&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neale (acc.) Mean</td>
<td>8;3 (1;11)</td>
<td>7;6 (0;10)</td>
</tr>
<tr>
<td>Neale (comp.) Mean</td>
<td>10;2 (1;6)</td>
<td>9;8 (1;9)</td>
</tr>
<tr>
<td>Delay (acc.) Mean</td>
<td>42.5 (19.0)</td>
<td>43.1 (16.5)</td>
</tr>
<tr>
<td>RPM Mean</td>
<td>67.5 (23.7)</td>
<td>70.2 (23.9)</td>
</tr>
</tbody>
</table>

TABLE 38. Comparison of the means and standard deviations of the error-scores (%) for the VCV discrimination test and the consonant-cluster discrimination tests for the proposed "PW2" and "NP2" sub-groups, and for the reading-age control group.

<table>
<thead>
<tr>
<th>SUB-GROUP / GROUP</th>
<th>&quot;PW2&quot;</th>
<th>&quot;NP2&quot;</th>
<th>RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEST</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VCV disc. Mean</td>
<td>10.8</td>
<td>1.5</td>
<td>1.8</td>
</tr>
<tr>
<td>S.D.</td>
<td>8.1</td>
<td>1.6</td>
<td>1.5</td>
</tr>
<tr>
<td>CC(S) disc. Mean</td>
<td>11.2</td>
<td>1.1</td>
<td>2.0</td>
</tr>
<tr>
<td>S.D.</td>
<td>6.9</td>
<td>1.8</td>
<td>3.0</td>
</tr>
<tr>
<td>CC(O) disc. Mean</td>
<td>12.0</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>S.D.</td>
<td>9.2</td>
<td>0.9</td>
<td>2.0</td>
</tr>
</tbody>
</table>

3.17. Summary.

A second "group-study" of SRD children using three of the speech-discrimination experiments previously employed in the main test-battery and in precisely the same manner, has replicated the finding of marked heterogeneity. A larger sub-group of ten children performed as accurately as reading- and chronological-age controls on these tasks, whilst another six showed consistent discrimination difficulties with error-rates often several standard deviations above the criterion-value. From the main test-battery data, there is evidence for partitioning the SRD-children into "PW"
and "NP" sub-groups in respect of:

i). nonword reading accuracy,
ii). VCV discrimination,
iii). discrimination of consonant-cluster substitutions, and

This is to say that they differ in respect of speech perceptual acuity and awareness of segmental phonology. However, the main effect of subject-group of the analysis of nonword repetition errors in the main test battery was not dependent on the performance of the four "PW" children alone but of the entire SRD-group. The storage and assembly of novel syllables for repetition is essentially another type of sequencing task, with which developmental dyslexics and language-impaired children have shown difficulties (Farmer and Klein, 1995).

In analysing the error-corpus for the “selected” and “unselected” SRD groups, and controls, on the VCV-discrimination test, a considerable proportion of voicing errors was noted. Errors also appeared to be similarly distributed across pairings differing in manner-of-articulation. These were of particular interest because much emphasis has been placed on the importance of place-of-articulation contrasts in generating discrimination errors in SRD children (e.g. Godfrey et al., 1980; Hurford and Sanders, 1990; Lieberman et al., 1985; Reed, 1989; Tallal, 1980; Watson and Miller, 1993 and Werker and Tees, 1987. However, some variety was provided by the demonstration of weaker discrimination of synthetic /pA/-/tA/ tokens by 1st grade SRD children than by CA controls by De Weirdt (1988), in that this concerned place-of-articulation discrimination for a voiceless rather than voiced stop pair.

The misidentification of certain consonants (such as /p/, /ð/ and /b/) along the voicing dimension had been noted by Masterson et al. (1995), but systematic testing of voice discrimination across several types of contrast would be necessary to provide a true estimate of the relative frequency of voicing errors. This dissertation
TABLE 39. The percentage of errors calculated across all 9 “place-of-articulation” and 5 “voicing” contrasts in the VCV discrimination test for the (S) selected (n = 13) and (U) unselected (n = 16) SRD groups, the RA-matched (n = 12) and CA (n = 12) control groups. The percentages of “miss” and “false positive” errors for contrasts differing in a single (phonetic) feature are also given. The errors relating to the /s/-/s/ (comparison) contrast were very infrequent and not included in these calculations.

<table>
<thead>
<tr>
<th>Group</th>
<th>Place</th>
<th>Voice</th>
<th>Miss</th>
<th>False Positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXP (S)</td>
<td>6.3</td>
<td>6.3</td>
<td>6.0</td>
<td>6.6</td>
</tr>
<tr>
<td>EXP (U)</td>
<td>5.1</td>
<td>5.9</td>
<td>6.2</td>
<td>4.5</td>
</tr>
<tr>
<td>RA</td>
<td>1.9</td>
<td>2.0</td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>CA</td>
<td>2.0</td>
<td>2.1</td>
<td>1.8</td>
<td>2.3</td>
</tr>
</tbody>
</table>

attempted such testing, and the data is summarised below in Table 39. The rate of voicing error for VCV discrimination, using the vowel /a/, was very similar to that of place errors for all groups. Data is also given in Table 39 on the proportion of “misses” and “false-positives” in single-feature contrasts. There is no evidence of a bias in either direction of the types of error on this particular discrimination test, for any listener-group. The apparent tendency for subject groups to frequently report a physically identical pair as “different” is of interest. It should not be assumed that perceptual errors concern only the failure to adequately process stimulus differences on a proportion of “different” trials (see Godfrey et al., 1981 for discussion of this point).

The reading-list data in Table 34 showed that the majority of (U) SRD subjects were extremely weak at word finding and had many phonological problems. Only three of these sixteen subjects made 35 % errors or less on nonword reading, the mean rate being 60 %. The criterion of 30 percentage points difference between individual reading-error rates concerning the irregular and nonword lists was used in order to define “phonological” and “surface” dyslexic patterns.

The relationship between cases of speech-perceptual weakness in the unselected (U) SRD group and the incidence of a reading-pattern consistent with “developmental phonological dyslexia” did not appear to be consistent. Two of the six “PW2”
children (U1 and U12) presented patterns consistent with developmental phonological dyslexia, whilst the pattern for three others was indeterminate (two of these had very weak reading skills). One other child (listener U14) provided an apparent "counter-example", his irregular word reading being less accurate than that of nonwords. He thus presented the morphemic pattern whilst showing relative speech perceptual weakness. Of the ten children in the "NP2" sub-group, five produced the error-pattern associated with "phonological" dyslexia but none had problems with speech perception.

Clearly, therefore, a simple (invariant) relationship between speech-perceptual acuity and the ability to decode unfamiliar items of "regular" orthography appears, in practice, to be inappropriate. Speech-perceptual difficulties are not a common characteristic of SRD children; many children's reading difficulties seem to arise despite normal speech-perceptual development. Demonstrable cases of speech-perceptual weakness, as measured in the pilot and main-phase experiments in this dissertation, are coincident with reading disability. Therefore, it seems possible that speech-perceptual difficulties and other problems concerning awareness of segmental phonology (in relation to a range of phoneme-grapheme correspondence rules) can act independently to impair the development of decoding skills for regular or irregular items. It is also possible that a given SRD child has significant problems with both such aspects of phonological awareness. Marked individual differences within an SRD group may then arise as a result of variability in the severity of problems in these areas.

3.18. Evidence of a Relationship between Type of Reading Impairment and Speech-Perceptual Weakness from Reading Performance.

What can be said is that the data on the incidence of reading-error type in "PW" children over two SRD groups suggests that such weakness is to some degree coincident with the evidence for developmental phonological dyslexia. Equally, it is possible to argue that these phenomena could be due to factors that are merely co-occurring, with no underlying causal relationship or trend. The small and unequal
numbers of children in the “PW” and “NP” sub-groups of both SRD groups make the application of formal statistical treatments problematic. However, it is possible to determine whether or not there is a trend in the data that could indicate a relationship between speech perceptual problems and reading error patterns. The proportion of nonword reading errors for the SRD sub-groups of both experimental groups which relate to singleton consonant or consonant cluster decoding, and those made by the younger control children, are calculated. Indications of a trend of proportionally more errors on single consonants in speech-perceptually weak children would strengthen the argument for such a relationship being not only lawful but having some causal basis.

Accordingly, an analysis was made of the reading errors concerning only consonants in the nonword reading test. Errors which involved consonant transposition, or the addition/deletion of single consonants or of consonant clusters were strictly excluded. There were twenty monosyllabic items in the list, each of CVC, CVCC or CCVC structure, therefore a total of 40 consonant “positions” or targets per subject were identified. Error rates were calculated on this basis, which comprised instances of consonant substitution, cluster reduction or cluster formation from a single consonant. The performance of the “PW” sub-group from the selected SRD children is compared to that of the corresponding “NP” sub-group and that of RA controls. Similarly, Table 40 below also gives the error rates for both the “PW2” and “NP2” sub-groups of the unselected SRD children. The total number of nonword reading errors is shown, together with the proportion of errors made concerning singleton consonants and consonant clusters (without reference to position within an item).

Several consistencies are evident in the above data. The speech-perceptually “weak” SRD children, from both the selected (S) and unselected (U) samples, showed very similar error rates. These listeners were equally likely, from this limited stimulus sample, to make errors on single consonants or consonant clusters. The normally perceiving children in either SRD group made fewer errors than children in their corresponding “PW” sub-groups, but at similar rates to each other. Also, they both showed a tendency
TABLE 40. Error-rates (%) on consonant decoding of (monosyllabic) nonword items, and the proportion of total errors (%) made concerning singleton (Prop. C) and consonant cluster (Prop. CC) positions. N = number of listeners in group/sub-group, # = total number of reading errors relating to consonants made by each group/sub-group.

<table>
<thead>
<tr>
<th>GROUP / SUB-GROUP</th>
<th>N</th>
<th>#</th>
<th>% errors</th>
<th>Prop. C</th>
<th>Prop. CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>(S) &quot;PW&quot;</td>
<td>4</td>
<td>26</td>
<td>16.2</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>(S) &quot;NP&quot;</td>
<td>9</td>
<td>35</td>
<td>9.7</td>
<td>31</td>
<td>69</td>
</tr>
<tr>
<td>(U) &quot;PW2&quot;</td>
<td>6</td>
<td>40</td>
<td>16.7</td>
<td>47</td>
<td>53</td>
</tr>
<tr>
<td>(U) &quot;NP2&quot;</td>
<td>10</td>
<td>43</td>
<td>10.8</td>
<td>26</td>
<td>74</td>
</tr>
<tr>
<td>RA control</td>
<td>12</td>
<td>28</td>
<td>5.8</td>
<td>21</td>
<td>79</td>
</tr>
</tbody>
</table>

to make proportionally more errors on decoding consonant clusters than singleton consonants; this finding concurs with normal spelling-error trends. The younger (RA) control children also made a majority of consonant reading errors on consonant clusters, in a similar proportion to the “NP” sub-groups, but made a smaller number of errors overall than did any SRD sub-group.

The greater proportion of errors suggested for the “PW” and “PW2” children for singleton consonant decoding is direct evidence that these listeners have greater problems with simple (regular) decoding rules, especially since their overall error rates were higher. The idea of a directional relationship between speech perceptual weakness, “developmental phonological dyslexia” and the proportion of errors concerning simpler grapheme-phoneme correspondence rules is supported by this trend.

The strength of the relationship between reading measures and speech discrimination tests was estimated by the use of multiple correlation, pooling across all listeners irrespective of reading status. Sample variations in the chronological age and non-verbal IQ of listeners were necessarily controlled-for. If the proportion of errors in dealing with simpler grapheme-phoneme correspondence rules is strongly associated with the proportion of errors on particular speech discrimination tests, then high correlation coefficients would be
associated with error scores for regular and nonword reading. The test was therefore directional, and was carried out on data which had previously been arc-sine transformed. With planned comparisons, the alpha criterion was set to \(0.05 / 9 = 0.0056\). The results for the distribution of regular word, and to a lesser extent for nonword error rates, did show significant correlations with the distributions of the three speech discrimination error scores. The VCV-nonword reading correlation value fell just outside the significance level set. The results are summarised below in Table 41.

<table>
<thead>
<tr>
<th>TEST</th>
<th>CC (SUB).</th>
<th>CC (OMIT).</th>
<th>VCV</th>
</tr>
</thead>
<tbody>
<tr>
<td>REGWD</td>
<td>0.3681</td>
<td>0.3782</td>
<td>0.3644</td>
</tr>
<tr>
<td></td>
<td>p = 0.004*</td>
<td>p = 0.003*</td>
<td>p = 0.004*</td>
</tr>
<tr>
<td>IRREGWD</td>
<td>0.2277</td>
<td>0.3182</td>
<td>0.1820</td>
</tr>
<tr>
<td></td>
<td>p = 0.054</td>
<td>p = 0.011</td>
<td>p = 0.101</td>
</tr>
<tr>
<td>NONWD</td>
<td>0.3969</td>
<td>0.3192</td>
<td>0.3461</td>
</tr>
<tr>
<td></td>
<td>p = 0.002*</td>
<td>p = 0.011</td>
<td>p = 0.006</td>
</tr>
</tbody>
</table>

The case for a relationship between speech perceptual weakness (A) and poor knowledge of simpler letter-sound correspondence rules (B) is evident, but no statements about causation between A and B are possible. The possibility of a third factor (C) operating to give rise to both A and B is acknowledged.
CHAPTER 4.

DISCUSSION OF RESULTS, A HYPOTHESIS OF SPEECH DISCRIMINATION DEFICITS, AND FURTHER RESEARCH.

4.1. Brief Summary of Results.

The essential purposes of the main phase of this study were: 1) to attempt to obtain detailed profiles of the perceptual abilities of individual SRD children and 2) to compare these with similar profiles for both same-age and reading-age control children. Each listener was widely tested on his/her ability to process speech sounds of varying complexity, and further data was gathered on error patterns in a set of reading tests, on the repetition of non-words and on a set of four psychoacoustic tests.1 For three speech-discrimination tests (involving inter-vocalic consonants, consonant cluster substitution and consonant-cluster omission) performance profiles were also obtained for a second group of (U) SRD children who had not been selected by applying exclusionary criteria.

In doing this, a clear picture has emerged: a sub-group of four SRD children (representing 30% of the selected (S) SRD group) showed a weakness in speech discrimination which extended to a range of phonological contrasts, and which was consistent over tests which used either real words or nonsense-syllable items. Similar evidence of comparative perceptual weakness also applied to a second sub-group of six SRD children (representing 37% of the unselected (U) SRD group).2 The term “perceptual weakness” (PW) is used because the rates of discrimination error for these children are relatively low in the context of two-alternative forced-choice (2AFC) tasks. However, they differed consistently and quite markedly from

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1 The results of the main phase of this study have recently been published (Adlard and Hazan, 1998).

