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Speech Perception in Children With Specific Reading Difficulties (Dyslexia)

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Many experimental studies over the last two decades have suggested that groups of children who suffer significant delay in reading also show a weakness in phoneme discrimination and identification. In order to look further at the relation between type of reading deficit, auditory acuity, and speech discrimination, a group of 13 children with specific reading difficulty (SRD), 12 chronological-age controls, and 12 reading-age controls were tested on a battery of speech-perceptual, psychoacoustic, and reading tests. A sub-group of children with Specific Reading Difficulty (SRD) were poor at speech discrimination tests, whereas the rest of the SRD group performed within norms. For this sub-group, discrimination performance was particularly poor for consonant contrasts differing in a single feature that was not acoustically salient, and problems were encountered with nasal and fricative contrasts as well as with stop contrasts. These children did not differ from controls in their performance on non-speech psychoacoustic tasks. An evaluation is made of the reported phonemic awareness skills of beginning readers with regard to speech-processing issues which may help in understanding what factors are important in reading development.

Research interest in the general area of language difficulty in children has grown amongst specialists in several fields, particularly over the last two decades. One of the central issues in developmental language difficulty arises from the possible limitations in perceptual and/or cognitive processing that could come to affect an individual's acquisition of reading and spelling skills. Efficient reading is a multi-component task, and attempts to discover which processes are vital to word recognition and sentence comprehension

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have often taken the developmental perspective (e.g. Snyder & Downey, 1991). Recent theories of reading development (e.g. Frith, 1985; Seymour, 1985) have emphasized the role of alphabetic and orthographic processing, and many experimental studies have looked specifically at the decoding and speech-discrimination abilities of nursery and primary-school children (e.g. Lenel & Cantor, 1981). Comparative studies of older children with reading difficulties have often produced measures of their phonological awareness that were similar to those of younger children (e.g. Aguiar & Brady, 1991; Treiman, 1984). Empirical evidence is accumulating that Specific Reading Difficulty (dyslexia) is, for many reading-disabled children, correlated with a relative weakness in tests of phonological awareness, phoneme discrimination, and segmentation (e.g. Catts, 1993; Mark, Shankweiler, Liberman, & Fowler, 1977; Snowling, 1981; Werker & Tees, 1987), of temporal order in speech (Cole & Scott, 1973), or of serial ordering (Corkin, 1974).

Early studies of perceptual abilities in a language-disabled population by Tallal and her colleagues using discrimination and temporal order judgement tasks suggested a selective impairment of consonant perception in dysphasic children (Tallal & Piercy, 1974, 1975; Tallal & Stark, 1981). It was concluded that developmental dysphasics had problems with discriminating consonant–vowel (CV) syllables because of "the brief duration of the discriminable components", and that particular problems arise in discriminating such stimuli when they are presented in rapid succession. As these children also showed difficulties in processing short tones (Tallal & Piercy, 1974, 1975), it was felt that they had a general auditory deficit in processing brief signals. More recently, Tallal and her colleagues have claimed some success in improving speech discrimination in such children after a period of training using speech in which temporal cues had been enhanced (Tallal et al., 1996). Tallal and her colleagues have mainly evaluated the perception of stop consonants, as they are marked by short and rapidly changing acoustic patterns. Many subsequent studies also focused on the identification of syllables containing an initial stop consonant (e.g. / ba/ versus / da/ and / da/ versus / ga/). Godfrey, Syrdal-Lasky, Millay, and Knox (1981), for example, demonstrated that the phoneme categories of SRD children were less sharply defined for their / da/ –/ ga/ than for their / ba/ –/ da/ contrasts and that identification functions for both contrasts had shallower gradients than those of adequately reading children of the same age.

However, the argument that problems were linked to a *general* auditory deficit was countered in a study by Tobey and Cullen (1984) testing children aged about 10 to 17 years with auditory memory and reading deficits. The experimental children were able to detect both simple and complex short-duration stimuli (fixed-frequency tones and both rising and falling brief tone-glides) about as well as did the normal age-matched controls. Signal durations for both tones and glides ranged from 5 to 120 msec, which cover those expected for formant transitions intrinsic to stop-consonants. Their suggestion was, therefore, that the problem was not one of auditory discrimination but was speech-specific.

The views of Tallal and her colleagues have also been challenged by more recent data. In their recent review, Studdert-Kennedy and Mody (1995) argue that Tallal's data on the temporal order judgement tests show that some children do indeed have difficulties in processing stimuli at rapid rates of presentation, but that this should not be confused with "a defect in temporal acoustic processing". Mody (1993) compared the discrimination of /ba/–/da/ with that of /ba/–/sa/ and /da/–/ʃa/ at short interstimulus intervals (ISIs) in SRD children. She found that errors increased with a decrease in ISI for the /ba/–/da/ contrast but not for the other contrasts. Also, children were not affected by decreasing ISIs in tests of auditory discrimination using non-speech stimuli. She therefore concluded that the problem experienced by the children was not linked to poor auditory discrimination or to the processing of rapidly changing transitions but, rather, to the processing of highly similar stimuli (i.e. differing in a single feature) presented in rapid succession.

Furthermore, recent studies have shown perceptual deficits in some reading-impaired listeners that are not limited to phonetic contrasts cued by brief pattern changes. Masterson, Hazan, and Wijayatilake (1995) have shown that the errors in phoneme discrimination made by two adult phonological dyslexics included evidence of problems with certain fricative contrasts such as /θ/–/f/ and /f/–/v/ in minimal-pair judgements, whereas consonant identification tests showed labelling errors, amongst others, of /p/ as /b/, /ð/ as /v/ and /f/ as /θ/. The unreliable labelling and discrimination of fricatives presented in three vowel environments (/i/, /a/ and /u/) is of great interest, as, for adults at least, the formant transitions into the following vowel are not the primary acoustic cues to place of articulation (Nittrouer, 1992). As in Mody’s study, errors were made for pairs of sounds that differed in a single feature and were acoustically similar (e.g. /θ/–/f/).

Problems in interpreting these findings may partly stem from the undifferentiated nature of the listener groups with respect to phonological difficulties (Elliott, Hammer, & Scholl, 1990; Godfrey et al., 1981; Lieberman, Meskill, Chatillon, & Schupack, 1985; Reed, 1989; Tallal & Stark, 1981; Werker & Tees, 1987). Definitions of distinctly different types of profiles of childhood dyslexia are not easily made, although Seymour (1985) gave specific error data on individual children who could be described as either “phonological” or “morphemic” dyslexics. For the phonological dyslexics, the main feature was said to be a large discrepancy in performance on irregular word and nonword reading tasks. Morphemic dyslexics tend to produce regularization errors, and Seymour and MacGregor (1984) claimed that this form of developmental dyslexia favoured “serial letter-by-letter processing at the expense of whole words or multi-letter segments”. This, in turn, was proposed as being due to “a primary disturbance of the wholistic function of the visual (graphemic) processor”. Morphemic dyslexics tend to make more errors as word-length increases, whereas phonological dyslexics do not—they make most of their errors when reading irregular words. Castles and Coltheart (1993) examined the regular, irregular, and nonword reading performance of a group of 56 developmental dyslexics compared to that of normally developing readers. They investigated the possibility of dissociating the reading-disabled sample into phonological and morphemic dyslexic groups based on deviations from a normative regression line. The conclusion was that a double dissociation existed between surface and phonological dyslexic reading patterns but that many of the children could simply not be classified in this way.

