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The development of reading: As you seek so shall you find

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In this paper we critically examine different methods of investigation of reading development and reading disability. We argue that there is need for longitudinal studies of reading where a differential design allows assessment of the relative degree of involvement of associated skills. We then describe one study of this type. The results chart the development of children who become skilled readers and of those with generalized or specific reading disability. They also demonstrate the crucial effects of decisions regarding subject matching, test design, and measurement of differential abilities on the outcomes of such investigations.

A cohort of 40 children was assessed for their abilities on 44 variables which involved reading, spelling, vocabulary, short-term memory (STM), visual skills, auditory–visual integration, language knowledge, rote knowledge and ordering ability as they developed from five to eight years old. Three groups were extracted at age eight on the basis of reading and IQ scores. Group A showed a relatively specific reading disability (high IQ, low reading), Group B were good readers of similarly high IQ, Group C showed a more generalized reading deficit whereby they were at the same level as Group A in reading but their IQ scores were low. The data were then searched retrospectively to describe the development of these patterns of ability from the very beginnings of reading acquisition.

The children with specific reading retardation differed from their better-reading peers in terms of relatively few variables which concerned phonological segmentation, STM and naming. The children with generalized reading disability differed from their better-reading peers in almost every respect, but the strong discriminators concerned phonological processing. The children with specific reading disability differed from those with generalized reading disability in terms of abilities which involve visual processing.

Thes patterns of ability were replicated at each age from five to seven years old.

This article reports an investigation of the development of reading ability in 15 children as they progress from five to eight years old. The set of abilities assessed includes many of those already implicated in current theories of reading and thus the work may at first sight appear little more than an attempted replication. This is not so. This study is a necessary simultaneous test of the complete combination of associated abilities. The problems associated with current methods of investigation of reading development make it necessary.

Theories of the development of reading stem from two main sources. The major tradition has been *ex post facto*, bivalent studies where two groups who differ in reading skill have been compared to see if they are also different in another ability which the researcher favours as being important. Reviewers then collate many such studies under titles like 'The psychology of reading' (e.g. Vernon, 1971; Gibson & Levin, 1975; Ellis & Miles, 1981; and Mitchell, 1982). A more idiographic approach has recently emerged where individual cases of reading disability have been studied in great detail (e.g. Coltheart, Patterson & Marshall, 1980; Coltheart, Masterson, Byng, Prior & Riddoch, 1983; Temple & Marshall, 1983). This approach has allowed the differentiation of acquired dyslexias according to their psycholinguistic abilities (Marshall & Newcombe, 1973; Patterson, 1981; A. W. Ellis, 1984). There are potential problems with both approaches.

Reviewers collect together studies of different children of different ages from different backgrounds and teaching methods and they expect, like Quetelet, that the average reader, *l'homme moyen*, will emerge. But if anything important is going to be said about the individual, after experimenting with a group, then the group has to be homogeneous for the relevant characteristics (Bergin & Strupp, 1972), otherwise the individual pattern will be obscured in group averages, the average response will not represent the performance of any individual in the group, and we cannot generalize from the group to any particular individual. Simon (1975) clearly states this case for the specifics of problem solving: 'If we are to understand human problem-solving behaviour, we must get a solid grip on the strategies that underlie that behaviour, and we must avoid blending together in a statistical stew quite diverse problem-solving behaviour whose real significance is lost in the averaging process'. What is true of problem solving is true of cognitive ability more generally – 'the only situations which should be grouped for statistical treatment are those which have for the individual rats or the individual children the same psychological structure and only for such periods of time as this structure exists' (Lewin, 1933).

Reviews often work at an even higher level than this: they group together studies of groups. Reading ability is a complex blend of many skills, strategies and much stored data. Each bivalent study typically investigates the relationship between reading and just one of these skills. But the significance, magnification and clarity of the findings are heavily dependent on the sample characteristics, the number of individuals tested, the discriminating power of the tests, and the way in which the reading disability subjects are matched to their controls. A review then builds up a whole picture from these separate pieces. But unless all of these determining factors are taken into account (and there is no well-specified procedure for so doing) then the resultant whole is a patchwork of views of different magnification and targets. It is a gross generalization and it does not allow easy comparison of importance of effects. Only differential studies of the same children allow this (Chapman & Chapman, 1973; Baron & Treiman, 1980).

An understanding of the development of reading will also be unforthcoming from such review efforts. If we want to study development then we must do so directly. Only when the same persons are tested repeatedly over time does it become possible to identify developmental changes and processes of organization within the individual. Cross-sectional studies which compare different groups of people at different points of acquisition must always come a poor second when reliable changes with age are to be detected, when teaching methods and teachers change with time, and when we do not wish to make the artificial assumption that the abilities of a younger cross-section were present in the older cross-section at a previous time (Kessen, 1960; Schaie, 1965).

Idiographic analysis is typically more fine-grained with detailed descriptions of the individual's behaviour on a wide range of abilities. Individual case descriptions are preserved because individuals are not lumped together in broadly defined categories. This methodology has a long tradition in clinical work and neuropsychology, it became part of the doctrine of behaviourism (Sidman, 1960), and it has been assimilated into almost all areas of psychological inquiry (Allport, 1961; Hersen & Barlow, 1976). In cognitive neuropsychology nowadays it is *de rigueur*, the justifications being (1) the statistical stew argument [theory], (2) the effort after thorough and fine-grained analysis [methodology], and (3) the rarity of particular cases [expediency]. Group experiments assume homogeneity, but homogeneity is an empirical matter to be assessed by looking for individual differences.