2 All four children in the “PW” sub-group of selected SRD children were girls, and all were right-handed for writing. Five of the six children in the “PW” sub-group of unselected SRD children were boys, and only the girl was left-handed for writing.
those of both reading- and chronological age controls. These problems occurred despite the stimulus pairs being presented in clear and with inter-stimulus intervals long enough to minimise the "time-pressure" of the task. The working hypothesis is proposed that the phonological deficit of "PW" SRD children centres on the analysis of sequences of phones. The internal phonological complexity of such sequences can vary substantially, and phonological complexity is also understood to vary with the position of such units within longer words (and nonwords). The fine-grained analysis of these units will determine the robustness and reliability of a listener's acquisition (segmentation) of their discrete phonetic contents. It is understood that the extent of the fine-grained auditory analysis of phonological units normally increments throughout childhood and is substantially complete, though not necessarily for each individual, by the age of about 12 years (see Hazan and Barrett, 1998).

Crucially, this "segmentation" process is not viewed as indicating a concentration of processing effort onto discrete phonetic segments using a narrow temporal window, but as reflecting the listener's gradually increasing ability to respond to and organise a variety of fine-grained acoustic cues within the original temporal window. Children who are less able than younger, reading-age matched, controls to discriminate minimal pairs even of low acoustic-phonetic complexity and high salience appear to show a developmental phonological deficit (see with reference to the work of, for example, Elbro, 1996 and Jusczyk, 1992). The process of normally-increasing segmentation skills with chronological age (Fowler, 1991) reflects the gradual development of complex perceptual functions in respect of continuous speech. It therefore reflects the ability to utilise and integrate these various analytical skills in an extremely efficient way.

An important point to note is that the remainder of the children comprising either the selected SRD group (70% of the total) or the unselected SRD group (63% of the total) performed within reading-age norms on the same speech discrimination tests. If these samples are representative of the specifically reading-disabled child
population as a whole, the suggestion is that problems with speech discrimination are only relevant to a minority of them. Problems in developing reading skills for the normally-perceiving remainder of the SRD children are likely to be due to factors concerning the selection and assembly, from an adequate internal "store", of items relevant to segmental phonology at the output stage of decoding. They could also be related to other problems, such as visual perceptual acuity or the short-term retention of multi-item sequences. Although they may also have been appropriate to the language-difficulties of the "PW" SRD children, factors of this type were not investigated here.

4.2. Addressing the Research Questions.

The first research question asked whether significant numbers of errors on perceptual tasks would be made by any subject listening to natural speech tokens. Many, but not all, of the findings of speech perceptual experiments quoted in Chapter 1 concerned the labelling and/or discrimination of synthetic speech tokens. In quiet, it was possible to show, in the first pilot test, that SRD children were less accurate than controls at discriminating a small range of phonemic contrasts in initial position for real word items, but that this was only the case amongst certain pairs which shared two phonemic features. In the main test-phase, a particular sub-group of SRD children were weaker at the discrimination of naturally produced inter-vocalic consonants (nonsense bi-syllables) and the discrimination of consonant cluster "onsets" in monosyllabic real-word pairs. For all listener-groups, there was an effect of pairs in natural minimal-pair discrimination where the vowel context was varied but, again, all items were familiar monosyllabic real words.

Errors were also found when listening to natural speech items in order to perform other types of task. The SRD group was less accurate than controls in repeating single real words in pilot testing, whilst they and the RA-controls were less accurate than CA-controls in repeating monosyllabic nonwords. For the main phase
test of nonword repetition, the SRD children were less accurate in repeating naturally-produced items which were either 4 or 5 syllables in length than were either control group. The task of initial-phoneme deletion in pilot testing also involved natural tokens and for this there was a strong effect of subject-group. The wide range of contrast-types in the various discrimination experiments ensured that there is ample evidence that SRD children are not always able to process efficiently speech items which have a multiplicity of acoustic-phonetic cues (i.e. exhibit cue-redundancy), even under ideal listening conditions.

The second question asked whether some classes of phoneme are less well discriminated? The groupwise data on the VCV test suggested that, whilst the SRD children produced higher error-rates on stop, fricative, nasal and approximant contrasts alike, the only reliable effect concerned stop consonants. Would there be evidence, also, of weaker phonetic discrimination between groups when the vowel environment was held constant than when, for the same single consonant contrasts, certain alternative following-vowel identities were found? There was a significant effect of listener group for the consonant cluster (substitution) test which contrasted, amongst others, a stop consonant with the lateral /l/, nasals with nasals and stops with nasals in second consonant position. Some support exists, therefore, for the proposal that different classes of phoneme can be confused when embedded within an initial consonant cluster where the absolute initial consonant is a fricative, and when singleton consonant contrasts are created using a constant vowel environment.

The third research question asked whether all, or only some, SRD children showed speech-perceptual weaknesses. There were no subject-group differences on the labelling consistency of children on four of the five conditions of DATE-GATE and SUE-SHOE continua. However, there appeared to be consistent evidence, using a performance-difference criterion, for perceptual weakness for four of the thirteen “selected” and six of the sixteen “unselected” SRD children on the VCV-discrimination test and the two consonant-cluster discrimination tests.
Many of these 29 experimental children performed well within reading-age control norms. Performance-consistency involving the same individuals within each of two different SRD groups is strong evidence that the greater the size of a reading-disabled experimental group the more likely it is to be heterogeneous as regards speech-perceptual skills. Although, in their review, Farmer and Klein (1995) had noted that some speech perceptual results revealed heterogeneity within the SRD group, this study is the first to demonstrate the consistency of this heterogeneity across a number of discrimination tests. The extent to which the classification of "phonologically" dyslexic sub-type could be applied to the sub-group of 4 “PW” SRD children and that of "surface" dyslexic sub-type to the perceptually “normal” sub-group of SRD children was unclear. Problems with developing clear criteria to support the argument for such a differentiation of SRD listeners, and to define each of these sub-types in a more rigorous and comprehensive fashion, have persisted. However, a convergence of experimental evidence to underpin the argument in favour of this sub-typing of SRD groups has recently been put forward by Stanovich, Siegel and Gottardo (1997).

The fourth research question asked whether SRD children would show weakness on non-verbal tasks. It had been suggested by Reed that a group of SRD children were less efficient in discriminating pairs of complex tones than were same-age controls (Reed, 1989). There was no evidence in this study that SRD children were weaker in the discrimination of stylised formant frequencies, formant frequency modulation or fundamental pitch, nor were they weaker than controls in detecting the presence of a silent gap between noise bursts, for any gap duration. These psycho-acoustic tests used a constant inter-stimulus interval (ISI) of 500 ms which may have been too long to reveal listener-group differences which have been proposed elsewhere to be related to short ISI’s of about 50 ms or less (e.g. Tallal, 1980). Also, this was a screening battery, so the discriminable steps, though equal, were quite large.

It should be pointed out that the typical ISI used here for the speech discrimination
tests in both pilot- and main-test phases was of the order of one second, so that the confusion effects found were not dependent on the operation of "short" intervals. Therefore the pattern of results seemed to relate strongly to factors intrinsic to the stimuli themselves, rather than to sensitivity to the stimulus intervals. Effects of brief ISI's could be regarded as separable from intrinsic stimulus factors for both speech and non-speech items.

4.3. Outcome of Stated Aims, and some Cross-Correlations with other Studies.

4.3.1. Pilot test-phase.

a). The first aim of pilot testing was to establish whether or not it was necessary to present only speech-discrimination stimuli where a single target consonant phoneme differed in a particular number of features (from manner-of-articulation, voice and place-of-articulation). The use of three groups of real-word stimulus-pairs in the minimal pairs test suggested that errors were made only within those contrasts which shared two, and therefore differed in just one, of these features. In particular, errors for one plosive and one fricative contrast were found, suggesting that prominent formant frequency transition cues were not a necessary aspect of stimulus confusion. The listener-group effect was significant, and informed the selection of nonsense bi-syllabic (inter-vocalic) pairings in the main phase of testing.

b). The next aim was to show whether the use of real-word stimuli could yield reliable speech-perceptual differences, or whether the unfamiliarity of nonsense material would be necessary to achieve this. The discrimination of monosyllabic real-word minimal-pairs was effective in the first pilot test, as was the use of single words in the monosyllabic word-repetition test: the performance of the SRD children was less accurate than that of controls. The initial-phoneme deletion task
used familiar monosyllabic words and produced, as noted above, a highly significant listener-group effect where SRD children were much less accurate even than RA controls. The familiarity of items at the lexical level may not consistently alleviate the problem, where it might arise for SRD children, of confusion at the sub-lexical (segmental) level.

The types of errors made in word repetition included substitution of the item-initial consonant by another consonant, substitution of a 2-consonant cluster for a singleton consonant in initial position, and reduction of item-final 2-consonant clusters to singleton consonants. These error-responses could contain confusions of perception as well as production difficulties. The findings could not be related to speech discrimination errors because of the several differences between the tasks.

c). The deletion of an initial (singleton) consonant from monosyllabic words was found to be very significantly weaker in SRD children than for either group of controls. There was evidence also of a range of different types of deletion error, such as repetition of the stimulus item and substituting another initial consonant for the to-be-deleted consonant, although simple failure to respond occurred on about half of all trials for the SRD group.

4.3.2. Main test-battery phase.

a). Reading lists.

With respect to error-scores on these, were the type of reading-error pattern and the incidence of speech perceptual weakness linked? An attempt to use types of reading-pattern as a means of distinguishing SRD ("dyslexic") sub-types was made by Boder (1973). Using a fairly large subject pool of dyslexic and normally-reading children, Castles and Coltheart (1993) attempted to use confidence level
criteria in order to provide a statistical under-pinning for the proposal that subgroups producing identifiably different patterns do exist. Whilst many reading-impaired subjects did not show strong differences in their level of performance on reading irregular and nonword items, Castles and Coltheart did find two subgroups whose accuracy was dissociated in opposite directions. The working hypothesis which motivated this test battery was that developmental phonological dyslexics showing particular weakness with nonword reading would be most likely to show evidence of speech-perceptual difficulties, whilst no such difficulties would be associated with the surface-dyslexic pattern of weaker irregular word than nonword reading.

Here, the children in the "PW" sub-group performed similarly on the reading of regular and irregular words to the "NP" sub-group and both control groups. However, all children in the "PW" sub-group performed below RA norms on their reading of nonwords with the difference between the sub-groups being significant: $t(11) = 1.85, p < 0.05$.

The question arises of finding a reliable quantitative measure of within-subject performance-difference for estimating the incidence of phonological- and surface-dyslexic "patterns". Castles and Coltheart (1993) used a 95% confidence limit on the sets of scores generated by a group of 56 dyslexic and 56 control children. This approach could not be adopted here because of the necessarily much smaller size of the listener-groups. A quantitative criterion must be related to the equivalent mean error-scores for the RA control group, as the nonword reading ability of reading-age matched children is the crucial comparison.

For the experimental group as a whole the difference in mean error-scores between irregular word and nonword reading lists was about 18 percentage points, with standard deviations of about 20 (see Table 14). The equivalent scores for the RA controls differed by about 12 percentage points, with a standard deviation, again, of about 20 for each score (see Table 16). Therefore, a criterion of 30 percentage-
points difference would be a principled and substantial criterion, and one based on the statistics for relevant listener-groups. Thirty percentage-points difference is greater than the difference between the mean error-scores for these lists for either subject-group. It corresponds to 1.5 standard deviations of the mean error-rate of RA control children's nonword reading, and represents performance-differences which could be expected to be, for each individual, greater than any test-retest variability.

On this basis, two of the four "PW" children produced a phonologically dyslexic pattern (subjects E9 and E11). None of the remaining SRD children in the selected group, and none of the CA group, showed this degree of difference between irregular word and nonword reading list accuracy in either direction. Of the RA control children, two (R7 and R8) produced the "phonologically dyslexic" reading-pattern (essentially because both were particularly weak at nonword reading), but none produced the "surface-dyslexic" pattern.

For the unselected (U) SRD children, six children showed speech-perceptual weakness (Table 35). Of these six (U1, U9, U12, U13, U14, and U16) one met this criterion for a pattern of "phonological" dyslexia (U12), and one met this criterion for "surface" dyslexia (U14). Two members of this group (U13 and U16) had very weak reading abilities, emphasised by their low regular-word accuracy. Of the 10 "normally-perceiving" sub-group in the unselected SRD sample, five met this criterion for the "phonological" and one for the "surface" dyslexic pattern.

Clearly there is no necessary link between the pattern of reading difficulty (at least for these particular lists of items) and speech discrimination weakness. A single criterion of relative weakness in reading either the irregular word or the nonword list may be inadequate in trying to make such classifications. Many SRD children showed marked weakness in nonword reading (producing means of 58 % and 60 % errors for the selected and unselected groups respectively). The absence of such a link within this SRD group was due to (a) frequent poor knowledge of many of the
letter-sound associations for irregular orthography, combined with (b) frequent
poor generalisation of the simple (regular) letter-sound association rules to the
decoding of nonwords. In fact, on this evidence, reading success itself does not
seem to guarantee accuracy with nonword reading up to about 10 years of age.

For illustrative purposes, the mean errors made on each of the reading lists can be
compared for this study and that of Castles and Coltheart, even though their content
differed somewhat. The respective SRD groups made 18 and 32 % errors on
regular words, 41 and 62 % errors on irregular words, and 58 and 57 % errors on
the nonword items. The relatively weak performance of the SRD children in the
Castles and Coltheart study on both regular- and irregular-word reading is in line
with their higher mean (and range) of reading delay, but it is interesting that the
mean nonword-reading scores are very similar. The Masterson et al. (1995) study
yielded a 56 % mean error-rate for nonword reading by two SRD adults. Also, the
respective standard deviations about the mean scores were also similar in these
three studies. This comparability, despite using somewhat-different item-lists
(Castles and Coltheart used some multi-syllabic items), suggests that individual
SRD children (and adults) are similarly-weak on this task even for items of very
simple construction (typically CVC and CVCC).

Analysis of the type of errors made in nonword reading across SRD groups is
relevant, but important stimulus-differences must be noted. The nonword list used
by Masterson et al. contained several graphemes not used here, but which featured
prominently in the decoding errors of their adult subjects. In particular, “y” and “j”
were not used in initial position; neither were “th”, “ss” or “sh” used in final
position, since they can be represented by the single phonemes /θ/, /s/ and /ʃ/
respectively. This means that some of the errors which Masterson et al. listed
could not have occurred here, notably /z/ for /j/ and /f/ for /θ/.