If phonologically dyslexic children have most difficulty with phonemic awareness, this may be, at least in part, because their ability to identify and discriminate particular phonemes, and subsequent alphabetic knowledge, is unreliable or unstable at a perceptual level. Such confusions might not be as frequent with “morphemic” children. Therefore, undifferentiated groups of language-disabled children might yield data that give a distorted picture of the relative importance of speech perceptual deficits in the reading-disabled population.

The encoding of phonological segments in a continuous acoustic signal could remain a problem for some time after a child begins to read at school. A study by Fowler, Liberman, and Shankweiler (1977) showed that there was a consistent tendency by 7- to 9-year-old normally developing children to misread the final consonant and particularly the medial vowel in real monosyllabic CVC words. The older children made fewer errors on all measures, and the conclusion was that the beginning readers were comparatively weak at syllable segmentation. The errors in consonant identification reported by Fowler et al. were always close to the actual phoneme, with the response often sharing many features with the target phoneme, but the vowel errors were more random in terms of feature-similarity. This finding resembles the consonant confusions with auditory presentation in increasing levels of noise collected from adult listeners by Miller and Nicely (1955).

The aims of this study were two-fold. The first was to discover whether a proportion of children within a reading-disabled group were performing outside normal limits in a range of speech discrimination tests and to relate performance on speech tests to performance on reading tests that highlight specific patterns of reading errors (based on Castles & Coltheart, 1993). The second aim was to determine the types of phonetic contrast for which discrimination errors are obtained for these reading-disabled children. In order to do this, a battery of speech discrimination and identification tests was used, which included a wide range of consonant contrasts of varying levels of complexity and of differing degrees of acoustic salience. In order to corroborate previous findings that deficits are at the level of phonetic processing rather than linked to general auditory deficits, the children were also given psychoacoustic tests of temporal and frequency acuity.

THE EXPERIMENT

Method

Listeners

The experimental group comprised children with reading problems who were referred by class teachers and/ or remedial teachers working within local authority (state) junior schools in North West London and South Hertfordshire. The selection criteria used were that: (a) children were aged between 9 and 12 years; (b) they had English as their mother tongue; (c) they were suffering no emotional problems due to causes other than those that might arise from their reading problem; (d) their reading delay was within the range of 18–36 months, as determined by their performance on the Neale Analysis (British edition)–Revised (1989) administered to all children by the first author; and (e) they had no current or earlier problems with speech production.[1]

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[1] No use was made, as an exclusion criterion, of the approximate socio-economic status of participants' parents, nor of matching subjects by gender or by handedness for writing, although a careful note was kept of these last two variables.

The Neale Analysis test was chosen as it is commonly in use in the schools in which the children were tested and has been standardized internationally over many years. Raven's Progressive Matrices (Raven, Court, & Raven, 1988) were used to estimate non-verbal intelligence.

The experimental group included 9 boys and 4 girls aged between 9;3 and 11;7 yrs (mean: 10;4 years). Their mean reading delay was 27 months, and their reading age ranged between 6;10 and 10;1 yrs (mean: 8;1 yrs). Details of their RPM, Neale accuracy, and comprehension scores are included in Table 1. Twelve of the children were right-handed, and one left-handed for writing.

Two groups of controls were tested. Reading-age controls were necessary to compare experimental children's performance on the reading tests with children of an equivalent reading experience. Chronological-age controls were also tested, as they would have the same degree of maturity as the experimental children in terms of their speech perceptual development.

The chronological-age-matched (CA) control group comprising 12 children (8 boys and 4 girls) aged between 9;3 and 11;2 years (mean: 10;1 years) was drawn substantially from the same school classes as were the SRD children on the same exclusion criteria. Each child's reading skills were considered to be at least age-appropriate, although in practice many were reading beyond their age-equivalent range (reading age range: 9;6–13+ years, mean: 11;9 years). Mean scores on standard tests are given in Table 1. Nine were right-handed and three left-handed for writing.

The reading-age-matched (RA) control group also comprised 12 children (6 boys and 6 girls) aged between 7;7 and 8;9 years (mean: 8;2 years). Each child was chosen so as to have a reading age within two months of the reading age of one of the experimental children (reading age range: 6;10 to 9;11 yrs; mean: 8;2 yrs). Mean scores on standard tests are given in Table 1. Ten were right-handed and two left-handed for writing.

Test Materials

Test of Reading Accuracy. Lists of regular and irregular words and nonwords were presented in order to judge the decoding of regular phonology and also to look at the difference in performance between irregular and nonword reading, which is seen as indicative of ‘‘phonological’’ dyslexia. All words used were taken from an age-appropriate vocabulary list—the Alpha (7) list (Edwards & Gibbon, 1964). From Castles and Coltheart (1993) we drew 11 regular and 11 irregular words, which fulfilled this criterion; a further 9 words in each category were chosen from the Alpha list.[2]

The 20 nonwords used were derived from the monosyllabic lists of two recently published sources: Castles and Coltheart (1993), and Laxon, Masterson, and Coltheart (1991). Nonwords were scored by reference to the production of a monosyllabic response and regular phonemic pronunciation, and, as children were instructed that these were ‘‘nonsense words’’, without reference to the pronunciation of real words that some might resemble (assuming adequate lexical knowledge). Full listings of the reading-test items, including the acceptable pronunciations for each nonword item, are included in Appendix A.

Speech Discrimination Tests. A battery of speech discrimination tests was prepared. The test material is described below. For all tests, anechoic recordings of the word list produced by one of three phonetically trained English RP speakers (one male, two female) were made onto a DAT

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[2] The issue of word-selection for the regular and irregular lists is not a straightforward one and needs some rationalization. Words included in previous studies were kept in the same category as when previously used. Close letter–sound correspondence of the consonant phonemes was regarded as the main criterion of regularity for the words used.

tape.[3] The stimuli were acquired on a Sun Sparc station at a sampling rate of 44.1 kHz, segmented, and then stored in individual speech files. All stimuli were resampled at a sampling rate of 20 kHz or above, except the "cluster substitution" stimuli, which were resampled at 10 kHz. After equalization of signal intensities, the various speech discrimination tests were recorded onto separate cassette tapes with an interstimulus interval of about 1 sec and an intertrial interval of about 5 sec. All words included in the speech discrimination tests were drawn from the Alpha (7) lists.

Minimal Pair Discrimination Test. The aim of this test was to evaluate listeners' ability to discriminate consonant contrasts in the context of monosyllabic real-word minimal pairs. There were 16 minimal pairs (see Appendix B): 11 differed only in the initial phoneme, and 5 pairs with initial two-consonant clusters differed only in the second consonant of the cluster. In all minimal pairs with the exception of "skip-slip", the consonant varied in one feature only: either place of articulation or voicing. Each "different" pair was presented four times, and there were equal numbers of "same" pairs, giving a total of 128 trials.

Consonant-cluster Discrimination Test (Omission Condition). The aim of this test was to evaluate listeners' ability to discriminate monosyllabic words with initial consonant clusters. There were 8 word pairs in which one word had an initial two-consonant cluster and the second was identical except for the omission of the second consonant in the cluster (e.g. "pay"–"play"; see Appendix B for full list). Each "different" pair was presented five times, and there were equal numbers of "same" pairs, giving a total of 160 trials.