Most of the nonword reading errors they listed for their two subjects involved the
simplification of medial vowels and final consonants. Here, the total of 29
children tested on the same list of items (of CVC, CVCC and CVCV construction) in two SRD groups also produced mostly vowel-simplification errors. In both cases, diphthongs were frequently realised as monophthongs. These subjects made similar numbers of errors for initial as for final consonants, but particular errors were more frequently present in respect of final consonants. For initial consonants they tended almost exclusively to confuse fricatives with other fricatives, but the (fewer) errors with stops and nasals frequently involved phonemes of different manners of production. The current study found, as was also evident from the error-data of the Masterson et al. study, that different single-consonant graphemes in initial position were read as consonant clusters (e.g. “f” = /fl/ or /fr/, “r” = /fr/, “t” = /fr/ or /tr/ and “m” = /bl/ or /pl/). There were several 2-consonant clusters in final position of items on the list used in this study, many of these being simplified by reduction to a single consonant. This reduction mirrored the errors of nonword repetition noted by SRD children in the pilot test, mostly concerning phonemes of low acoustic prominence in final position. Particularly frequent examples were “lm” = /m/ x 6, “ft” = /t/ x 12, “lk” = /k/ x 15 and “nt” = /t/ x 9. Further, some final single consonants were decoded as clusters, e.g. “t” = /nt/ or /st/, “d” = /nd/ and “k” = /lk/. In terms of the types of errors made on vowel and fricative correspondences, the results of this and the Masterson et al. study were particularly comparable.

b). VCV discrimination.

A substantial range of inter-vocalic stimuli was used with the aim of determining, for different listener groups, the extent of perceptual confusion for different types of consonant when free of lexical information. These stimuli provided a controlled and constant vowel framework. Relatively large separation of the steady-state portions of the second and third formant frequencies is a feature of the open, back vowel /a/. Some of the speech perceptual errors reported in the literature for SRD children may have depended, in part, on the identity of the particular vowel chosen (see e.g. Tallal et al., 1996). Therefore, the use of other vowel environments in the
VCV test might have produced, here, somewhat-different error-patterns both within and across listener-groups.

Considering each class of consonant individually, it is clear, for instance, that plosives are intrinsically more complex than nasals in terms of the differences in the number and duration of acoustic events. However, when each consonant is paired together with another consonant of the same class with which it shares two phonetic features, as was the case here, their complexity is similar. Each VCV contrast was regarded as less complex than each of the consonant-cluster contrasts in the substitution test, by reference to the number and adjacency of acoustic cues concerning consonant identity.

The SRD children’s mean error-rates were higher than those of either group of controls for all four consonant classes. The only class of consonant for which the experimental group as a whole differed significantly from the control groups was plosives because, with this particular set of contrasts, the two groups of controls made virtually no errors. However, the control groups made some errors for each of fricative, nasal and approximant contrasts, the majority of these being contributed by only one or two individuals. One of the most acoustically difficult contrasts for language-normal listeners to discriminate is that of /m/-/n/. Nasal murmur is characterised by an acoustically stable low amplitude, low frequency signal. The mean error-rates for nasals were higher than for other classes of consonant for all listener-groups.

Although the differences in groupwise error-scores for the fricative, nasal and approximant contrasts fell just short of significance, notable error rates (between 15 and 25% on average) were obtained consistently for four SRD children. They involved their discrimination of voicing and place contrasts amongst fricatives, and of place contrasts amongst nasals and approximants. These four children contributed a substantial majority of the discrimination errors for each contrast. A single comparison contrast (consisting of a fricative pair differing in both voicing
and place-of-articulation) was associated with only 5 discrimination errors for the entire SRD group, all of which were made by children in the "PW" sub-group. No errors were made by controls. The results of the discrimination of single-consonant minimal-pairs in a study by Hurford and Sanders (1990) are in broad agreement with the results for the sub-group of 4 SRD children discussed here. A group of second grade SRD children were shown to be significantly weaker than same-age controls on discrimination of natural /bi/-/di/, /di/-/gi/ and /bi/-/gi/ utterances.

The results of several discrimination studies presenting pairs of tokens across the phoneme boundary of synthetic CV-continua are also quoted since, although not strictly comparable, they are in broad general agreement with the findings here, and involved further variation of vowel context. The findings for SRD children of Godfrey et al. (1981) for /da/-/ga/ discrimination, and of Reed (1989) and Werker and Tees (1987) for /ba/-/da/ discrimination, claimed that listener-group effects were due to the weaker performance of the reading-disabled group as a whole. However, in this dissertation, it was evident that a majority of the SRD group were able to discriminate, for instance, /aba/-/ada/ and /ada/-/aga/, which were high in acoustic similarity, and each of the other minimal pairs as accurately as could control children. Also, selected pairs of tokens taken from a synthetic /pA/-/tA/ continuum were reported to be less well discriminated by first-grade SRD children (about 6-7 years old) than by CA controls (de Weerd, 1988). Steffens et al. (1992) also showed that reading disabled listeners performed more weakly on a within-category discrimination task. These studies indicated that speech discrimination difficulties for plosives in SRD children were not restricted to the /a/ environment. They might be similarly-evident for voiceless as for voiced place contrasts, and could apply to a range of minimal-pairs which were not acoustically-phonetically complex.

For SRD adults, within-category discrimination of /ba/-/da/ tokens was again less accurate than for age-matched controls (Steffens et al., 1992), as was their discrimination of /ta/-/ka/ in another study by Watson and Miller (1993). The
work in this thesis has extended these findings to show that some SRD child-
listeners will make errors at similar rates amongst fricative, nasal and approximant
minimal-pairs, whilst others are able to discriminate all contrasts, even plosives,
within normal limits of accuracy. Much of the consonant discrimination work with
adult SRD's suggests that, without some form of re-training intervention, these
perceptual problems in children will persist into adulthood. Variability in the
speech-perceptual skills of sample groups of adult SRD listeners could have been
responsible for the substantially-similar rates of confusion for all listeners in an
extensive consonant discrimination task described by Cornelissen et al., (1996).

c). Consonant clusters.

Generally, naturally produced consonant-cluster onsets are regarded as being of
high complexity because of an increased number, relative to naturally-produced
singleton consonants of whatever class, of acoustic cues which are present in a
rapidly-occurring sequence. This is taken to be the case even though more cues
may be concatenated in some clusters than others, e.g. "spill"-"still" /spɪl/-/stɪl/
and "smack"-"snack" /smæk/-/snæk/. The complexity of consonant-clusters is
regarded as also being responsible for the confusion by SRD listeners of contrasts
differing in either two or three phonemic features. "Different" pairs in the
consonant cluster (omission) condition were, therefore, low in acoustic similarity
since they contained different numbers of phones. "Different" pairs in the
consonant cluster (substitution) condition varied in acoustic similarity. For
example, the extent of acoustic cue difference in the "star"-"scar" contrast (high in
acoustic similarity) was understood to be smaller than that in the "snow"-"slow"
contrast (intermediate acoustic similarity). Pairs such as "smart"-"start" differ in
all three phonetic features and are understood to be low in acoustic similarity.
However, there was no simple relationship between feature-difference and mean
error-rate for these stimuli, and the performance of all subjects remained well
above chance.
There was clear performance-heterogeneity within the SRD-group: the “PW” sub-group produced the bulk of same/different discrimination errors for these two stimulus conditions (substitution and omission). Contrasts differing by only one phonetic feature in the cluster "substitution" test were associated with the highest discrimination error rates, particularly for /sm/-/sn/. This contrast is regarded as high in acoustic similarity. However, the main test-battery produced evidence for some confusion of naturally produced word-initial consonant clusters which differed, for the second consonant of the cluster, by more than one phonetic feature (i.e. pairs which were low in acoustic similarity but high in acoustic-phonetic salience). They produced mean error-rates of about 16 % when discriminating /sk/-/sl/, /sm/-/st/ and /st/-/sl/ onsets, the first two of which differ by all three such features. With reference to the second-clustered consonants within different pairings, confusions were indicated between stops and laterals, voiceless stops, nasals, a nasal and lateral-approximant, and a voiceless stop and a nasal. Individual differences in the ability to process temporal cues within such highly salient onsets could not, alone, account for the range of discrimination errors indicated. Two of the four members of the “PW” sub-group of children (E11 and E12) had some difficulty in discriminating clusters in the "omission" condition, in which a singleton consonant and a two-consonant cluster were compared on each "different" trial. Their error-rates averaged 19 % for the /f/-/fr/, /s/-/sw/ and /b/-/bl/ contrasts, but was lower for several other pairs.

Differences in the intensity and spectral structure of phonetic-features such as stop bursts and nasal murmur within initial consonant clusters suggest that both spectral analysis and amplitude variables need to be accommodated in a more comprehensive theory of discrimination difficulty by individual SRD children. Their speech perceptual acuity does appear to be reduced relative to other listeners for the discrimination of some minimal-pairs that are high in acoustic-phonetic complexity. To this extent they can be said to be “vulnerable” to such complexity. They are also vulnerable, from the VCV findings, to paired items which are low in acoustic-phonetic complexity, e.g. /ara/-/awa/ and /ama/-/ana/. The underlying
problem seems to relate commonly to the discrimination of speech patterns that are low in acoustic-phonetic complexity but acoustically similar, and many others that are not acoustically similar but which are high in complexity. The "PW" sub-group seem to be somewhat less able (or less consistent) than other SRD's and controls to resolve small acoustic differences between a limited number of salient acoustic cues when complexity is low, or larger acoustic differences between several salient acoustic cues when complexity is high. That is, it seems that these children are vulnerable to independent effects of both acoustic similarity and phonological complexity.

d). Natural minimal-pairs.

Do some of the same phonetic contrasts as were used in the VCV discrimination test prove more difficult to discriminate in certain vowel contexts than others? The degree of acoustic salience is not only related to the consonant contrast under investigation but also to the vowel context in which the consonant appears, as this will determine the extent of formant transitions present (e.g. Dorman, Studdert-Kennedy and Raphael, 1977). With regard to the stimulus set used here, these variables enabled the better discrimination of particular minimal-pairs having /m/-/n/, /f/-/v/ or /s/-/z/ in initial position. High error rates were obtained for "met-net" but the error rates for "man-nan" were negligible, whilst the "Sue"-"shoe" (/su/-/Ju/) contrast was more often confused than that of "sign"-"shine" (/sain/-/Jain/). The fact that the same sub-set of pairings were more often confused by each of the listener groups, and to similar extents, suggested that vowel contexts for a given consonant contrast varied somewhat in acoustic salience, and that their discrimination by listeners did not vary with reading status. It is proposed that the frequency-extent, frequency-separation and characteristic paths of second and third formant frequency transitions will vary in perceptually important ways with the identity of the following vowel.

Differences in the spectral proximity of the paths of certain formant frequency
transitions (e.g. which is often minimal between F2 and F3 for the vowel /i/) might be instrumental in generating vowel context effects. Vowel-context effects have also been reported for normal adult perception of fricative-voice contrasts. Whalen (1981), Nittrouer and Studdert-Kennedy (1987) and Nittrouer (1992) have shown that they rely for the consistent labelling of synthetic fricatives, in FV tokens, largely on perceiving the characteristics of F2 / F3 transition paths from the noise to the corresponding vowel-formants. In particular, Whalen (1981) showed that ambiguous fricative noise was more often classified as /s/ before /s/ transitions and /ʃ/ before /ʃ/ transitions.

The "vowel context" effect, which reduces with age, was said to be separable and additive to that of formant transition information in young children (Nittrouer, 1992). Nittrouer and Studdert-Kennedy (1987) reported larger shifts in phoneme-boundaries for /su/-/ʃu/ and /si/-/ʃi/ as a function of "vocalic transition" (i.e. vowel context) for 3 and 5 year-old children than for 7 year-olds and adults. Here, the large effect of vowel context involving cues of high acoustic salience introduced differences in acoustic-phonetic similarity across pairs.

e). Speech pattern identification.

Speech pattern identification tests assess a different level of processing from that of "same"-"different" discrimination, i.e. the ability to group elements of a continuum into distinct phonemic categories. This task mirrors in a controlled way the between- and within-speaker variability which listeners are faced with in normal communication. The synthetic continua had been labelled consistently by a volunteer panel of 4 naïve but language-normal adult listeners and have since been used in a normative study with children aged 6-12 years (Hazan and Barrett, 1998).

These tests were performed in order to establish whether SRD children label high-quality speech tokens, within “full-cues" and “reduced-cues" continua, less
consistently than do same-age and reading-age controls. Which, if any, cues do these SRD children appear able to use contrastively in labelling tokens from a plosive place continuum and from a fricative voice continuum? The weaknesses in phonetic acuity shown may not, it seems, be simply described in terms of the faulty processing of any particular type of acoustic cue. Results suggested that individual SRD-children probably relied on a number of different acoustic-phonetic cues in order to attempt to categorise the tokens. Surprisingly, mean identification function gradients for combined-cue conditions for both DATE-GATE (/deit/-/geit/) and SUE-ZOO (/su/-/zu/) contrasts did not differ significantly between groups. Great variability in performance was seen within groups, however. These results will be compared, where relevant, with those of other studies using combined- and reduced-cues continua.

The /delt/-/gelt/ continua.

The labelling functions of the /deit/-/geit/ continuum in the current study showed that two of the "PW" SRD children and at least two children from the "NP" subgroup failed to demonstrate consistent performance on the combined cues version, and on both reduced-cues versions. This was also true of two children from each of the control groups. The lexical nature of the tokens, and the use of particular vowel environment, may have also had an effect on the perceptual decisions made.

A comparison with the labelling performance of reading groups in this study is possible with the /da/-/ga/ continuum used by Godfrey et al. (1981), although their tokens did not appear to contain burst information. The slope of their controls' groupwise function was steeper than that of SRD's, but the difference only approached significance. Phoneme-boundary positions did not differ. The SRD's functions showed less consistent labelling of both endpoints, with a highly significant stimulus x group interaction (more /da/ responses). However, their CA controls' labelling functions were much less categorical for /da/-/ga/ than /ba/-/da/, which Godfrey et al. related to the availability of fewer formant-transition

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differences in the former case. It would seem that listener groups in the Godfrey et al. study, and in the current study, were similarly dependent on the presence of cue-redundancy.

For the reduced-cue tokens, results confirmed previous findings by Nittrouer (1992) that children below the age of about 7 years tend to give greater perceptual weight to dynamic formant transition information than older children or adult listeners. Indeed, for all groups, performance was better for the F2-transition condition of the DATE-GATE contrast than for the burst condition. Two of the four "PW" SRD children (E7 and E11) gave evidence of being able to use formant transition information in labelling the DATE-GATE contrast, but none of them could use burst information alone. Tallal and her colleagues might have predicted that not only the “PW” sub-group but the majority of SRD-children would be less able than normals to use rapid formant transitions as sole cues to the contrast.

The majority of subjects in both control groups labelled the burst-only version randomly. More of the younger controls were able to label the transitions-only version of the DATE-GATE continuum either progressively or categorically than were the older (CA) controls (supporting the proposal of heavier weighting for formant transition information in younger language-normal children). Overall, the presence of formant transition cues appears necessary, but not always sufficient, for the categorical perception of plosives in a place continuum. Independent evidence for this is that reading-group differences were not significant for identification of a /pA/-/tA/ continuum since the labelling by controls was not, overall, more consistent (De Weirdt, 1988). Further, the ability of Masterson et al’s (1995) CA control subjects to label a /ba/-/pa/ continuum in a categorical fashion using VOT-differences but with spectral cues to vowel onset neutralised was superior to that of their adult SRD subjects.

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The /su/-/zu/ continua.

Large variations in labelling consistency between SRD subjects were also observed in the current study for the SUE-ZOO continua, but with similar variability between subjects in the CA and RA control groups (n = 12). From this, it is not clear if children aged 8-11 years, irrespective of reading status, are less able than language-normal adults to use friction spectra, friction durations and phonation cues contrastively.

With the voice bar removed, the SRD children were less able than controls to use friction duration differences contrastively between /su/ and /zu/, suggesting that at least some of the temporal aspects of speech patterns, for which dynamic spectral factors are less prominent, may be less accurately coded. Several points emerged clearly from the identification data in this study:-

* The SRD-group as a whole, and the PW sub-group in particular, did not differ reliably from controls in their labelling of combined-cues continua. This similarity arose from the inconsistent labelling performance of several members of each listener group.

* Individual children in listener groups/sub-groups differed quite widely in the contrastive use they seemed able to make of different types of acoustic-phonetic cue.

* This general weakness in categorising stimuli in which particular acoustic cues are absent suggests that some children might be reliant on redundancy of acoustic cue information (i.e. cue-multiplicity) and might also show some difficulty in perceiving other types of "cue-degraded" speech, such as that degraded by noise, or filtered speech.
* Consistent labelling of tokens in children up to the age of about 10 years need not be strongly positively correlated with reading-status. Equally, as Hazan and Shi (1995) found to be true for adults, identification errors could also indicate individual variability in perceptual strategies when contrasts are of relatively low acoustic salience (high in acoustic similarity). Also, research on individual differences in acoustic cue weighting does indicate that some adult listeners with normal hearing thresholds appear to require greater redundancy of cue information in their categorisation of phonemic contrasts (Hazan and Rosen, 1991). A normative study of children aged 6-12 years has shown that those aged 12 were still producing identification functions with shallower gradients than adults for a range of contrasts (Hazan and Barrett, 1998). In speech-perceptually normal children, taking into account the contrastive use made of the remaining cues in reduced-cues continua, an increase with chronological age appears to take place in the “weighting” of the burst cue relative to that of formant transitions in a stop place continuum. This could mean that increase in burst cue weighting is a process which varies more in rate of development amongst individuals than, for example, change in weighting of friction duration in a fricative voicing continuum. It should again be remembered that the use of particular vowel-contexts might affect children’s labelling consistency.

f). Nonword repetition.

The main aim of this test was to establish whether SRD children making more nonword than irregular word reading errors also repeat polysyllabic nonwords less accurately than other SRD’s and controls. This aim makes the assumption that a sample of SRD children without noticeable production difficulties will not differ significantly in their repetition accuracy for monosyllabic nonword items, and that if higher error-rates are found for children weak in nonword reading, this will be attributable to weaknesses in speech perception.

Effects of nonword (syllabic) length and listener-group were found for the nonword
repetition test based on recorded productions of the CNRep test list (Gathercole et al., 1994). These effects were in the predicted direction: that SRD children were weaker than controls on this task, and this difference was based on the weaker performance of the experimental group on the 4- and 5-syllable items. According to a modified t-test, the higher rates of repetition-error for the “PW” sub-group of SRD children approached significance relative to the performance of the “NP” sub-group.

The mean error rate for bi-syllabic nonword items in this work was only 4.6 % for the SRD group, therefore a similar or lower score might be expected for monosyllabic items. The repetition of monosyllabic nonwords was omitted from main phase testing because a higher-than-expected error rate had been repeatedly found by Gathercole et al. (1994). A 16 % error rate was reported for both of the adult SRD subjects in the Masterson et al. (1995) study, which did not use polysyllabic items. Therefore, they appeared to have replicated Gathercole et al’s (1994) problem with monosyllabic items. The decision to use, in this study, only 2- to 5-syllable nonwords (as per the revised CNRep) makes comparison impossible with Masterson et al’s result. Comparison with the results of Gathercole et al. is complicated by the fact that their percentile scores were based on the results of language-normal children who were mostly younger than those tested here.

The performance of the RA control group (mean age 8;2 years) was equivalent to approximately the 50th percentile of Gathercole et al’s normative scores for children in the age range 8;0 - 8;11 years. That of the SRD group (mean age 10;4 years) could not be directly related to their data, which ends with age range 9;0 - 9;11 years. However, if simple extrapolations are made of the rate of increase in number of items correctly repeated per step in their age-range, this SRD group’s mean score would have corresponded to that between the 10th and 25th normative percentile. It also corresponded to the mid-range of the mean scores (50th percentile) for Gathercole et al’s groups of children who were aged 7;0 - 7;11 years.
and 8:0 - 8:11 years. Thus the particular weakness of these SRD children's performance in repeating the longer nonword items resulted in an overall score which corresponded to that of language-normal children who were at least 2 calendar years younger than they were. Interestingly, therefore, SRD's mean "nonword repetition" age appeared to be delayed by a period very similar to their mean reading delay (which was 27 months).

An understanding of the probable nature of the nonword repetition problems of SRD children is not possible without some detailed examination of the pattern of errors made by this group for longer items. In many cases, attempts involved correct repetition of the first syllable, and of the final syllable when both the consonants and the associated vowels were not acoustically complex, for instance:-

"defermication"
/difemikeiʃʌn/ → /difæmækeiʃʌn/, /difɔmɪteʃʌn/, and
"detratapillic"
/detrapillic/ → /detrəpillic/, /detræləpillic/, /detrælərəpillic/,
/detrəpillic/, /detrəkapillic/, /detrəælorapillic/ and /detrəpillic/
(individual's final responses in each case).

In such data-sets there is clear evidence of "close" phonetic errors and phonological errors, e.g. /k/ → /t/ and /fæmi/ → /fæmæ/ re. "defermication", and /t/ → /d/, /t/ → /l/, /t/ → /k/, /ræθ/ → /rææθræ/ re. "detratapillic." Errors of phonetic substitution and omission were associated with the presence of initial consonant clusters, final consonant clusters and un-stressed consonants. For instance, SRD children showed considerable difficulty with the phonology of:

"pristoractional"
/pristræækʃʌnɔl/ → /pristræækʃʌl/, /pristɪnætʃʊrɔl/, /prɪstræækʃʌnɔl/,
/pristræækʃʌnɔl/, /prɪstɪnækʃʌnɔl/, /prɪnsəpædʒʌnɔl/,
and with that of

“frescovent”

/freskavɔnt/ → /restkavɔnt/, /fleskarɔnt/, /freskarɔnt/, /fleʃgan/,

/frestgrɔnt/ and /frestɔvɔnt/.

Particular segmental errors here were:

/pr/ → /p/,

/aræk/ → /ənæt/, /ənæk/,

/r/ → /ɜ/,

/fr/ → /r/,

/v/ → /ɹ/,

/sk/ → /ʃ/, /st/, /stk/.

The complex, unstressed phonology comprising the final two syllables of “underbrantuand” /əndəbræntʃuənd/ provided the following final responses from individuals:

/əndəbræntʃul/, /əndəbræntʃən/, /əndəbræntʃən/ and /əndəbrændjund/.

Cluster-reductions and close phonetic errors, discovered in response to discrimination tasks created in this dissertation, appear to be due to misperceptions. There is evidence in the structure of the response-phonologies that other errors could be due to psycholinguistic factors. For example, working memory limitations would be most likely to result in a preponderance of errors in medial position, as is typical of results from normal listeners in the serial recall of unrelated single word lists (e.g. Murdoch, 1962). Vocabulary limitations in recall for SRD children would limit the contribution of long-term memory. For long, unfamiliar speech sound patterns, attention in such listeners is possibly captured by their increased need to store, process and sequence the acoustic-phonetic details of the first-occurring syllable(s), whilst the unprocessed content is more likely to be the source of “close” errors. The existence of predominantly close errors could
indicate that attempts are made to complete the response by incorporating acoustic-phonetic information from the pre-perceptual sensory information store, but which is relatively fast-decaying for all listeners (see e.g. Pisoni and Sawusch, 1975)

Equally, however, the psycholinguistic difficulties could have been triggered by the relative perceptual complexity of certain stimulus items. The apparent repetition of prior-occurring segments (or the anticipation of later-occurring segments), the addition of intrusive segments and the inclusion of apparent lexicalisations in part of the response (e.g. /pristonætʃural/), suggest that SRD children are having difficulty in planning the repetition of longer nonword items. The rapid presentation of phonotactically-legal syllables in an unfamiliar (nonsense) combination can be expected to introduce, for them, a number of information-handling constraints. In such circumstances, SRD children seem to find it easier to distribute (maintain) attention to initial and final syllables. The attentional load in working STM would be relatively increased for the processing of medial syllables due to contextual acoustic complexity (syllabic length), and again due to any intrinsic acoustic complexity. This limitation could be expected to be more marked when the initial and/or final syllables of some items are themselves acoustically complex. As a result the group data revealed a concentration of errors in the medial syllables, although these were often phonetically “close”.

Although the number of errors in the repetition of longer items by the RA control group was significantly lower than that of the SRD children, analysis of the error-distribution showed several strong similarities between the two groups. The evidence gathered here suggests that this developmental difficulty for the processing of nonwords for immediate repetition is common to at least the majority of SRD children. Empirical evidence has shown that the repetition of longer real words, such as “medicine”, “helicopter” and “agriculture”, is weaker in SRD than in 3rd grade CA control children, even when the items are of high frequency (Brady, Poggie and Merlo, 1986; Brady, Poggie and Rapala, 1989). The inclusion of a group of RA control children would probably have been of further interest in these experiments. If reading-disabled children are demonstrating a
developmentally based language limitation in this task, close examination of the error types, error rates and error distributions for SRD and RA groups might have been shown to be very similar. Skills such as syllabic sequencing, articulatory programming, spread of attention and high rates of spontaneous covert rehearsal may each be vital, but predicated on the need for good and increasing phonological acuity.

The suggestion is that the learning of new words, whether to be read or repeated is a demanding and lengthy task for young LN children. It requires a great deal of attention to matching planned rehearsals of items to adequate phonological representations with the minimum of delay. The existence of a phonological weakness (deficit) would clearly have serious consequences for the detailed operation of these functions.

**g). Psychoacoustic tests**

Are SRD children generally as sensitive in detecting brief silent gaps between noise bursts, pitch differences, and frequency-modulations in tones with speech-relevant centre-frequencies as are normally-reading controls, or are they also less accurate on non-speech discrimination tasks?

There were no main effects of group for any of these four tests, but individual performances on certain tests varied widely from group means. In the formant frequency (analogue) discrimination test, SRD-subject E4 made many "same" responses to large-difference pairings. Individuals from the control groups produced similarly idiosyncratic patterns of response, particularly subjects C 2, R 9, R 11 and R 12. In fact, R 9 responded "same" to every trial on this test. There was little consistency of individuals' response-variance across tests: if they were inaccurate on any one test they might be accurate on each of the others. The overall position was that there was no basis for distinguishing the performance of either the SRD children as a group from that of either group of controls, or that of
"PW" children from the "NP" sub-group of SRD children.

These tests may simply have been insufficiently sensitive to detect possible differences in the perceptual skills of different listener-groups. If the "steps" between conditions were too large, such changes as reductions in silent gap duration, reductions in the amplitude and bandwidth of the simple tone stimuli, greater frequency of tone-modulation at each modulation-depth, combined with, or independent of, decreases in ISI might have been effective. Ideally, such stimuli should be embedded within an invariant environment of other speech-related acoustic components, and have appropriate intensities and durations. In general, a single parameter of change of relatively high amplitude and long duration might well be easy for all subject-groups to detect. Phonetic features relevant to particular consonant contrasts involve a number of acoustic-cues (parameters), often, individually, of low amplitude and short duration, acting in concert.

The importance of the temporal interval between paired stimuli for discrimination tasks has been emphasised by Tallal and other workers. The effect on discrimination accuracy for non-speech items has been reported as varying with listener group. SLI and SRD children are somewhat disadvantaged by brief, but not by long, ISI's. The duration of an inter-stimulus interval has also been regarded as crucial to the accuracy of temporal-order judgements of non-speech based stimuli. Tallal (1980) showed that SRD children aged 8-12 years were less able than same-age controls to report the correct temporal order of two complex tones when the ISI was very short (about 10 ms) but roughly as accurate as controls at longer intervals (about 300 ms). Reed reported similar effects for SRD children using intervals of 0 to 400 ms for two complex tones, but not for synthetic vowels (Reed, 1989). Mody, however, found that her group of young "poor" readers, who had a similar chronological age to those of Tallal (1980), were as accurate as same-age controls on the discrimination of non-speech sine-wave patterns under reduced ISI conditions (100, 50 and 10 ms). One ISI of 500 ms was used throughout each of the four non-verbal discrimination tests in this dissertation. The argument that
shorter intervals (50 ms or less) would have produced more discrimination errors in SRD children is plausible.

In an attempt to estimate the difference limen (DL) for formant frequency transition for normal subjects as a function of age, Eguchi (1976) used single tones in an ABX design. The data for 10 adults and 90 children (10 for each of 9 chronological ages) were expressed only as means without standard deviations (no information on individual variability). The frequency-sets used (300, 500 and 700 Hz for one stimulus, and 1000, 1500 and 2000 Hz for another) were of similar values to vowel formant frequencies (F1 and F2). The criterion used was 75 % correct. Since Eguchi noted that the difference limen (calculated as dF/F) was constant when expressed as a proportion of the stimulus frequency (dF/F(%)), a single function illustrated the developmental changes. He found that the size of the difference limen decreased with age. The difference limens were about 25 % for 7-year-olds and 12 % for 9-year-olds; they then more gradually approached an adult value of about 6 % by about age 11 years.

The formant frequency discrimination and frequency modulation discrimination tests used in this study could be compared to the Eguchi findings, since the standard frequency was 1000 Hz for these tests. The standard frequency was 125 Hz for pitch discrimination and the size of the DL for the reading groups could also be estimated from this. The step size that related in the current tests to a score of 75 % correct was estimated. For formant frequency discrimination this was in the region of 8-12 % (80-120 Hz), but was generally below chance level for the 4 % step size (40 Hz). The frequency modulation data was given as half the total modulation depth; for instance, the 60 and 120 Hz stimuli related to DL’s of 30 and 60 Hz (i.e. 3 and 6 %) respectively. The equivalent of the Eguchi criterion was achieved approximately for the 60 Hz step which is in good agreement with his dF/F(%) data for children of 10 years and over, and adults. Lastly, the equivalent pitch discrimination DL was about 3 %. Overall, it appears that the smallest DL’s quoted by Eguchi were quite close to those found here for the older subjects (EXP and CA mean ages were about 10
years). However, the DL values for the reading-age control children, whose mean age was 8 years, were estimated to be very similar to those of the other subject groups in three of the psychoacoustic tests used here. In the Eguchi study this was as high as about 16%, but his use of the ABX presentation design may have somewhat disadvantaged the youngest subjects (aged 7 and 8 years).