Consonant-cluster Discrimination Test (Substitution Condition). In this test, there were 8 word pairs in which the words differed only in the second consonant of their initial consonant cluster (see Appendix B). In order to provide enough minimal pairs in this condition, two words not occurring in the Alpha (7) list were used: "snack" and "scar". Each "different" pair was presented five times, and there were equal numbers of "same" pairs, giving a total of 160 trials.

Intervocalic Consonant Discrimination Test. The aim of this test was to evaluate consonant discrimination within nonsense words with a vowel–consonant–vowel (VCV) structure. The consonant in the paired VCVs had the same manner of articulation but differed in either voicing or place of articulation (see Appendix B). Each "different" pair was presented four times, and there were equal numbers of "same" pairs, giving a total of 240 trials, divided into 4 blocks of 60 trials each. Any possible learning effect was minimized by presenting the blocks over the course of several (non-consecutive) days.

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

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[3] The minimal pair test and word repetition test were recorded by female speaker EA. The VCV test was recorded by female speaker GW. The cluster omission and substitution tests were recorded by male speaker JM.

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 to create a stimulus continuum, the elements of which are presented to the listener in random order for identification. 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, & Brady, 1997). The following test conditions were used:

(a) DATE–GATE test (/d/–/g/ stop place contrast)
1. *Combined-cue condition*: cued by changes in burst frequency and F2 transition
2. *Burst alone condition*: cued by changes in burst frequency
3. *Transition alone condition*: cued by changes in F2 transition

(b) SUE–ZOO test (/s/–/z/ fricative voicing contrast)
1. *Combined-cue condition*: cued by changes in friction duration and intensity of voice bar
2. *Friction alone condition*: cued by changes in friction duration

Nonword Repetition Test. The Nonword Repetition Test has been promoted and widely used by Gathercole and Baddeley (e.g. 1989) and modified in recent years, notably in Gathercole, Willis, Baddeley, & Emslie (1994). In this work, consistently poorer nonword repetition scores are obtained for reading-disabled children. It is not certain whether any children showing notable weakness in the reading of nonwords (developmental phonological dyslexics) are particularly inaccurate at this task. This nonword test was therefore included in the test battery principally to look at this possibility.

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, as Gathercole et al. (1994) had reported that their repetition scores were less reliable than those of the other stimuli. Forty nonwords were included, and each item was presented once only.

Psychoacoustic Tests. General tests of auditory acuity were felt to be necessary to discover whether or not discrimination problems were limited to speech sounds. The Early Auditory Test battery developed by Bailey is designed to be brief and easy to administer and consists of four tests designed to investigate temporal and spectral processing (for a further description see Morris, Franklin, Ellis, Turner, & Bailey, 1996). Each trial consisted of a pair of sounds, separated by a 500-msec silent interval; the intertrial interval was 4 sec. "Same" trials paired a reference stimulus with itself, and "different" trials paired the reference stimulus with one of a range of stimuli differing in various amounts of the parameter under investigation.

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 msec, 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 that had 4-, 8-, 12-, 16-, or 20-msec gaps in the noise. 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-msec 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 was used as a carrier for formant frequency modulation. "Same" trials in formant frequency modulation detection also used a 1000-Hz reference stimulus, pairing this on the "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 synthesized 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.

The test structure used for the gap detection, formant frequency discrimination, and pitch discrimination tests was identical. For these tests, 5 blocks of 12 trials were presented, so that in total listeners responded to 10 exemplars of each of the 6 stimulus pairings. For the formant-frequency modulation discrimination test, 3 blocks of 24 trials were presented, so that in total listeners responded to 12 exemplars of each of the 6 modulation magnitudes.

Procedures

Children were all tested individually over a number of sessions in a relatively quiet room at their school. The presentation of the entire test battery was usually completed within eight sessions of approximately 30 minutes, carried out on separate days.

Tests of Reading Accuracy. The three lists of items were presented first to each child in the following order: regular word, irregular word, nonword list. Each list was typewritten on a single sheet of paper, with the instructions that each word should be read aloud. The children could self-correct, and their responses were tape-recorded. Refused attempts were counted as errors, and the missing item was supplied by the experimenter. Nonword production was regarded as correct if for a particular item it corresponded to one of the pronunciations transcribed in Appendix A.

Standard Tests of Reading and Non-verbal Intelligence. The Neale Tests and RPM were presented in the standard way. For the Neale test, measures were made of accuracy and comprehension, but not of rate. As stated in the instructions, the experimenter provided the missing item in case of error.

Speech Discrimination Tests. A similar format was used for all listening tests. Recordings on audio-cassettes 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 identification (e.g. Darwin, 1971). It was thought that monaural presentation would help to maintain the auditory attention of children throughout the listening period.

Minimal-pair stimuli were presented at a comfortable listening level, averaging about 61 dB SPL (as measured using a Bruel and Kjaer Type 2231 Sound Level Meter). The child heard a pair of stimuli and gave an oral response of "same" or "different" after each trial. A small set of simple practice trials was presented before testing in order to ensure that each task was understood.

Listeners were allowed to self-correct, the last attempt taken as their response. General encouragement was given but not systematic feedback.

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 following trial within about 2 sec of the previous response. As 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.

Nonword Repetition Test. The tape was played to listeners as described above, and the child's repetition was recorded on another tape; all errors were transcribed and counted as simple percentages.

Psychoacoustic Tests. The test procedure was the same as for the speech discrimination tests. Administration of each test was preceded by a familiarization procedure in which identical stimulus pairs and pairs with the largest difference on the relevant stimulus dimension were presented alternately, until the experimenter was satisfied that a child understood the particular task.

Group Results

Tests of Reading Accuracy. The mean error scores in reading the word-lists are given in Table 1 for the three listener groups. A two-way analysis of variance (ANOVA) for unbalanced groups was used to test the main effects of listener group and word list. The main effect of subject group was significant, $F(2, 34) = 20.42$, $p = .0001$, and Duncan's Multiple Range Post-hoc Test showed that all groups differed significantly from each other. The main effect of list type was also significant, $F(2, 34) = 57.77$, $p = .0001$, as was the Word List × Subject Group interaction, $F(4, 34) = 6.05$, $p = .0003$.

The data were then examined to look in greater detail at group effects for each word list. Post-hoc tests (Duncan's Multiple Range Test) showed that the regular-word error rate for the experimental group differed significantly from that of either control group, $F(2, 34) = 8.80$, $p = .0008$. There was also a significant effect of listener group on the irregular word-list scores, $F(2, 34) = 12.81$, $p = .0001$, and the experimental group again differed significantly from both control groups. The reading-age control group performed significantly worse than did the chronological-age control group. Finally, the experimental group was less accurate at nonword reading than either of the control groups, $F(2, 34) = 20.65$, $p = .0001$. Again, the reading-age controls performed worse on this test than did chronological-age controls.

Minimal-pair Discrimination Test. Mean error rates are presented in Table 2. A one-way ANOVA for unbalanced groups showed that the number of discrimination errors made overall by the experimental group did not differ significantly from those of the control groups.