4.4. Relevant Medical Factors.

An important consideration is whether children in the "PW" sub-group differed from other experimental children in relevant aspects of their medical histories. It has been hypothesised that failure to acquire well-established phonological categories might be linked to repeated episodes of intermittent hearing loss during crucial stages of the development of their speech perceptual abilities (Friel-Patti and Finitzo, 1990; Roberts et al., 1991). The period of hearing loss corresponds to the duration of middle ear infection (otitis media or OM) usually arising as a consequence of an episode of respiratory infection. Equally, other studies have found little evidence of a link between recurrent otitis media and weakness in phoneme discrimination (e.g. Bishop and Edmundson, 1986; Grievink, Peters, van Bon and Schilder, 1993). The two adult phonological dyslexics tested by Masterson et al. (1995), who showed evidence of speech-perceptual weakness, both reported repeated incidents of ear infections and otitis media during childhood.

For the current study, there was firm evidence of a history of otitis media for one child in the PW sub-group. Conversely, within the rest of the group of experimental children, two had a history of OM but showed no evidence of perceptual difficulties. These results concur with those of other studies which have concluded that episodes of early OM and known cases of dyslexia in first-degree relatives is the combination of factors which best predicts developmental reading-failure. The incidence of one or more early episodes of OM in the listener groups studied here was not predictive of the incidence of speech perceptual weakness.
The long-term perceptual/educational effects of intermittent conductive hearing-loss in children who have normal cochlear function and no familial history of reading-impairment seem, therefore, to be unclear. The presence of abnormal critical bandwidths has not been proposed for children who have suffered recurrent early episodes of OM and who later present as reading-impaired. If that were, however, the case, somewhat-abnormal performance on psychoacoustic tests of the type used here, particularly of frequency discrimination, might be expected.

The incidences of asthma and tinnitus in the samples were too low to enable comment on their possible effect on reading development. One SRD child in the "PW" sub-group did have a history of both recurrent OM and asthma. About half of the children in both of the SRD groups reported the presence of reading problems in first-degree relatives. This serves to illustrate, within a single-factor view of language learning difficulties in children, the potential of a genetic component compared to the possible long-term effects of acute, mostly commonplace, medical conditions such as earache and upper-respiratory infections.

4.5. The Pattern of Speech-Perceptual Results in a Wider Context.

4.5.1. Language impairment as developmental "delay"?

Do the results of the perceptual tests in this study help to clarify the understanding of difficulties as due to "delayed" development or not? Since the "PW" children concerned were aged between 9 and 11 years at the time of testing, could some form of developmental breakdown have brought about their pattern of acoustic-phonetic deficit?

The problems of non-dyslexic poorly-reading children and those with early language delay have been considered by some to be the result of a developmental "lag" with respect to the "normal pattern" (e.g. Scarborough and Dobrich, 1990;
Stanovich, Nathan and Zolman, 1988). Scarborough and Dobrich emphasised that 3-year-old language-disabled children may exhibit a wide range of productive problems together with difficulties of phoneme discrimination and segmentation, but many of these seem either to resolve or reduce by the end of Grade 2 (i.e. by about 7 years of age). This was not true of those with early signs of reading difficulty, and seemed untrue of children with poor segmentation abilities (Kamhi, Lee and Nelson, 1985). Early language impairments seem to differ not only in type but also in outcome.

Although the Scarborough and Dobrich study used a very small sample (n=4), and they warned of the dangers of over-generalisation, they estimated that much of the recovery they observed was illusory, in that three of these children were later found to have significant problems with reading development. This group produced shorter mean lengths of utterance at a given age than CA controls, often used simpler grammatical constructions, and made more consonant production errors. None of these factors, alone or in combination, appears predictive of reading failure. Scarborough and Dobrich’s main conclusion was that the best single predictor of reading failure in young children was that of reading disability in first-degree relatives (parents and siblings). The possibility that this is also true of SRD children led to the inclusion of information on familial reading/spelling problems in the medical-educational questionnaire.

The ability to understand, at age 3-4 years, the meaning of a word bearing a particular initial phoneme (say /m/ or /n/) when a semantic context is available, and to produce it accurately, should not imply that such children will also be able to make fine perceptual distinctions between acoustically-similar phonemes. There was ample evidence from the identification functions for "date" - "gate" and "Sue" - "zoo" continua, that not all reading-age controls (mean actual age about 8 years) or chronological-age controls (mean actual age about 10 years) were labelling tokens consistently. The normal developmental trend for increasing ability to label stimuli along a continuum in a categorical fashion is both slow and gradual, and the
evidence here and elsewhere shows considerable individual differences in this skill (Hazan and Rosen, 1991; Hazan and Shi, 1995). Differences in the contrastive use which listeners can make of specific acoustic-phonetic cues, and in the effects that changes in vowel environment may have on the identification of an immediately-preceding consonant, serve to show that the concept of phoneme "acquisition" is a complex one.

If children's discrimination skills normally follow a course from early sensitivity to predominantly low-frequency based cues to later-emerging sensitivity to mid- and high frequency based cues (Fourcin, 1978), the "PW" sub-group's performance on the test-battery does not seem to be related to it. As noted, a particular discrepancy arises with the SRD error-rates found for the nasal contrast used (/m/-/n/). It is acquired early productively in normal development through the adequate repetition of certain common words, and therefore in particular vowel environments. However, it was discriminated weakly by listeners varying widely in chronological age and in reading ability in the natural minimal-pairs discrimination test. For instance, discrimination errors for this contrast were also relatively common for the RA control children. It remains possible that the discrepancy is mainly due to the intrinsic difficulty of their discrimination in controlled conditions, since the /m/ - /n/ contrast is marked by low frequency, low amplitude components.

Neither the comparative rate nor the wide distribution of the SRD children's discrimination errors on the VCV and consonant-cluster stimuli would suggest that they had failed merely to reach some particular "level" or "stage" of development. Rather than a developmental block, which would imply clear and stable performance within a restricted level of perceptual competence, some of these discrimination confusions relate to phonemes which are normally acquired early, and others which are acquired late. A unitary delay which occurred early in development could account for this, but would conflict with the evidence for the majority of discrimination problems being related to pairs differing in only one feature. In particular, the ability to discriminate "close" acoustic-phonetic contrasts
of this type is believed to mature later in the normal developmental sequence (Fourcin, 1978). Again, the traditional implications of the term "developmental delay" seem therefore not to apply straightforwardly. The apparent breadth and subtlety of the perceptual difficulties shown by the "PW" sub-group suggest a general limitation of the ability to process acoustic-phonetic cues, but at a stable and moderate level of dysfunction of discrimination. Finally, use of the word "delay" implies that spontaneous improvements and substantial (eventual) recovery are possible. The evidence from studies of reading-disabled adults who had speech-perceptual problems as children is that, conversely, such problems tend to persist. The discrimination performance of the "PW" sub-group was consistently worse, for certain tests, than that of even the reading-age controls, indicating that their phonetic acuity was not merely delayed but deviant.

4.5.2. Are productive and perceptual difficulties linked or independent?

The issue appears, from some studies, to depend on the age of child subjects and on the details of their language-learning status. Normative studies on this issue are not numerous, and seem to provide no reliable findings. Locke and Goldstein (1971) estimated that a mild relationship existed between those phonemes which had been mis-identified and those which had been mis-articulated by a group of language-normal kindergarten children. Much of this relationship could perhaps be accounted for by wide individual differences on these two measures within developmental norms. From the point of view of the design of experiments on speech perception in a dyslexic group, it illustrates still further the importance of defining the extent, if any, of reading-disabled children's other language-related problems.

In a study of the phonetic inventories and the phonemic awareness of LI children with widely-varying degrees of production-disorder, Magnusson (1995) found a general tendency for 4-6 year-olds with "more-deviant" production accuracy to be.... "less phonologically aware than those with minor problems." The level of
phonological awareness (being judgements of whether target phones or phone-sequences are identical or not) did not mirror the seriousness of the (productive) phonological disorder, but the type of phonological disorder was decisive.

From within LI groups, research suggests that the type of language-disorder, specifically the production deficit, may provide closer links with perceptual deficits. Tallal, Stark and Curtiss (1976) suggested that those dysphasic children who had greater difficulty than others in the group in pronouncing test items were also weakest at discriminating stop consonants in CV syllables. Although the presence of production problems in some language-impaired children can be readily appreciated as being closely linked to, and exacerbated by, speech perceptual deficits (e.g. those SLI listeners with receptive-expressive disorders, particularly aphasics), it remains quite possible that those members of Tallal and Stark’s (1981) LI experimental group who showed both discrimination and production errors did so as a result of deficits which were unrelated. That a number of instances of shorter- or longer-than-normal VOT duration, or of increased vowel-length in production were related to these individuals’ speech-discrimination weaknesses needed to explicitly demonstrated rather than merely implied.

The production and perception of speech might, in fact, be substantially independent of each other. In a review of the [cortical] organisation of the perception and production of speech, Morais and Kolinsky (1994) noted that these processes seemed to require anatomically distinct systems. Production can be affected by a lesion in Broca’s area whilst speech recognition remains intact, with the reverse being true for a lesion in Wernicke’s area. This would imply that separate representations are needed for the processing of “input” and of “output” phonology. Indeed, Morais and Kolinsky cite a study by Shallice, MacLeod and Lewis (1985) in which very little interference (in performance terms) was observed for subjects reading words aloud by having to listen simultaneously for a target word in a list of spoken words. This would be a difficult point for motor theorists.
to negotiate by using their account of how speech is perceived. Further, it appears from positron emission tomography (PET) scanning work by Petersen et al. (1989) that auditory word-input does not "activate" the area(s) concerned with word repetition and reading aloud.

The question of whether poor articulation skills in children are associated with reading difficulties has been addressed empirically. Catts (1993) studied individual-subject data and estimated that as many as half of his 6-year-old LI children were within normal limits of reading ability in 1st and 2nd grades, and that articulation ability was unrelated to reading ability. Indeed, those with production problems alone read at or above the accuracy level of the CA control group. It remains likely that the articulation problems of some LI children (such as consonant cluster reduction) are based on motor-control, and not on either phonological awareness or rapid-naming deficits (MacLeod, Van Doorn and Reed, 1997). The balance of anatomical and behavioural evidence appears to be that production difficulties are very often additional to, and distinct from, any concurrent perceptual problem in a given LI child. The selection of SRD children in this dissertation precluded, by definition, those with productive problems since measures of speech-repetition ability were involved.

4.5.3. Temporal problems?

Normal speech perception must be able to very efficiently "identify" phonemes or "resolve" sequences of phones, and retain their order. Some theories of speech perception imply that the discrete serial identification of phones allows retention of the original sequence, but give little indication as to how all the necessary cue processing can be feasible for fluent speech. The discussion in the introduction suggested that larger units of analysis, perhaps relating to segmental phonology, were necessary to the adequate perception of speech.

The pattern of discrimination error-rates for various consonant-classes, despite the
availability of several different types of acoustic-phonetic cue, suggests the possibility that these four SRD-children's perceptual weaknesses are diverse in nature. Such diversity would also argue against an origin based specifically on a "temporal" deficit. The term "temporal deficit" is not of itself specific. Its use within much of the research literature has tended to be vague (see in particular Farmer and Klein, 1995) since it clearly contains several independent aspects. A full discussion of the issue would need to include the empirical evidence for listeners' problems with the discrimination of VOT in certain contrasts, the detection of release bursts for plosives, and the detection of friction-duration differences in particular fricative contrasts (e.g. /su/-/ʃu/). Other important variables would be the onset of voicing, and the detection of delayed onset of the F1 transition in voiceless plosives. Quite apart from these, and other, intrinsic temporal factors, the extrinsic variable of inter-stimulus interval (ISI) may also be relevant under certain conditions for reading-disabled groups (e.g. Mody and Studdert-Kennedy, 1997; Tallal, 1980).

The extent to which "temporal problems" are applicable to the difficulties shown by groups of LI children is also unclear. Manipulation of the duration of the entire speech signal has been used experimentally. Orchik, Holgate and Danko (1979) found that young children who were at risk for delayed language-development had weaker speech discrimination for compressed speech than another group not at risk. However, speech compression depressed the discrimination scores of both groups to a similar extent, with the non-risk group producing better discrimination scores in all conditions. The effect of compression (at 30 or 60% reduction in duration) for the at-risk group was possibly to increase the acoustic-phonetic complexity of the target words under time-pressure, but their recognition without compression was only about 85% accurate. This result is a further refutation of the hypothesis that perceptual difficulties arise primarily from limitations in the gross "temporal" processing of speech patterns in particular listener groups.

It is not valid to imply that temporal aspects of speech perception can be
considered independently. The “steady-state” portions of vowels are defined spectrally, whilst dynamic cues are defined spectro-temporally. Dynamic changes in speech-patterns, notably those relating to formant frequency transitions for a stop C + vowel and spectral changes within particular fricative-vowel syllables, are defined by the rate and extent of change in spectral composition and of changes in amplitude across elements of a speech pattern. The clarity of the argument for a “temporal” deficit in SRD listeners is obviously lacking.

4.5.4. Is a phonological deficit “linguistic” or “auditory”? 

The proposition could be made that a “phonological” explanation of problems with beginning reading can be represented by a low-level linguistic hypothesis. Increasing phonological awareness is seen as including gradual refinements of whatever analytical procedures involve generating accurate representations of items. Some candidates for these procedures would be the efficient operation of parallel processing, cue weighting, cue trading, and the perception of cue-salience. The product of these procedures is the ability to place individual phones into linguistic categories, and to “blend” adjacent phones efficiently. They are taken to be learnt implicitly as a result of continuous early exposure to the speech of different speakers, thus are shaped by linguistic experience. A phonological deficit, relative to some comparison group, would therefore be a linguistic deficit.

However, the above explanation would be unsatisfactory. The question arises as to the origin of the ability to define and detect “salient” acoustic-phonetic cues and to combine efficiently the information they carry so as to arrive at an unambiguous identification decision. These abilities are themselves, arguably, a function of the existence of more-basic auditory sensory properties which are capable of being integrated (functionally) into a series of perceptual units. They would need to be, or normally to become during early-years development, highly sensitive and highly resolved in spectro-temporal terms, such that they can become adapted or “shaped”
by repeated exposure to sources of native speech. Consequently, they can be viewed as being shaped by the accuracy with which speech-relevant auditory information is registered and classified.

Problems with the perception of phonology at the segmental level could be based on auditory deficits specific and subtle enough only to be manifest when speech (or closely speech-relevant) stimulus materials are used experimentally. The psychoacoustic tests used here did not address fully enough the issue of the potential relevance of basic auditory sensory properties to speech perception, therefore the question remains open. The duration, amplitude, temporal arrangement and diversity of the spectral characteristics typical of speech patterns would ideally need to be synthesised for a number of non-speech stimuli. Differences in these parameters would be varied in proportion to differences estimated for a range of, say, VCV minimal-pairs. The acoustic-phonetic characteristics of speakers' productions of such items could be specified by reference to vowel space and F1-F2 distance (Bradlow et al., 1996). Non-speech stimuli could incorporate formant transition characteristics that do not occur in speech, but preserve the "formant" frequency differences measured in live production. Similarly, "anomalous" plosive burst and friction spectra could be used in generating plosive-like and fricative-like non-speech stimuli. These might involve the use of anomalous energy-peaks, or simulations of nasal "murmur" at frequency ranges rather above, and at durations different to, those which are characteristic of the /m/-/n/ place distinction in natural production.