TABLE 1
Individual Results on the Word Reading Tests and Standardized Tests for Children in the Experimental Group, and Group Means for Controls

				Error Rates[a]			*Percentiles*		
Sub.	*Age*	*Read. Age*	*Read. Delay*	*Regular Words*	*Irreg. Words*	*Nonwd*	*Neale Acc.*	*Neale Comp.*	*Ravens*
1	10;9	7;11	2;10	10	40	55	12	85	82
2	10;5	8;1	2;4	25*	60*	60*	12	50	75
3	10;6	7;8	2;10	20*	65*	65*	8	36	95
4	10;11	9;5	1;6	5	10	35	26	94	73
5	10;9	9;3	1;6	5	15	30	26	85	95
6	9;5	7;4	2;1	30*	50*	60*	13	51	85
8	10;6	7;10	2;8	10	30	55	10	34	54
10	9;10	7;9	2;1	5	35	30	21	51	81
13	9;11	7;7	2;4	30*	65*	85*	18	64	95
7	9;8	7;4	2;4	25*	65*	60*	13	27	64
9	9;3	6;10	2;5	50*	35	95*	8	64	95
11	11;7	10;1	1;6	0	5	60*	23	85	67
12	10;4	7;7	2;9	20*	55*	75*	6	31	95
Mean	10;4	8;1	2;3	18.1	40.8	58.5	15	58	81
EXP	(0;8)	(0;11)	(0;6)	(14)	(21)	(20)	(7)	(23)	(14)
Mean	8;2	8;2		8.6	24.1	35.9	50	73	75
RA	(0;4)	(0;11)		(11)	(18)	(20)	(20)	(17)	(22)
Mean	10;1	11;9		0.8	7.9	12.5	69	80	88
CA	(0;8)	(1;7)		(2)	(5)	(13)	(20)	(21)	(9)

Note. Standard deviation measures are given in parentheses. The Neale and Ravens percentiles are age-appropriate.

* = scores that are greater than one standard deviation below reading-age control means.

[a] Error rates are given in percentages.

Consonant Cluster Discrimination Test (Omission Condition). Mean error rates are given in Table 2. A two-way ANOVA was carried out to examine the main effects of listener group and stimulus pair. The effect of listener group just failed to reach significance.

Consonant Cluster Discrimination Test (Substitution). A two-way ANOVA was performed to test the main effects of listener group and minimal pair. The effect of listener group was significant, $F(2, 34) = 4.05$, $p < .05$, and post-hoc analyses showed that error rates for the experimental group were significantly higher than those obtained for the two control groups. The effect of minimal pair was also significant, $F(7, 34) = 2.59$, $p = .01$. Post-hoc analysis revealed that pairs “smack”–“snack” and “spill”–“still” were associated with significantly higher error rates than were any of the other pairs. An examination of the rank 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), whereas the substituted consonant in the two

TABLE 2
Individual Results on the Speech Discrimination and Nonword Repetition Test for Children in the Experimental Group, and Group Means

	Error Rates[a]				
Sub.	*Minimal Pair*	*Cluster Omission*	*Cluster Substitution*	*VCV*	*Nonword Repetition*
1	8.6	0.6	5.0	2.1	15.0
2	7	2.5	1.2	0.4	42.5*
3	4.6	0.6	1.2	0.4	42.5*
4	6.2	1.9	1.2	2.5	7.5
5	3.1	2.5	1.2	1.7	7.5
6	3.1	1.2	3.8	1.3	17.5
8	10.2*	1.2	0.0	1.7	17.5
10	4.6	1.2	1.2	1.3	5.0
13	9.4*	3.1	3.1	0.0	32.5*
7	3.1	4.4*	6.9*	5.0*	25.0
9	10.2*	2.5	13.0*	13.8*	47.5*
11	5.5	14.0*	17.5*	21.7*	12.5
12	17.2*	37.0*	28.0*	28.0*	32.5*
Mean	7.14	5.59	*6.41* (*8.3*)	6.15 (9.1)	*23.3* (*14.7*)
EXP	(4.0)	(10.1)			
Mean	6.13	1.08	2.14	1.98	16.6
RA	(3.0)	(2.1)	(3.0)	(1.5)	(10.7)
Mean	4.61	0.51	0.77	1.92	9.4
CA	(2.3)	(0.6)	(1.0)	(1.6)	(6.0)

Note: Standard deviation measures are given in parentheses. Where the between-group difference was significant, the group mean that differed statistically is given in italics.

* = scores that are greater than one standard deviation below reading-age control means.

[a] Error rates are given in percentages.

pairs with the lowest error rates differed in three features (manner, place of articulation, and voicing).

Intervocalic Consonant (VCV) Discrimination Test. Data were analysed in terms of the overall percentage of errors (see Table 2) and also to examine the number of errors within each consonant category classified in terms of manner of articulation (see Table 3). The errors could be in terms either of voicing or of place of articulation.

A two-way ANOVA was carried out with the factors of listener group and consonant category. The main effect of listener group was not significant, $p > 0.05$. However, the effect of consonant category was significant, $F(4, 34) = 8.51$, $p = .0001$, as was the Listener Group × Consonant Category interaction, $F(8, 34) = 3.35$, p .0016. Post-hoc analyses carried out on the data for individual consonant categories reveal that the listener groups differed significantly in their error rates for stops, $F(2, 34) = 3.83$, $p < .05$, with the experimental group showing higher error rates than either of the control groups. The difference in scores for the other consonant categories failed to reach significance, although a higher mean error rate was always obtained by the experimental group.

TABLE 3
Mean Error Percentages for the Discrimination of Intervocalic Consonant Contrasts Classified in Terms of Their Manner of Production

Group	*Stops*		*Fricatives*		*Nasals*		*Approximants*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
EXP	*5.77*	*9.4*	6.25	8.1	8.65	15.2	5.77	8.8
RA	0.43	0.5	2.39	2.3	4.17	9.36	2.78	4.29
CA	0.43	0.7	3.12	2.8	4.17	6.7	2.08	2.9

Note. Where the between-group difference was significant, the group mean that differed statistically is given in italics.

Synthetic Speech Pattern Identification Tests. The mean identification functions obtained for the three listener groups are presented in Figures 1 and 2. These were obtained by averaging the percentages obtained at each stimulus step by all listeners in each group. Statistics carried out to test the significance of group and condition differences were, however, based on gradient measures obtained for each individual identification function. A maximum likelihood estimation (MLE) procedure (Bock & Jones, 1968) was used to fit a cumulative normal function (probit analysis) to each listener's set of data per test condition. A measure was obtained of the gradient of the fitted curve; this measure 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 ANOVA to look at the effect of listener group on function gradient.

Data were 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 significant neither for the combined-cue DATE–GATE test, $p > 0.05$, nor for the combined-cue SUE–ZOO test, $p > 0.05$. On average, identification functions obtained for the single-cue functions were less steep than those of the combined-cue functions. The difference between listener groups only reached significance for the "friction-only" condition of the SUE–ZOO test, $F(2, 33) = 3.34$, $p < .05$, where the mean gradient for the experimental group was significantly shallower than that for the chronological-age controls.

Nonword Repetition Test. A two-way ANOVA for unbalanced groups was carried out to look at the main effects of listener group and syllable length on nonword repetition error scores (see Table 4). The main effect of listener group was significant, $F(2, 34) = 7.22$, $p < .005$, and post-hoc analyses showed that the experimental group had significantly higher error scores than did either of the control groups. The main effect of syllable length was also highly significant, $F(3, 34) = 25.26$, $p = .0001$, as was the Listener Group × Syllable length interaction, $F(6, 34) = 2.59$, $p < .05$. An examination of the means suggests that the listener groups did not differ in their error rates for the two-syllable words, but the experimental group made more errors when repeating longer nonwords.

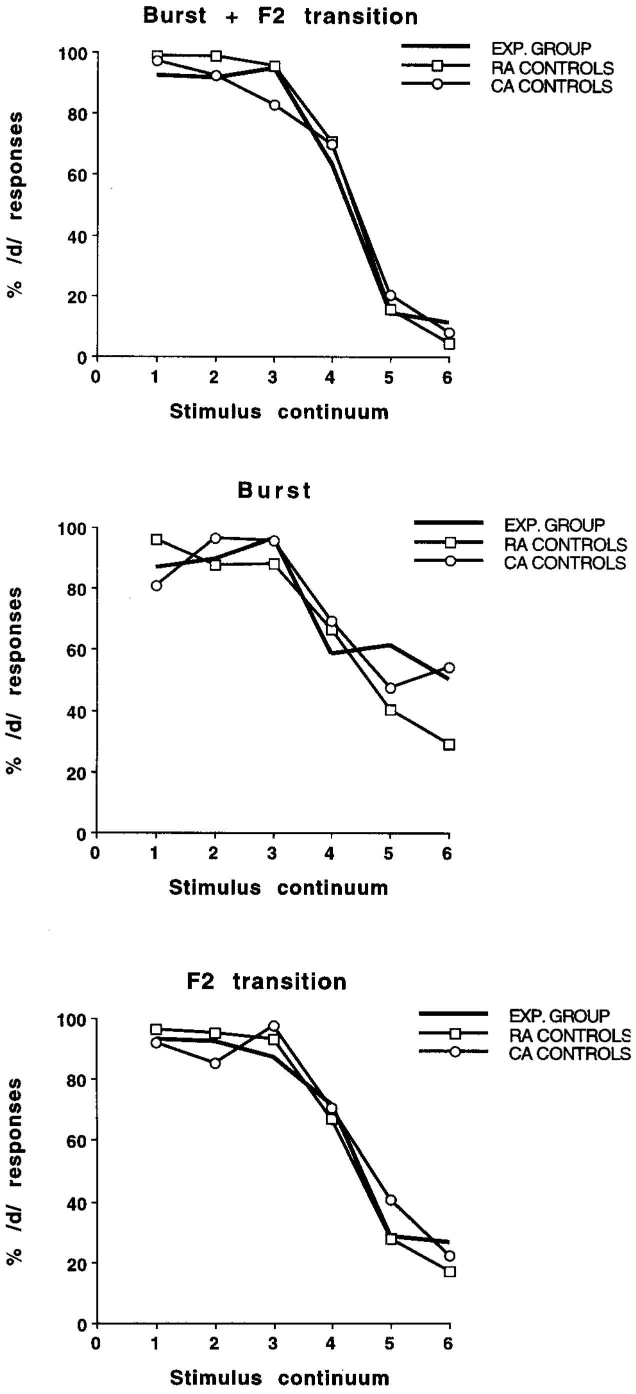

FIG. 1. Mean identification functions for the combined-cue and single-cue conditions of the DATE–GATE test.

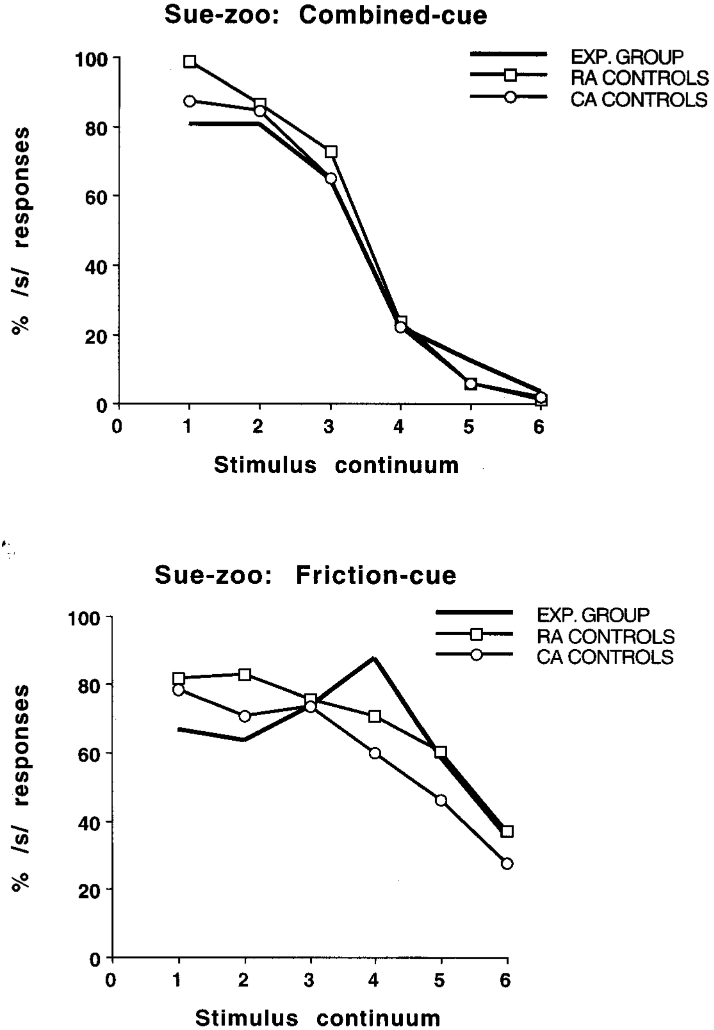

FIG. 2. Mean identification functions for the combined-cue and single-cue conditions of the SUE–ZOO test.

Psychoacoustic Tests. A summary of the mean percentage of correct discrimination over all stimulus pairs for each of the four tests in the psychoacoustic test battery is given in Table 5. For each test, a two-way ANOVA was carried out on the scores obtained for the "different" pairs in order to examine the main effect of listener group and stimulus pair. For none of the four psychoacoustic tests was the effect of listener group significant. The effect of stimulus pair was in all cases significant and in the expected direction: pairs that differed by small degrees were more difficult to discriminate than were other stimulus pairs.

TABLE 4
Mean Error Percentages[a] for Nonword Repetition by Listener Group and by Item Length.

	No. Syllables							
	Two		*Three*		*Four*		*Five*	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
EXP	4.6	7.8	16.9	13.1	33.6	25.3	38.5	28.6
RA	3.3	6.5	3.3	4.9	11.4	11.0	26.9	21.4
CA	3.3	4.9	3.3	6.5	9.9	8.2	22.2	15.7

TABLE 5
Mean Discrimination Error Percentages for Psychoacoustic Tests

	Gap Detection		*F0 Discrimination*		*Freq. Discrimination*		*Freq. Modulation*	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
EXP	11.1	7.3	16.5	11.9	23.8	16.4	28.7	15.3
RA	9.8	8.9	19.7	17.8	40.7	33.1	28.6	8.1
CA	6.8	6.2	10.5	16.0	21.3	9.2	26.9	8.3

Results for Sub-group of Experimental Children

Individual scores for children in the experimental group are presented in Tables 1 and 2. These were examined to assess whether certain children within the group showed distinctly different patterns of performance on the various speech discrimination tests. Performance within the normal range was defined as being within one standard deviation of *reading-age* control means. This is a stringent criterion when applied to the speech discrimination tests, as the RA children were about two years younger than the experimental children and would therefore be expected to be at an earlier stage of perceptual maturity. It is also a criterion previously used in similar experiments (Watson, 1992). Of the 13 experimental children, 4 (e7, e9, e11, e12) were found to be performing below norm on at least three out of the four natural-speech discrimination tests (see Table 2); this pattern of performance was only seen for one of the 24 control children (r11).