An account of the perceptual limitations of the "PW" sub-group will be attempted by considering their patterns of results across the main test-battery in tandem with how the types of speech stimuli differ. The experimental results laid out in the previous two chapters showed clearly that there were no pairs of speech patterns
that this SRD sub-group was completely unable to discriminate. They made between 9 and 26% errors in the discrimination of individual contrasts for stimuli varying widely in phonemic-content and acoustic-phonetic complexity (the VCV and consonant cluster experiments).

The basis for description of their perceptual difficulties will be that of the need for rapid representation of various acoustic-phonetic cues, adopting the theoretical approach (laid out in the introduction) of "passive" models of normal speech-perception. It has been suggested that phonemes within speech contrasts are not classified individually and then compared on a serial basis, but that acoustic-phonetic evidence for the identity of several adjacent phonemes is (necessarily) processed partly in parallel (e.g. Remington, 1977). Vowels have been shown to be better identified when presented in a consonantal syllabic context than in isolation (e.g. Strange, Edman and Jenkins, 1979). That study stressed the importance of the availability of dynamic information incorporated in the syllable, particularly formant transition paths and relative item-duration. In effect, perceptual decisions are deferred briefly to allow the accrual of different sources of spectro-temporal cue-information relevant to a phonological segment such as a syllable (Miller and Liberman, 1979). The hypothesis outlined below assumes that the ability of SRD children to retain information in a pre-categorical acoustic store is similar to that of language-normal children, as was argued to be the case following consideration of a range of independent studies of their STM performance.

The discrimination of two speech-patterns involves the detection of dimensions of difference in their individual acoustic-phonetic characteristics. The variability of cue-representations need not be understood as referring only to the accuracy of spectral analysis, since the temporal structure of the signal, and of the neural response itself, could also form part of the basis of a speech-perceptual weakness. Furthermore, how rapidly, and to what extent, speech-patterns differ in amplitude (level) is highly relevant to cueing changes in manner of production. It is also relevant to the fact that voicing contrasts were present in some of the consonant
cluster (substitution) minimal-pairs for second-consonant position (e.g. /st/-/sl/ and /st/-/sm/), for which frequent confusions by these children were also found. Discrete speech elements, such as release bursts for plosives or fricative noise, may also differ in amplitude.

In order to correctly signal the occurrence of a given minimal-pair as “same” or “different”, the relationship between the representations of salient acoustic cues to paired items is viewed as one being based, potentially, on all dimensions in which tokens can vary, i.e. spectro-temporal, and amplitude parameters. Perceptual confusions are most likely when speech contrasts contain cues of high acoustic similarity. The response of one or more auditory analysers of each of the phone sequences would appear to be sub-optimal on a proportion of trials. The phonological analyses of some children were relatively inaccurate for phonetically “close” pairs in low-complexity configurations (VCV discrimination), and for both phonetically “close” and some phonetically “distant” pairs in high-complexity configurations (CC(S) discrimination).

The same/different discrimination problems of “PW” SRD children could be described in terms of an auditory analysis of speech material which incorporated some variability in the composite neural response to a series of complex spectro-temporal events. Spectro-temporal comparisons of speech tokens are expected to concern measures of spectral range and spectral analysis, and the changes in these values over time both within and between tokens. Such measures are understood to constitute much of the processing of each of a series of “cue matrices.”

On a random basis and with moderate frequency of occurrence, response variation at the neural level can be in an overall direction which subjectively enlarges or reduces the difference between corresponding acoustic cue(s) for the two test items relative to the value(s) associated with “normal” discrimination performance. These changes are assumed to be brief and to have the potential to directly affect response selection. Raised differences overall between one or more aspects of
subjects’ representations of acoustic-phonetic events at the neural level are understood to effectively lower the “perceived-difference threshold”, and so will tend to increase the likelihood of a “different” response on a “same” trial. Similarly, reduced differences overall between aspects of representations of these events effectively raise the “perceived-difference threshold”, and so will tend to increase the likelihood of a “same” response on a “different” trial. The variability of spectro-temporal difference thresholds in these listeners (which can be abbreviated to VSTDT) is referred to as a “first order” speech perceptual weakness, and incorporates sensitivity to differences in signal amplitude within and between phone segments.

The “first order” weakness is seen as additional to the phonological deficits of the SRD group as a whole on nonword reading and nonword repetition, which can be referred to as a “second order” weakness. That is, perceptually weak SRD children have both a first and a second order phonological weakness, whilst SRD children who appear to have speech discrimination skills which are within normal limits have a second order weakness only. The nature of this second order phonological weakness would need to be the subject of further research, but it appears closely related to the psycholinguistic demands of these tasks, and perhaps to the syllabic length of items. How closely these demands approach the limits of the psycholinguistic abilities of RA control children would also need to be considered carefully.

The ‘first order’ phonological weakness hypothesis (VSTDT) is based on consonant discrimination results with a fixed vowel context. They are dissociated from findings on a) labelling experiments, and b) the natural minimal pairs test, where consonant discrimination included some variation of vowel context. For these tasks, no reliable performance differences were found between SRD and control groups, except for the labelling of the reduced-cues version of the /su/-/zu/ contrast on which the SRD group performed less consistently. The weak categorical perception of the /ba/-/da/ and /su/-/zu/ tokens displayed by several members of each of the reading groups strongly suggests a common fragility of
aspects of their phonological acuity, one which is probably not addressed by the use only of extreme exemplars in same/different discrimination tests. Different reading groups produced similar error rates for a sub-set of minimal pairs in “natural minimal pairs” discrimination. The variation in vowel contexts and speaker characteristics suggests again that listeners’ phonological skills were not uniformly robust, a result which was supported by variations in labelling consistency of some of the members of a group of older LN children reported by Hazan and Barrett (1998). Reading group differences were not shown for any of the four psychoacoustic tasks, it is thought, because of their simpler acoustic content and the fact that step sizes between conditions may have been inappropriately large.

The number and type of different contrasts which were shown to be confused by the “PW” children suggests that their collective deficits in speech discrimination could be global in terms of the range of acoustic cues likely to be involved, but at a moderate level. For a given contrast, the hypothesis is non-specific as to which cue or cues may be involved in responding, as these could vary between subjects. Its consistency with the experimental findings for two samples of SRD children is summarised as follows:

* A moderate but persistent deficit in the resolution of a range of spectro-temporal and amplitude values pertaining to natural speech would concur with the finding, for real-word discrimination in the first pilot test, that only certain contrasts which shared two phonetic features were consistently confused. In this pilot, the type of contrast for word-initial, singleton consonants (place-of-articulation or voicing), as well as phonemic context, were also seen as being relevant to determining which word-pairs would tend to be confused. This comparison can be made, by referring to Table 6 in Chapter 2, for “fit”-“sit” /fit/-/sit/ (P) and “till”-“kill” /t1l/-/kt1l/ (P) against “big”-“pig” /b1g/-/p1g/ (V) and “die”-“guy” /d11/-/g11/ (P)).

* Holding the vowel context constant for a range of single consonants showed,
again, that minimal-pairs sharing two phonetic features were more frequently confused by an SRD sub-group than all other listener-groups (in VCV discrimination). For contrasts of high acoustic similarity the effect was not limited by phoneme-class. Nasal place contrasts (marked principally by low frequency, low amplitude energy of relatively long duration) were at least as poorly discriminated as, for instance, stop place contrasts (marked principally by formant frequency transitions, VOT differences, and the spectral range of brief release bursts). Referring to the defining features of a sample of VCV contrasts illustrates the potential diversity of speech perceptual weakness in individual listeners.

* Increasing the acoustic-phonetic complexity of word-onsets by using words with 2-consonant clusters in initial position also introduced large differences in the degree of acoustic similarity of many of the contrasts in both the substitution and omission conditions. The error-rates observed for contrasts differing by either two or three phonetic features (e.g. "snow"-"slow" /snəu/-/sləu/, "start"-"smart" /stɑːt/-/smɑːt/ and "bow"-"blow" /bəʊ/-/bləʊ/) were similar to those for some contrasts differing by only one feature. This could be understood if the perceptually confusing effects of acoustic-phonetic complexity for these contrasts were sufficient to counter, for the "PW" children, the perceptually distinguishing effects of low acoustic similarity. In broad terms, the perceptual advantage of the presence of certain amplitude differences, and differences in spectral characteristics, may have been eliminated by the perceptual disadvantage (for them) of having to process several brief and different speech events occurring in rapid succession which pertain to each consonant cluster. Decreasing acoustic similarity by using minimal-pairs differing by two or more features, while keeping onset-complexity low was shown to maximise discrimination performance for a small group of SRD children in the first pilot test.

* The use of "natural" minimal-pairs in a "same"-"different" discrimination task produced an effect of pairs (vowel context change) but not one of listener-group. Here, many of the contrasts presented concerned single consonants in initial
position. High acoustic similarity in the /m/-/n/ nasal place contrast was associated with relatively high error-rates except for the /æn/ context. Changes in vowel context can enhance or diminish the perceptual effect of the acoustic similarity of a given consonant contrast by its effect on both the spectral and temporal aspects of the extent of formant frequency transitions (Dorman et al., 1977). It is suggested that this effect is perceptually large and, consequently, similarly effective for all listener-groups.

* No effect of listener-group was found for the labelling of copy-synthesised continua except the reduced-cues version of SUE-ZOO. In this case, tokens differed only in friction duration, for which the "PW" SRD children were significantly less consistent than the "NP" sub-group and controls. That their consistent (relative) weakness in performance was evident on a number of speech discrimination tests emphasises the differences in the perceptual requirements. The discrimination of naturally produced minimal-pairs involves stimuli that contain a full complement of acoustic-phonetic cues.

4.7. Significance of Results.

The discrimination experiments described above have begun to provide a range of empirical evidence that an important determinant of the discriminability of speech contrasts can be the intrinsic acoustic-cue structure of the speech items used. This was shown here without the need for fast rates of item presentation, as was also evident from the speech discrimination work reported by Mody (1993). Mody regarded the consonant-confusion effects in poor readers, such as /ba/ - /da/, as due to their phonemic similarity.

This study regards the perceptual confusions of SRD-subjects as relating, more precisely, to the acoustic similarity of certain pairings, so that, under certain contextual conditions, their acoustic-phonetic structure can be crucial to their distinctiveness. It has been proposed here that a supplementary effect of perceptual
confusion can arise with some pairs which are complex in acoustic-phonetic terms, and which share fewer phonemic features. Also, for two SRD-children, the acoustic-phonetic complexity of discriminations involving consonant clusters does not lie only within specified phonemic segments, but also in the relative difficulty of detecting the presence/absence of an entire consonant when adjacent to another consonant. The phoneme-detection deficit noted in the consonant-cluster omission task involved second-position consonants which differed, across pairs, in manner-of-articulation. They were either voiceless stops (e.g. /set/-/stet/) or approximants, including /r/ and /w/ (e.g. /frog/-/frog/ and /tin/-/twin/). Approximants are cued by longer F1 transitions than for stops (Studdert-Kennedy and Mody, 1995). Therefore, the phoneme detection involved in this discrimination test, and which was found to be weaker in the “PW” sub-group, could be seen as providing supplementary evidence which contradicts the hypothesis of a temporal (or “rate”) deficit in language-impaired children.

Mody (1993) found weakness in the detection of the F1 transition in the /set/-/stet/ contrast for the ambiguous tokens in a synthetic continuum for poor, but not good, readers. This contrast is heavily cued by the presence of a cutback (40 ms) transition with /t/. It should not necessarily be concluded, as Mody (1993) does, that stimuli which are phonetically similar, i.e. which differ in a single feature, will necessarily be problematic for such children. Indeed, in the minimal-pair test, which also comprised a wide range of single-consonant and consonant-cluster contrasts differing in a single feature (either place of articulation or voicing), only a sub-set of minimal pairs appeared to be difficult to discriminate. These were not the plosive contrasts which have been implicated in many studies, but nasal place contrasts (“met-net”, “mail-nail” and “smack-snack”), for which the highest error rates were also obtained in the VCV test, and fricative place and voicing contrasts (“Sue-shoe”, “fine-vine”). The discrimination of target-phonemes for these children depends on the identity of the adjacent phonemes as well as on the details of their own acoustic properties.

There is a need, therefore, to go further than Mody (1993) and argue that the
contrasts which are likely to be most problematic are the ones which are not merely phonetically similar (i.e. differ in one feature only) but also acoustically similar (irrespective of the salience of the cues present). Measures of acoustic distance between stimuli have been shown to be correlated to a certain extent with measures of perceptual distance resulting from intelligibility experiments with normal adult listeners (e.g. Krull, 1990). It is also argued that problems in discrimination are not limited to contrasts which are marked by transient temporal cues, as suggested by Tallal's work, but that they can also be present for consonant contrasts which contain spectral cues which are not acoustically salient. The contrasts which these children found particularly difficult to discriminate are also the ones for which errors were found for children in the control groups, though at lower rates than for the experimental sub-group (cf. Masterson et al., 1995).

The impact of phonemic confusion on alphabetic awareness may be greater than the perceptual error-rates obtained here would suggest. An error-rate of 5 to 10 % for a two-alternative forced choice discrimination task represents performance, of course, well above chance. However, these error rates were obtained for high-quality recordings of isolated words presented in ideal listening conditions. The rate at which instruction is given in a noisy classroom may frequently create, for some children, a higher degree of confusion compared to that for citation presentation in a quiet room. The normal development of receptive phonology would seem to suggest (from the evidence of Treiman, 1984) that, in early stages, sensitivity to certain speech sounds (e.g. to the second phoneme of a word bearing an initial consonant cluster) is not obvious from either their own production attempts or their spelling. The discrimination performance by some listeners, under ideal listening conditions, to speech materials in citation form throughout this set of experiments suggests that some developmental dyslexics have not entirely achieved such sensitivity to complex acoustic events by the age of about 10 years.

Phonological “distinctness” in word recognition has been put forward by Elbro (1996) as being a relevant model for the phonological deficit of SRD children.
“Distinctness” was regarded as preferable to a “segmentation” model (Fowler, 1991) because the latter does not specify the distinctness of their representations, only their sizes. Conversely, the “distinctness” model is non-specific about unit-size but concerned about levels of distinctness and how this is relevant to ideas of “neighbourhood density” (Luce, Pisoni and Goldinger, 1990). According to this, indistinct words are easily confused in high-density neighbourhoods, less so in low-density neighbourhoods for a given level of distinctness. Experiments which mimic reductions in the perceptual distinctness of real words by presenting them in random noise have tended to show that recognition is affected by differences in word frequency, even for monosyllabic words (Brady, Shankweiler and Mann, 1983). Frequency effects were comparable for listeners with different levels of reading skill. If distinctness were central to auditory word recognition, it is likely that noise masking of the features of whole words would have had more effect on the reading-disabled than the normally reading group, and that a very clear effect of item-length would have been evident. Furthermore, auditory closure skills for a forward-gating procedure employing highly familiar monosyllabic words were as good among children with language difficulties as with language normal children (Elliott, Scholl, Grant and Hammer, 1990). Elliott et al. did show that, although the LD group had good word retrieval skills, they demonstrated relatively poor “fine grained” analysis (labelling continua of /ba/-/da/ and /ba/-/pa/). It would appear that the “distinctness” versus “segmentation” argument as a basis for the phonological deficit of SRD children (and reading-impaired SLI children) is not strictly necessary. Inadequate segmentation can potentially occur in one or more elements of a phonological string or whole word, reducing its distinctness at whatever level.

Normative data (e.g. Fowler et al. (1977) concerning position-sensitive phoneme-substitution, and Treiman (1985a) on the spelling of CVC nonwords by 8-year-old children) suggests that, in the early months and years of reading experience, children are dependent on phonological discreteness to be able to both encode and decode efficiently. There have been many estimates of the segmentation and blending abilities of groups of reading-impaired children (e.g. Bradley and Bryant,
1983; Treiman, 1984). From this work, there is broad agreement that SRD children's "phonemic awareness" and phonological knowledge is significantly reduced in relation to that of same-age and reading-age matched control groups. It has been the aim of this dissertation to argue that one of the major factors determining the inferred rapid development of phonological knowledge and vocabulary growth is one which intimately depends on a high degree of phonetic acuity. Given phonemic contrasts vary in acoustic-phonetic "salience"; those of low salience are more likely to be acquired late in the normal course of language acquisition, and seem to be especially problematic for some reading-disabled children. Another important factor may be "complexity" which may interact with the "salience" of acoustic cues: some phonemic contrasts of greater acoustic-phonemic prominence were also confused by this SRD sub-group, but only for "complex" stimuli. Therefore, those who do show relative weakness in speech discrimination seem to be at risk for attaining full phonological knowledge, at least as far as this relates to the phonetic analysis of initial consonant-clusters.

Specific points are as follows:

* The high reading-error rates for both irregular and nonword items for SRD-children made clear that a simple division of the data into developmental phonological and developmental morphemic "patterns" was inappropriate. Many of the (monosyllabic) nonwords used in these reading tests contain the same vowel digraphs which, in real-words, are important in determining the orthographic regularity and the consistency of pronunciation (Glushko, 1979). Decoding of irregular and nonword lists may thus give rise to many errors by SRD-children as a result of their very limited knowledge of grapheme-phoneme correspondence rules. This knowledge has been argued to be necessary to secure the accurate selection and blending of segments in the preparation of output phonology (e.g. Baron and Strawson, 1976). However, it appears possible that training involving explicit exposure to recurring multi-letter strings assists SRD-children to read other words which also contain them (see the study on Dutch SRD children by Van Daal,
This study has demonstrated clearly that it should not be assumed that all SRD-children have a speech perceptual problem associated with their reading delay. The results for the VCV and consonant-cluster discrimination tests showed that individual error-rates did not form a continuous distribution. Use of the objective criterion of at least one standard deviation below the corresponding RA-group mean score confirmed the partitioning of children into either the "PW" or the "NP" sub-group. Partitioning on the same basis was also shown to be valid for a second (unselected) group of SRD-children, suggesting that this may be a true feature of the SRD population as a whole, irrespective of chronological age.

The extent of the discrimination-weaknesses of SRD-children has not previously been examined systematically. Save for the occurrence of phonemes /m/ and /n/ in either medial or final position in words to be discriminated in the Wepman test and used by Masterson et al. (1995), confusions of approximant and nasal contrasts had not been previously been demonstrated for SRD subjects, nor for "language-impaired" groups of children.

Previous studies have tended to use only single-consonant contrasts which differ in only one phonemic feature (e.g. Gregory et al., 1981; Hurford and Sanders, 1990; Mody, 1993; and Reed, 1989). This study is the first to ask whether phonological complexity has a particular effect for SRD children on the distinctiveness of phonemes. It has been shown that, for natural speech stimuli, the perceptual "weakness" of a sub-group of SRD-children can include, for consonant-cluster onsets, the relatively inaccurate discrimination of pairs with target-phonemes differing in manner-of-articulation, as well as those differing only in terms of voicing and/or place-of-articulation. In this respect, the discrimination skills of these children appear somewhat susceptible to "phonological" complexity. Given the high incidence of consonant clusters in English orthography and the high, maintained, speech-rate of fluent (native) speakers, a considerable proportion
of the speech signal will be phonologically complex and present a potentially-significant problem for some SRD (and, presumably, some LI) children and adults. Difficulties with the processing of speech patterns which are acoustically and phonetically complex obviously creates implications of how generally this might undermine their establishment of stable grapheme-phoneme correspondences.

* The speech-perceptual weakness includes a broad tendency to perceive "same" pairs stimuli as different with a similar frequency as perceiving "different" pairs as the same. This shows that there is no evidence of a systematic response-bias being used, but reflects perceptual judgements based on the internal representation of the properties of both types of stimulus pair.

* A vowel context effect in the discrimination of certain phoneme-contrasts was indicated in previous studies (e.g. Tallal et al., 1996) but this work is the first to demonstrate systematically that it can apply to the discrimination of fricative and nasal contrasts as well as stop contrasts. What was also made clear is that this effect was shown by language-normal controls as well as by SRD-children, for the same sub-set of contrasts. This result indicates that vowel context is a strong factor in the determination of cue-salience, and that difficulties with phoneme-discrimination shown for SRD-children are possibly context-dependent.

* The identification data showed that, within the necessary constraints of comparing the results of subject groups with those of smaller sub-groups, some "PW" children were able to make similar contrastive use of more-highly weighted ("primary") cues, notably the F2 transition paths in both the full- and reduced-cues DATE-GATE continua. Also, in common with some of the "NP" sub-group of SRD-children, and with controls, a number of the "PW" sub-group of children seemed to be able to use the burst cue contrastively. However, they were significantly weaker than other subjects in making contrastive use of friction duration in the reduced-cues version of the fricative voice continuum. It may be the case that "PW" children are less able generally to make use of "secondary"
acoustic-cues in labelling tasks.

* Whilst SRD children differed on most discrimination tasks, there was general deficiency on the repetition of longer nonword items. Similarities existed in the type of repetition errors made on a sub-set of nonword items between the SRD and RA control groups. Psycholinguistic factors such as the ability to blend novel speech material and to distribute attention adequately, within short-term working memory, across storage and articulatory planning tasks appeared responsible for some of the variance. Younger controls were also much less skilled than older LN children at this task, and may similarly have been performing near the limits of their phonological acuity and working memory. A group of SRD children have also been shown to be weaker than CA controls at repeating longer, familiar real words (Brady, Poggie and Rapala, 1989). It was clear from an informal analysis of the accuracy shown for a selected prose passage within the Neale Reading test (this dissertation) that both SRD and RA control children made errors of a similar type to substantially the same set of multi-syllabic words. These included consonant substitutions and medial syllable deletions. It appears that some of the decoding problems of SRD children considered in this thesis and in, for instance the Brady et al. (1989) study, are closely related to the meta-phonological limitations that are developmentally normal in younger children, except that the performance of the former is generally weaker still. For both groups, bizarre reading errors (phonologically implausible) were rare.

* The use of longer nonword items has elsewhere, as in this thesis, indicated limits to the psycholinguistic skills, possibly involving the distribution of auditory attention and the functional size of working STM, of SRD children and reading-age matched LN listeners. These difficulties often seem to apply irrespective of lexical status and largely irrespective of the familiarity of longer real words.

* In order to establish whether, for any individual SRD listener, the "weighting"
of particular acoustic-phonetic cues may be heavier than for others in a given minimal-pair discrimination, a set of modified CV or CVC tokens could be used in perceptual re-training. Baseline scores would be acquired through the use of unenhanced recordings on a range of minimal-pairs. Very precise local modifications can be made to natural speech tokens, following the method outlined in Hazan and Simpson (1998); Simpson and Hazan (1997). It is possible to increase the amplitude of one or more portions of specific acoustic events in what then become different versions of a contrast. Their continued presentation in successive training trials for different sub-groups of listeners might show whether any or all such enhancements improved discrimination. Identification consistency could then be tested by using similarly-modified continua for the same contrasts. Younger (RA) controls might also show post-training improvements for the same speech materials. This design avoids the conditions introduced in the Merzenich et al. (1996) trials, where amplitude enhancement of most or all of the consonantal segments of nonsense syllables seems to have occurred, together with changes in consonant duration and inter-stimulus interval. By segregating different feature-enhancements in different recorded versions of the same contrast, it may also be possible to highlight individual differences in their perceptual effectiveness following training, when presentation of the un-enhanced stimuli would be reintroduced.

* A subsequent stage of remediation could involve the structured visual presentation of, say, the CVC, VC or CV syllables which together comprise a 3- or 4-syllable word. Their appearance individually on screen in their natural order would coincide temporally with the recorded presentation, binaurally over earphones, of one or more enhanced versions of the corresponding phonology. The letter-strings would appear horizontally separated on the monitor, whilst the entire sequence was repeated without blending. Controlling the speech feedback in this way would follow the general approach used by Elbro et al. (1996). Next, the first two syllables would then be joined with the utterance presented simultaneously (and repeated) to assist with awareness of the correct blending. This routine would
be repeated for each additional syllable until the letter-string is complete. The explicit presentation of syllable boundaries, coupled with amplitude-enhanced speech signals, would hopefully begin to strengthen a child’s knowledge of particular syllabic structures, in conjunction with that of the overall sound-pattern. Of further use might be extended training on phonological units which related to syllables common to several different words appropriate to their spoken vocabulary.

This study is the first to show that at least two individual SRD-children who were weak on real-speech discrimination were able, specifically, to use formant frequency transition information contrastively. This is a direct contradiction of Tallal’s claim that SRD and language-impaired children have a deficit, for CV stimuli, in the perception of formant frequency transition information. The results also suggest that there may be large differences in the extent to which individual members of such a sub-group can utilise this and other cue-information in a labelling task. The variation in labelling consistency by members of the "NP" sub-group and by controls emphasises the limited value of plotting data points for identification functions that are based only on group/sub-group means.

4.8. Proposals for further research.

The difference in performance on individual speech-discrimination tests was defined by reference to accuracy-levels at least one standard deviation below the mean of the equivalent scores of the reading-age group. In circumstances where access to suitable children was restricted in terms of numbers, a small number of children were nevertheless found who gave evidence of speech-perceptual weakness. In order to make parametric statistical analysis possible, a follow-up study would be needed to assess the strength of the proposed link between particular patterns of reading-list accuracy and speech perceptual acuity.
A large number of volunteer SRD-children would need to be screened on Neale Analysis (accuracy), the reading-lists, and presentations of speech-discrimination stimuli in order to efficiently assemble same-size sub-groups of "perceptually-weak" and "perceptually-normal" SRD individuals. These results would again be correlated with data on their individual patterns of reading-error and estimated reading delay. An attempt would be included to test for frank differences in the levels of alphabetic knowledge by reading group, by including tests of letter naming and letter sounds. Groups of CA and RA controls and SRD (NP) and SRD (PW) listeners, each with about 20 members, would be needed, paying particular attention to the pair-wise matching of reading-impaired and RA-control children.

To assist in this the original criterion for chronological age range (9 to 12 years inclusive) and delay-range (18 to 36 months inclusive) would be retained, as would the testing of subjects individually. As before, RA-controls would be carefully selected with reference to their estimated (Neale reading accuracy) age-equivalent score. To ensure control of written vocabulary level, real-word stimuli would again be drawn from the appropriate Alpha-listings.

The investigation would include the following issues:

* Whether significant heterogeneity of speech-perceptual skills is a basic characteristic of larger sample-groups of SRD-subjects;

* How closely group-heterogeneity in speech-perceptual acuity can be tied to the incidence of developmental phonological dyslexia, using the criterion that the irregular word reading of each "PW" SRD-child is at least 30 percentage points more accurate than his/her nonword reading;

* Whether any children who could be reasonably described as speech-perceptually "weak" have relative difficulty with all VCV discrimination, consonant-cluster discrimination, and nonword-repetition tests, or only a majority of them;
* Whether there are any cases of children showing reasonable nonword reading skills (say 20% errors or less) but with consistent speech-based perceptual weakness;

* Whether the effects of stimulus-complexity consist: i) of confusions in the discrimination of contrasts marked by larger phonetic-feature differences, as well as of many of those marked by single phonetic-feature differences in consonant-cluster (substitution) discrimination, and ii) of phoneme-omission in the consonant-cluster (omission) condition;

* Whether some individuals in all subject-groups show labelling inconsistency, particularly for reduced-cue continua; and

* Whether some individuals in all subject-groups show inconsistency in a more extensive, systematic test of the effect of vocalic context in the discrimination of naturally produced minimal-pairs.

Depending on the distribution of chronological age of the SRD and normally reading children who come forward, there may be a case for using two experimental groups (e.g. one of children aged 9-12 years, another of children aged 13-16 years). Under these circumstances, it would of course be necessary to provide a second matched-pairs RA control group.

Developmental phonological dyslexia may persist at least into adolescence (despite possible improvements in reading accuracy due to remediation programs and/or reading strategies utilising contextual information). In such cases a test of reading-accuracy to screen subjects may be inappropriate. A supplementary screening test of, say, spelling-to-dictation may be necessary to establish the extent of their phonological awareness, before proceeding to tests of speech-perceptual acuity. The ability to test the speech-perceptual acuity of adolescent and adult SRD groups
would establish whether:

* Persistence of weakness in speech-discrimination obtains, as was indicated in the work reported here on the “unselected” group of SRD children, for a range of phoneme contrasts;

* It would be appropriate, in principle, to re-test, at least once, the discrimination and identification skills of a younger group of reading-disabled children after a suitable interval, using the original stimuli.
REFERENCES


* 


* 


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Memory, 2(2), 103-127.

gratings: A criterion problem for measuring visual persistence. Vision
Research, 25, 1729-1733.


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Appendix A.

Chapter 2. Pilot minimal-pair test: preliminary trials.

The phonetic features by which each contrast differs are indicated by M = manner-of-articulation and P = place-of-articulation., V = voicing

EXAMPLES

1. hit lit  /hit/  /lit/  diff MVP
2. fine wine  /fain/  /wain/  diff MVP
3. meal meal  /mil/  /mil/  
4. done won  /dən/  /wən/  diff MP

PRACTICE TRIALS

1. hot pot  /hot/  /pôt/  diff MP
2. more for  /mə/  /fə/  diff MVP
3. tin win  /tın/  /wın/  diff MVP
4. read need  /rid/  /nid/  diff MP
5. bite light  /bait/  /lait/  diff MP
6. sack pack  /sæk/  /pæk/  diff MP
7. leaf leaf  /lif/  /lif/  

The pilot test began, and the experimenter said:-

"Now I'm going to start the tape and, in a moment, you'll hear the words over these headphones in your right ear only. If you want to have a break at any time, just tell me and I will stop the tape."