Mean error rates for speech discrimination tests (Figure 3) are plotted separately for this "perceptual weakness" sub-group and for the rest of the experimental group and presented with the scores for the two control groups. It can clearly be seen that when the data for the four children in the perceptual weakness sub-group are removed, means for the rest of the experimental group are totally within reading- and chronological-age control norms.

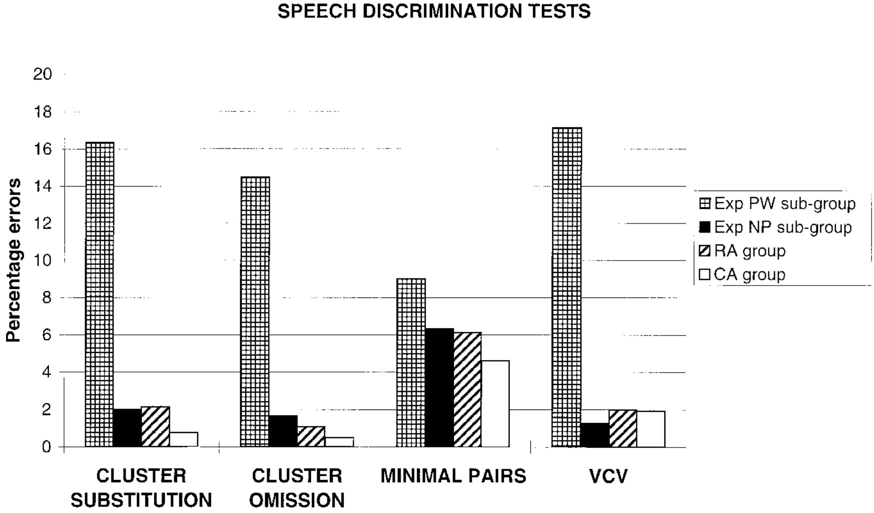

FIG. 3. Bar charts showing mean error scores obtained by the two (NP = normal perception; PW = perceptual weakness) experimental sub-groups and the two control groups on the speech discrimination tasks.

Scores obtained for the VCV test were examined in greater detail to see whether the sub-group of experimental children appeared to have particular difficulty with certain types of consonant contrasts. Bar charts showing the percentage of errors obtained for stop, fricative, nasal, and approximant contrasts are presented in Figure 4. Mean error rates of between 15 and 25% were obtained by this group for all four categories of consonants, with the highest error rate seen for / m/ –/ n/ discrimination.

The performance of the "perceptual weakness" sub-group was then examined to see whether these children differed from the rest of the experimental children and controls on the tests in the battery that did not involve speech discrimination. As the number of children in the experimental sub-groups was small, statistical evaluations of any difference in performance were not carried out.

Tests of Reading Accuracy. Percentages of reading errors for the two experimental sub-groups and two control groups are presented in Figure 5. It appears that children in the two experimental sub-groups gave similar performance on the reading of regular and irregular words. All children in the perceptual weakness sub-group performed below RA norms on their reading of nonwords; the difference in scores between the two sub-groups is significant, $t(11) = 1.85$, $p < .05$, one-tailed.

Standardized Tests of Reading and Non-verbal Intelligence. There appeared to be no difference between groups in terms of their non-verbal intelligence.

Speech Pattern Identification Tests. For the DATE–GATE test, 2 of the 4 children labelled the contrast categorically in the combined-cue condition. In the "burst cue" condition, all 4 children were unable to identify the endpoints of the continuum confidently. However, so were 6 of the other experimental children, 8 of the reading age

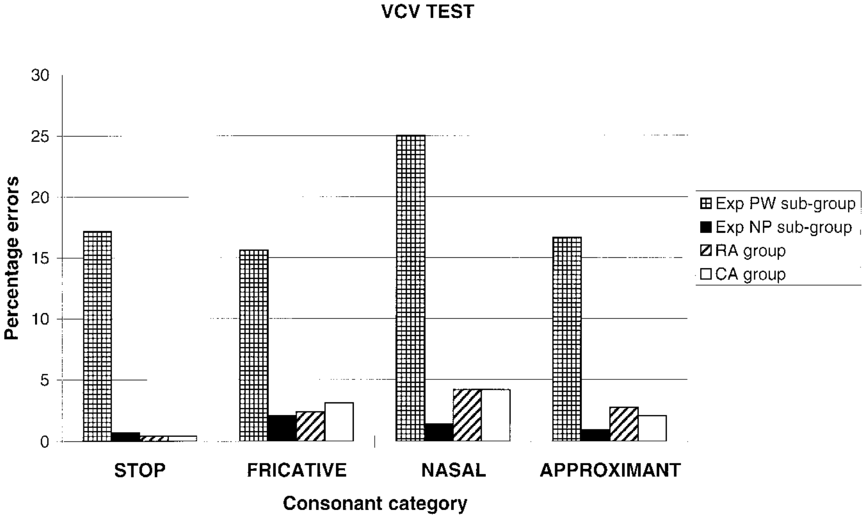

FIG. 4. Bar charts showing mean error scores obtained by the two (NP = normal perception; PW = perceptual weakness) experimental sub-groups and the two control groups for different consonant categories in the VCV discrimination tasks.

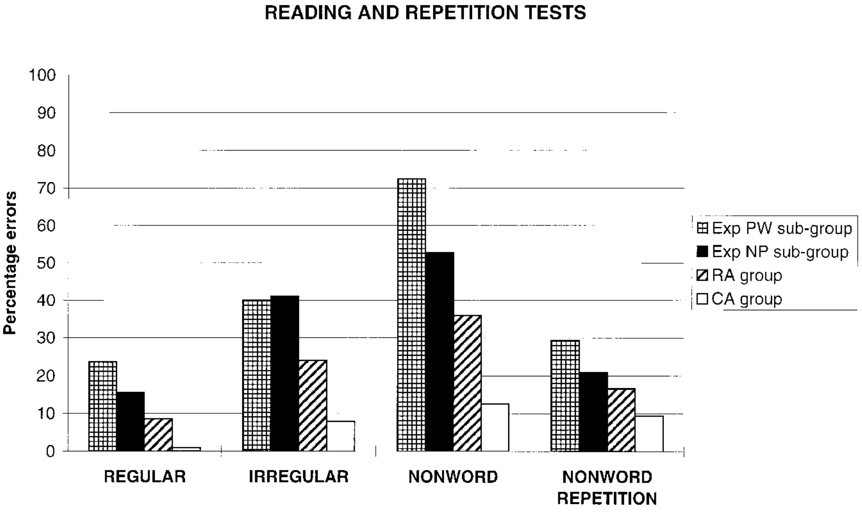

FIG. 5. Bar charts showing mean error scores obtained by the two (NP = normal perception; PW = perceptual weakness) experimental sub-groups and the two control groups on the reading and nonword repetition tasks.

controls, and 11 of the chronological-age controls. In the "F2 transition" condition, 2 of the children (e9 and e12) were labelling the contrast 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, whereas the other half showed evidence of poor identification.