The listener was told to place the headphones so that the one with the red marker was over his/her right ear, and to adjust them until they fitted comfortably. When s/he was ready the tape was started.
Chapter 3.

Table 11. Data calculated for standardised tests for SRD listeners (n = 13) being the Neale (Revised) Accuracy and Comprehension tests with both scores expressed as an equivalent reading age, and Ravens’ Progressive Matrices (RPM) with the score expressed as a percentile. C.A. = chronological age. Delays refer to reading accuracy and are given in "years; months" format.

<table>
<thead>
<tr>
<th>SUB.</th>
<th>C.A.</th>
<th>ACCURACY</th>
<th>COMP.</th>
<th>RPM</th>
<th>DELAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
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<td>12;1</td>
<td>82</td>
<td>2;10</td>
</tr>
<tr>
<td>E2</td>
<td>10;5</td>
<td>8;1</td>
<td>10;2</td>
<td>75</td>
<td>2;4</td>
</tr>
<tr>
<td>E3</td>
<td>10;6</td>
<td>7;8</td>
<td>9;8</td>
<td>95</td>
<td>2;10</td>
</tr>
<tr>
<td>E4</td>
<td>10;11</td>
<td>9;5</td>
<td>13;0</td>
<td>73</td>
<td>1;6</td>
</tr>
<tr>
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<td>10;9</td>
<td>9;3</td>
<td>12;1</td>
<td>95</td>
<td>1;6</td>
</tr>
<tr>
<td>E6</td>
<td>9;5</td>
<td>7;4</td>
<td>9;8</td>
<td>85</td>
<td>2;1</td>
</tr>
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<td>7;4</td>
<td>7;11</td>
<td>64</td>
<td>2;4</td>
</tr>
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<td>7;10</td>
<td>9;5</td>
<td>54</td>
<td>2;8</td>
</tr>
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<td>9;3</td>
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<td>10;6</td>
<td>95</td>
<td>2;5</td>
</tr>
<tr>
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<td>7;9</td>
<td>9;8</td>
<td>81</td>
<td>2;1</td>
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<td>E11</td>
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<td>10;1</td>
<td>12;8</td>
<td>67</td>
<td>1;6</td>
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<td>9;2</td>
<td>95</td>
<td>2;9</td>
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<td>7;7</td>
<td>10;6</td>
<td>95</td>
<td>2;4</td>
</tr>
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<td>Mean</td>
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<td>10;6</td>
<td>81</td>
<td>2;3</td>
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<td>S.D.</td>
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<td>0;11</td>
<td>1;6</td>
<td>14</td>
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Table 12. Data calculated for standardised tests for the chronological age (CA) control group (n=12), being Neale-(R) Accuracy and Comprehension, (scores expressed as an equivalent reading-age), and Ravens’ Progressive Matrices (scores given as a percentile).

<table>
<thead>
<tr>
<th>SUB.</th>
<th>C.A.</th>
<th>ACCURACY</th>
<th>COMP.</th>
<th>RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>10;8</td>
<td>13;0</td>
<td>13;0</td>
<td>95</td>
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<td>10;0</td>
<td>9;6</td>
<td>8;11</td>
<td>64</td>
</tr>
<tr>
<td>C4</td>
<td>10;8</td>
<td>13;0</td>
<td>13;0</td>
<td>92</td>
</tr>
<tr>
<td>C5</td>
<td>9;3</td>
<td>13;0</td>
<td>13;0</td>
<td>95</td>
</tr>
<tr>
<td>C6</td>
<td>9;11</td>
<td>11;10</td>
<td>9;11</td>
<td>90</td>
</tr>
<tr>
<td>C7</td>
<td>11;2</td>
<td>13;0</td>
<td>13;0</td>
<td>88</td>
</tr>
<tr>
<td>C8</td>
<td>9;6</td>
<td>10;10</td>
<td>13;0</td>
<td>95</td>
</tr>
<tr>
<td>C9</td>
<td>9;6</td>
<td>10;11</td>
<td>11;4</td>
<td>95</td>
</tr>
<tr>
<td>C10</td>
<td>10;5</td>
<td>12;10</td>
<td>13;0</td>
<td>85</td>
</tr>
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</tr>
<tr>
<td>C12</td>
<td>9;5</td>
<td>8;3</td>
<td>9;8</td>
<td>84</td>
</tr>
<tr>
<td>Mean</td>
<td>10;1</td>
<td>11;9</td>
<td>12;7</td>
<td>88</td>
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<tr>
<td>S.D.</td>
<td>0;8</td>
<td>1;7</td>
<td>1;5</td>
<td>9</td>
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</tbody>
</table>
TABLE 13. Data calculated for standardised tests for the Reading-Age (RA) matched control group (n=12), being Neale-(R) Accuracy and Comprehension (scores expressed as an equivalent reading-age), and Raven's Progressive Matrices (scores given as a percentile).

<table>
<thead>
<tr>
<th>SUB.</th>
<th>C.A.</th>
<th>ACCURACY</th>
<th>COMP.</th>
<th>RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
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<td>9;2</td>
<td>27</td>
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<td>R2</td>
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<td>11;4</td>
<td>90</td>
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<td>R3</td>
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<td>8;1</td>
<td>10;2</td>
<td>56</td>
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<td>8;8</td>
<td>62</td>
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<tr>
<td>R5</td>
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<td>9;11</td>
<td>10;6</td>
<td>65</td>
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<td>11;1</td>
<td>94</td>
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<td>55</td>
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<td>R9</td>
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</tr>
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<td>R10</td>
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<td>7;11</td>
<td>8;5</td>
<td>84</td>
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<tr>
<td>R11</td>
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<td>7;6</td>
<td>8;5</td>
<td>95</td>
</tr>
<tr>
<td>R12</td>
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<td>6;10</td>
<td>8;11</td>
<td>95</td>
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<tr>
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<td>8;1</td>
<td>9;5</td>
<td>75</td>
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<td>0;11</td>
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<td>22</td>
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TABLE 14. Error scores (percent) for the SRD children on the Regular (REG), Irregular (IRR) and Nonword (NW) reading list tests, the intervocalic (VCV) discrimination test, the consonant cluster "Substitution" (CC(S)) and "Omission" (CC(O)) discrimination tests. The estimated mean reading rate for each reading test (seconds per item) is given under 'rate'.

<table>
<thead>
<tr>
<th>SUB.</th>
<th>REG, rate</th>
<th>IRR, rate</th>
<th>NW rate</th>
<th>VCV rate</th>
<th>CC(S)</th>
<th>CC(O)</th>
<th>C.A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>1.55</td>
<td>1.85</td>
<td>55</td>
<td>2.06</td>
<td>2.1</td>
<td>5</td>
<td>10;9</td>
</tr>
<tr>
<td>E2</td>
<td>3.9</td>
<td>2.75</td>
<td>60</td>
<td>1.91</td>
<td>0.4</td>
<td>1.2</td>
<td>10;5</td>
</tr>
<tr>
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<td>2.19</td>
<td>3.19</td>
<td>65</td>
<td>2.62</td>
<td>0.4</td>
<td>1.2</td>
<td>10;6</td>
</tr>
<tr>
<td>E4</td>
<td>5.15</td>
<td>10</td>
<td>35</td>
<td>3.97</td>
<td>2.5</td>
<td>1.2</td>
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<td>5.12</td>
<td>14.6</td>
<td>30</td>
<td>2.62</td>
<td>1.7</td>
<td>1.2</td>
<td>10;9</td>
</tr>
<tr>
<td>E6</td>
<td>30</td>
<td>4.35</td>
<td>60</td>
<td>5.4</td>
<td>1.2</td>
<td>1.2</td>
<td>9;5</td>
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<td>25</td>
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<td>5</td>
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<tr>
<td>E8</td>
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<td>30</td>
<td>1.7</td>
<td>55</td>
<td>2.17</td>
<td>1.7</td>
<td>10;6</td>
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<tr>
<td>E9</td>
<td>50</td>
<td>3.55</td>
<td>35</td>
<td>4.45</td>
<td>2.37</td>
<td>13.8</td>
<td>2.5</td>
</tr>
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<td>1.88</td>
<td>30</td>
<td>3.34</td>
<td>1.3</td>
<td>1.2</td>
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<tr>
<td>E11</td>
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<td>5</td>
<td>1.2</td>
<td>60</td>
<td>1.7</td>
<td>21.7</td>
<td>17.5</td>
</tr>
<tr>
<td>E12</td>
<td>20</td>
<td>5.12</td>
<td>75</td>
<td>3.12</td>
<td>28</td>
<td>28</td>
<td>37</td>
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<tr>
<td>E13</td>
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<td>85</td>
<td>4.57</td>
<td>0</td>
<td>3.1</td>
<td>9;11</td>
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<tr>
<td>Mean</td>
<td>18</td>
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<td>3.04</td>
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<td>1.29</td>
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<td>1.11</td>
<td>9.1</td>
<td>8.3</td>
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<td>3.33</td>
<td>1.8</td>
<td>2</td>
<td>1</td>
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<tr>
<td>RA</td>
<td>11</td>
<td>1.78</td>
<td>21</td>
<td>1.93</td>
<td>1.5</td>
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<td>1.26</td>
<td>11</td>
<td>1.7</td>
<td>1.9</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
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<td>0.63</td>
<td>13</td>
<td>0.92</td>
<td>1.6</td>
<td>1</td>
<td>0.6</td>
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TABLE 15. Error scores (%) for the chronological-age control (CA) group for the Regular, Irregular and Nonword reading list tests and the consonant-cluster and VCV speech discrimination tests. Individual reading rates for each list are given under ‘rate’.

<table>
<thead>
<tr>
<th>SUB.</th>
<th>REG. rate</th>
<th>IRREG. rate</th>
<th>NW rate</th>
<th>VCV rate</th>
<th>CC(S)</th>
<th>CC(O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>0.121</td>
<td>5.113</td>
<td>15.123</td>
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<td>0</td>
<td></td>
</tr>
<tr>
<td>C2</td>
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<td>10.136</td>
<td>1.2</td>
<td>3.1</td>
<td>1.9</td>
</tr>
<tr>
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<td>5.123</td>
<td>15.168</td>
<td>20.248</td>
<td>1.2</td>
<td>1.9</td>
<td>0</td>
</tr>
<tr>
<td>C4</td>
<td>0.108</td>
<td>5.115</td>
<td>10.103</td>
<td>1.2</td>
<td>0.0</td>
<td>0.6</td>
</tr>
<tr>
<td>C5</td>
<td>0.18</td>
<td>5.17</td>
<td>5.115</td>
<td>2.9</td>
<td>0.6</td>
<td>0</td>
</tr>
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<td>C6</td>
<td>0.79</td>
<td>5.078</td>
<td>50.107</td>
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<td>0.6</td>
<td>0</td>
</tr>
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<td>0.92</td>
<td>5.094</td>
<td>2.28</td>
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<td>0.6</td>
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<td>1.2</td>
</tr>
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<td>C9</td>
<td>0.75</td>
<td>5.085</td>
<td>5.117</td>
<td>0</td>
<td>0</td>
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<tr>
<td>C10</td>
<td>0.125</td>
<td>10.085</td>
<td>5.15</td>
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<td>0.6</td>
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<td>C11</td>
<td>0.64</td>
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<td>0</td>
<td>1.06</td>
<td>0.8</td>
<td>0</td>
</tr>
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<td>40.417</td>
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<td>0</td>
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<td>11.17</td>
<td>1.9</td>
<td>0.8</td>
<td>0.5</td>
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<td>S.D.</td>
<td>2.036</td>
<td>5.063</td>
<td>13.092</td>
<td>1.6</td>
<td>1</td>
<td>0.6</td>
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</table>

TABLE 16. Error scores (%) for the Reading-Age matched (RA) control group for the Regular, Irregular and Nonword reading list tests, and the consonant-cluster and VCV speech discrimination tests. Individual reading rates for each list are given under ‘rate’.

<table>
<thead>
<tr>
<th>SUB.</th>
<th>REG. rate</th>
<th>IRREG. rate</th>
<th>NW rate</th>
<th>VCV rate</th>
<th>CC(S)</th>
<th>CC(O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>2.01</td>
<td>15.21</td>
<td>15.3</td>
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<td>0</td>
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<tr>
<td>R2</td>
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<td>15.144</td>
<td>20.189</td>
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<td>0.6</td>
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<td>R3</td>
<td>2.35</td>
<td>15.168</td>
<td>35.263</td>
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<td>6.2</td>
<td>0.6</td>
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<td>0.72</td>
<td>10.115</td>
<td>25.157</td>
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<td>9.4</td>
<td>6.9</td>
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<td>0.59</td>
<td>5.09</td>
<td>5.121</td>
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<td>3.1</td>
<td>1.9</td>
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Appendix B.

Medical-educational questionnaire.

SUBJECT PROFILE SHEET.

Subject initials ....................... Gender ....................... Date of birth ............ / ........... /19 Age .....................

School .................................. District .........................

NEALE ANALYSIS

Date tested / /19 Accuracy .............. * Comprehension ...... * Estimated R.A. yr. mo.

RAVENS PROGRESSIVE MATRICES Date tested / /19 Score ........

MEDICAL HISTORY


Normal complex-tone thresholds? y / n. Otitis media? y / n / NK.

If yes, how many OM episodes? From what age? yr. mo.


Sensori-neural/other hearing loss? y / n. Other clinical information:

REMEDICATION

Is this made available usually on the school premises?

What methods used for this child?

When and how often made available?

What is the average LENGTH and NUMBER of sessions / week?

Overall, how long has this child been receiving such training?

Hand used for writing: Familial dyslexia y / n.

Details .........................
## Appendix C.

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<tr>
<th>REGULAR</th>
<th>IRREGULAR</th>
<th>NONWORD</th>
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<tr>
<td>take /teɪk/</td>
<td>come /kʌm/</td>
<td>deat /dɪt/</td>
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<tr>
<td>free /fri/</td>
<td>sure /ʃər/</td>
<td>poad /pɔʊd/</td>
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<td>market /mɑkɪt/</td>
<td>island /aɪlənd/</td>
<td>valm /vælm/, /vɑlmd/</td>
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<td>answer /ˈɑnsər/</td>
<td>faft /fæft/, /faft/</td>
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<td>blind /blaɪnd/</td>
<td>bolk / bolk/</td>
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<td>pretty /ˈprɪti/</td>
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<td>break /breɪk/</td>
<td>vook / vʊk/, /vʊk/</td>
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<td>iron /aɪrən/</td>
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<td>knee /ni/</td>
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<td>pear /peə/</td>
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<td>zoul / zɔul/, /zʊl/, /zəʊl/</td>
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