These 4 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 and when it was cued by friction duration alone. This type of performance was not unique to children in the sub-group, however, as 4 children in the rest of the experimental group and 2 of the 24 control children showed similar performance.

Psychoacoustic Tests. There was no evidence of systematically poorer performance on the psychoacoustic tests by experimental children in the perceptual weakness sub-group than by the 9 remaining SRD children or either control group.

DISCUSSION

The aim of this study was to attempt to obtain a detailed profile of the perceptual abilities of individual SRD children by testing each exhaustively on their ability to process both speech and non-speech sounds of varying complexity and gathering data on their error patterns in a set of reading tests. In doing this, a clear picture has emerged: a sub-group of SRD children (30% of our sample) are showing a weakness in perceptual processing, which extends to a range of phonological contrasts and is consistent over a set of speech discrimination tests with real and nonsense words. These problems occurred despite the stimulus pairs being presented with long interstimulus intervals. All four children in this sub-group were girls, and all were right-handed. We use the term “weakness” because the rates of discrimination and identification errors for these children are relatively low; however, they differ significantly from those of both reading- and chronological-age controls. The children in this sub-group did not appear to be performing significantly worse than other experimental or control children on the set of psychoacoustic tests. However, these tests may not have been sufficiently sensitive to detect the possible existence of small differences in performance between the groups. Children in this “perceptual weakness” sub-group were also generally similar to the rest of the SRD group in terms of their standardized scores and their reading of regular and irregular words, although all children in this sub-group performed badly on their reading of nonwords. This latter result concurs with the findings of Masterson et al. (1995) that children with developmental dyslexia who were poor at phonemic discrimination were also poor at nonword reading. We can surmise that, for these children, a weakness in speech perceptual processing is at least a contributing factor to their failure to develop age-appropriate reading skills.

An important point to note is that the rest of the children within the SRD group (70% of the total group) performed within chronological- and reading-age norms on speech discrimination tests and therefore showed no evidence of perceptual difficulties. If this sample is representative of the reading-disabled population, this, therefore, suggests that problems with speech discrimination are seen only in a minority of SRD children. Problems in developing reading skills for the rest of the SRD children are likely to be due to factors not investigated here.

The speech discrimination tests included in the battery contained phonemic contrasts of varying complexity, from those marked by steady-state acoustic patterns in the low-frequency region to those marked by combinations of transient acoustic patterns in the high-frequency region (Fourcin, 1978). Children in the perceptual weakness sub-group obtained much higher error scores than did other children in the cluster-substitution test, which involved the discrimination of minimal pairs involving acoustically complex consonant contrasts. In this test, the two minimal pairs that received significantly higher error scores—"smack"–"snack" and "spill"–"still", differed in a single feature only (place of articulation), whereas all except one of the other pairs differed in two or three features (e.g. both manner and place of articulation). High error scores in relation to the control and other SRD children were also obtained for VCV minimal pairs that differed in a single feature. Here, the only class of consonants for which the experimental group as a whole differed significantly from the control groups was stops. However, sizable error rates (between 15 and 25% on average) were also obtained in the discrimination of voicing or place contrasts in fricatives, and place contrasts in nasals and approximants. However, we should not necessarily conclude, as Mody (1993) does, that stimuli that are phonetically similar—that is, that differ in a single feature—will necessarily be problematic for such children. Indeed, in the minimal-pair test, which included 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 stop contrasts that 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").

We need therefore to go further than Mody (1993) and argue that the contrasts that are likely to be problematic are those that are not merely phonetically similar (i.e. differ in one feature only) but also acoustically similar (i.e. differ in a feature that is not acoustically salient). 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). We would also argue that problems in discrimination are not limited to contrasts that are marked by transient temporal cues, as suggested by Tallal's work, but they can also be present for consonant contrasts that contain spectral cues that are not acoustically salient. The contrasts that these children found particularly difficult to discriminate are also those 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).

Degree of acoustic salience is related not only to the consonant contrast under investigation but also to the vocalic context in which the consonant appears, as this will determine the extent of formant transitions present (e.g. Dorman, Studdert-Kennedy, & Raphael, 1977). For example, in the minimal pair test, high error rates were obtained for "met"–"net", but the error rates for "man"–"nan" were negligible. A similar effect of vocalic context, which gives further credence to the acoustic salience argument, was found in recent work by Tallal and her colleagues (Tallal et al., 1996), who report differences in performance levels for [ba–da] and [bɛ–dɛ] identification tests.

Speech pattern identification tests assess a different level of processing—namely, the ability to group elements of a continuum into distinct phonemic categories. This task mirrors in a controlled way the inter- and intra-speaker variability that listeners are faced with in normal communication. Previous studies (e.g. Godfrey et al., 1981) had found that, on average, categorization of / da/ –/ ga/ stimuli in children with dyslexia was less steep than that of controls. Here, surprisingly, mean identification function gradients for combined-cue conditions for both DATE–GATE and SUE–ZOO contrasts did not differ significantly between groups. Great variability in performance was seen within groups, however. In the single-cue conditions, results confirmed previous findings by Nittrouer (1992) that children gave greater perceptual weight to dynamic formant transition information than adult listeners. Indeed, for all groups, performance was better for the F2-transition condition of the DATE–GATE contrast than for the burst condition. Similarly, for the SUE–ZOO contrast, performance was very poor when the contrast was simply cued by the duration of the fricative portion. The performance of the perceptual weakness subgroup appeared generally to be poor for single-cue test conditions in which the acoustic difference between stimuli had been minimized. It must be noted, however, that two of these four children showed remarkably good ability to label the DATE–GATE contrast when cued by a change in formant transition alone. Tallal and her colleagues might have predicted that such children would not be able to use rapid formant transitions as sole cues to the contrast. Poor performance for single-cue conditions was also found with some other children in this study, and 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 categorization of phonemic contrasts (Hazan & Rosen, 1991). A general weakness in categorizing stimuli in which certain acoustic cues are missing suggests that some children might be reliant on redundancy of acoustic cue information (i.e. multiple cues) and might also show some difficulty in perceiving other types of "cue-degraded" speech, such as speech degraded by noise or filtered speech.

An important consideration is whether children in the sub-group differed from other experimental children in relevant aspects of their medical histories. It could be hypothesized 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 & Finitzo, 1990), although some studies have found little evidence of a link between recurrent otitis media and weakness in phonemic discrimination (Bishop & Edmundson, 1986; Grievink, Peters, van Bon, & Schilder, 1993). The two adult phonological dyslexics tested by Masterson et al. (1995), who showed evidence of perceptual weakness, both reported repeated incidents of ear infections and otitis media during childhood. However, here, there was firm evidence of a history of otitis media for only one child in the sub-group. Conversely, within the rest of the group of experimental children, two had histories of otitis media but showed no evidence of perceptual difficulties.

Another important consideration is whether the children in the sub-group differed from other experimental children in their patterns of reading difficulties. The working hypothesis that motivated this test battery was that developmental phonological dyslexics showing particular weakness with nonword reading would be most likely to show evidence of perceptual difficulties. The method of confidence limits used by Castles and Coltheart (1993) in differentiating between the accuracy of regular, irregular, and nonword reading to label a large group of dyslexic children as, basically, phonological or morphemic types was found to be of no particular help in predicting the performance on similar reading tests for our sample of children. It is not known what the size of the increase in error rate for nonword over irregular word reading should be for a child to be classified as phonologically dyslexic, or how relatively poor a child's irregular word reading needs to be for him/ her to be regarded as a morphemic (or surface) dyslexic. In any event, within our sub-group, only two children out of four showed a clear increase in errors (over twice as many) for nonword reading than for irregular word reading, which could be considered a strong indication of a pattern of phonological dyslexia. However, this pattern was also seen in six children in the rest of the experimental group, and these children did not show consistent problems with the natural-speech discrimination tests. It should be noted that all four children in the subgroup did show high error rates (60% or over) for nonword reading. There were no cases of a child performing well on the nonword list reading test and making numerous errors in a range of speech discrimination tests.

The impact of phonemic confusion on alphabetic awareness may be greater than the perceptual-error rates obtained here would suggest. An error rate of 5–10% for a two-alternative forced choice discrimination task represents performance, of course, well above chance. However, these error rates were obtained for presentation of high-quality isolated words presented in ideal listening conditions. The rate at which instruction is given in a noisy classroom may frequently create, for some children, at higher degree of confusion than that for citation presentation in a quiet room. Normal development of receptive phonology would seem to suggest (from the evidence of Treiman, 1984) that at early stages of development 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. Performance by some listeners under ideal listening conditions to 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.

Normative data from, for example, Fowler et al. (1977) concerning position-sensitive phoneme substitution and from Treiman (1985) on the spelling of CVC nonwords by 8-year-old children suggests that there is a tendency in the early months and years of reading experience for children to be highly dependent on the phonological discreteness of the speech signal in being able to decode accurately from print or to encode the spoken material into a plausible spelling. There have been many estimates of the segmentation and blending abilities of groups of reading-impaired children (e.g. Bradley & Bryant, 1983; Treiman, 1984), with the result that there is broad agreement that their phonemic awareness and phonological knowledge is significantly reduced in relation to that of same-age and reading-age-matched controls. It has been the aim of this paper to argue that one of the major factors determining the development of phonological knowledge and vocabulary growth can be usefully described in terms of acoustic-phonetic salience: phonemic contrasts that are not acoustically salient are typically acquired late in the normal course of language acquisition and seem to be especially problematic for some SRD children. Not all reading-disabled children are similarly affected by this dimension. However, those who do show relative weakness in speech discrimination seem to be at risk for the attainment of full phonological knowledge, if this process is one relying largely on increasingly detailed perceptual learning over time.

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APPENDIX A
REGULAR, IRREGULAR, AND NONWORD LISTS

Regular	Irregular	Nonword		Regular	Irregular	Nonword	
take	come	deat	/ diːt/	chicken	brought	zone	/ zəʊm/
free	sure	poad	/ pəʊd/	wedding	ceiling	roin	/ rɔɪn/
market	island	valm	/ vɑːlm/ or / vælm/	snap	knee	toud	/ tud/ or / tɑʊd/
escape	answer	faft	/ fɑːft/ or / fæft/	tail	bowl	hoil	/ hɔɪl/
plant	blind	bolk	/ bɒlk/	most	shoe	nint	/ nɪnt/
middle	pretty	zast	/ zɑːst/ or / zæst/	care	pear	prin	/ prɪn/
chain	break	vook	/ vʊk/	noise	guard	mulp	/ mʌlp/
drop	lose	basp	/ bɑːsp/ or / bæsp/	pump	tune	sut	/ sʌt/
luck	soup	fost	/ fɒst/ or / fəʊst/	rescue	could	lif	/ lɪf/
next	iron	vood	/ vud/	bright	bough	zoul	/ zul/ , / zəʊl/ , / zɑʊl/

APPENDIX B
MATERIALS USED IN SPEECH DISCRIMINATION TESTS

1. Minimal Pair Test

List of minimal pairs with their phonemic transcription and indication of features in which they vary (P = place of articulation, M = manner of articulation, V = voicing)

net–met	/ net/ –/ met	(P)	clown–crown	/ klɑʊn/ –/ kravn	(P)
nail–mail	/ neɪl/ –/ meɪl/	(P)	smack–snack	/ smæk/ –/ snæk	(P)
nan–man	/ næn/ –/ mæn/	(P)	spill–still	/ spɪl/ –/ stɪl/	(P)
date–gate	/ deɪt/ –/ geɪt/	(P)	buy–pie	/ bɑɪ/ –/ pɑɪ/	(V)
done–gun	/ dʌn/ –/ gʌn/	(P)	bin–pin	/ bɪn/ –/ pɪn/	(V)
Sue–shoe	/ suː/ –ʃuː/	(P)	fine–vine	/ fɑɪn/ –/ vɑɪn/	(V)
sign–shine	/ sɑɪn/ –ʃɑɪn/	(P)	fan–van	/ fæn/ –/ væn/	(V)
grass–glass	/ grɑːs/ –/ glɑːs/	(P)	skip–slip	/ skɪp/ –/ slɪp/	(PMV)

2. Cluster Omission Test

Word-pairs used in the OMISSION condition, with their broad phonemic transcriptions

pay–play	/ peɪ/ –/ pleɪ/	sell–spell	/ sel/ –/ spel/
say–stay	/ seɪ/ –/ steɪ/	dive–drive	/ dɑɪv/ –/ drɑɪv/
fog–frog	/ fɒg/ –/ frɒg/	tin–twin	/ tɪn/ –/ twɪn/
seat–sweet	/ siːt/ –/ swiːt/	bow–blow	/ bəʊ/ –/ bləʊ/

3. Cluster Substitution Test

Word-pairs used in the SUBSTITUTION condition, with their phonemic transcriptions and an indication of the features in which substituted consonants vary (P = place of articulation, M = manner of articulation, V = voicing)

spot–slot	/ spɒt/ –/ slɒt/	PMV	snow–slow	/ snəʊ/ –/ sləʊ/	PM
stick–slick	/ stɪk/ –/ slɪk/	PMV	smack–snack	/ smæk/ –/ snæk/	P
start–smart	/ stɑːt/ –/ smɑːt/	PMV	spill–still	/ spɪl/ –/ stɪl/	P
skip–slip	/ skɪp/ –/ slɪp/	PMV	star–scar	/ stɑː/ –/ skɑː/	P

4. VCV Test

VCV pairs used, classified in terms of the features in which they vary

Stop place contrasts	/ ɑdɑ/ –/ ɑbɑ/	/ ɑgɑ/ –/ ɑdɑ/	/ ɑkɑ/ –/ ɑpɑ/
Stop voicing contrasts	/ ɑbɑ/ –/ ɑpɑ/	/ ɑtɑ/ –/ ɑdɑ/	/ ɑgɑ/ –/ ɑkɑ/
Fricative place contrasts	/ ɑvɑ/ –/ ɑʒɑ/	/ ɑʃɑ/ –/ ɑsɑ/	
Fricative voicing contrasts	/ ɑfɑ/ –/ ɑvɑ/	/ ɑʃɑ/ –/ ɑʒɑ/	
Nasal place contrasts	/ ɑmɑ/ –/ ɑnɑ/		
Approximant place contrasts	/ ɑrɑ/ –/ ɑwɑ/	/ ɑrɑ/ –/ ɑjɑ/	/ ɑlɑ/ –/ ɑrɑ/
Fricative place/ voicing contrast	/ ɑsɑ/ –/ ɑʒɑ/		