There are, however, potential problems with individual case studies. Even though they attempt to understand the reading of the individual subject in terms of the functioning of available information-processing modules or subabilities, the problem of generalized deficit entails that there must also be the comparison of module function level with that of normal individuals – deficiency is assessed against the norm. Thus the methodology is idiographic within the individual subject, but there should always be accompanying normative comparison. So for the acquired dyslexias we find 'The prevailing assumption is one of what we might call "pure subtraction". The theoretical models describe the processing routes employed in normal, fluent reading. The disabilities of the dyslectic reader are attributed to damage to certain of these routes. Such reading abilities as remain are held to be due to the routes that have survived intact operating without any rearrangement. In this reckoning, the various syndromes of acquired dyslexia allow us a privileged view of the normal reading system operating with one or other processing module "unplugged"' (Henderson, 1981). But this normative comparison is often insufficient: (i) sometimes it is third hand and indirect, the performance of the individual being assessed and then compared with a *theoretical* performance of a 'normal' subject as predicted from the prevailing model (see Bryant & Impey (in press) for their criticisms of Temple & Marshall, 1983, and Coltheart *et al.*, 1983); (ii) the selective impairment is often far from clear cut, for example surviving modules are said to be 'normal' if normal accuracy levels are reached even though the patient may be taking six times longer to do the task (Henderson, 1981). Group studies are criticized because of the common finding of general ability or deficit (for example a child with poor educational opportunities will be relatively poor at calculus and using a trampoline even though the abilities are essentially unrelated) and rigorous design procedures to demonstrate differential deficit using equally discriminating tests are advocated to investigate this (e.g. Baron & Trieman, 1980). The rough and ready comparison procedures used in single-case studies will allow generalized deficits to be subjectively attributed the status of specificity whenever cases are not clear cut and this seems to be especially the case with developmental disorders where the 'pure subtraction' model does not seem to apply (e.g. the efforts to categorize developmental dyslexics as corresponding to surface or deep acquired dyslexia: Holmes, 1978; A. W. Ellis, 1979*a*; Jorm, 1979; Baddeley *et al.*, 1982; Snowling, 1983).

The most obvious limitation of studying a single case is that one does not know if the results from this case are relevant even to other, apparently similar, cases, never mind totally different ones. We introduced single-subject designs because of the worries of false generalization from heterogeneous group means to individual group members. But similarly 'There is no logical reason why neuropsychology, when it addresses general theoretical issues, should be freed from the rigours of generalizing across individuals' (Henderson, 1981).

These extreme cases taken to illustrate nomothetic and single-case approaches may well be straw men with feet of clay. Our emphasis on these problems with idiographic designs, group designs and reviews should not be taken to imply that studies using these designs are necessarily worthless. There are good and sensible and there are bad and misguided examples of work using each approach. One is not necessarily better than the other. If the population of minds was homogeneous, if everyone, at all stages of development, read in the same way then there would be nothing to choose between the generalization power of idiographic and group studies. But homogeneity is an empirical matter, and these potential problems require that the current theories of reading and reading development be validated using longitudinal, differential methods designed to circumvent them.

We cannot necessarily generalize from the group to the individual, nor can we necessarily generalize from the individual to the group. So it is time we studied both. To increase the base for generalization from a single-case study, there must be a repetition of the investigation with similar cases along with adequate collection of appropriate normative data. To increase the base for generalization from a group study one fractionates the investigation into a collection of individual diagnostic profiles and investigates the degree of homogeneity. These ideals require a representative sample of normal children to be assessed with the same detail as found in individual case studies. This study should be analysed (i) as a collection of single-case studies, (ii) using agglomerative grouping of the individuals who show similar profiles, (iii) as a group study with appropriate multivariate analyses, (iv) as a study of a potentially heterogeneous group which is fractioned by clustering techniques into more homogeneous subgroups. If we are interested in development then the study must also be longitudinal.

This is a major research effort. In the present study we have made a first attempt. In operationalizing the design we have had to compromise several of the ideals. We could only use a subset of potentially relevant variables (our choice was guided by the content of the literature concerning reading that was current in 1979). The wide coverage entailed a relatively coarse analysis and some of the detail typical of single-subject analyses had to be sacrificed. In retrospect we wish that we had started with younger children. Even so, we believe that this first effort is illuminating.

In this paper we concentrate on the development of three small groups of children: specific reading retardates, good readers, and general reading retardates. We make these comparisons because there seems to be some confusion in the literature between studies of developmental dyslexia and studies of reading. N. C. Ellis (1984) asked 'What doesn't predict reading ability?' and showed that with the current data for 40 children almost every ability that was tested showed a significant correlation with reading ability, yet at the same time relatively little predicts reading *once IQ is controlled.* The matching procedures that are adopted determine to what extent one is studying reading as a synthesis of different information-processing abilities and strategies and to what extent one considers it in the context of general development.

Method

Subjects

Children were selected from five schools within a five-mile radius in North Wales. Selection was conditional on the following criteria: age at initial testing between 4·9 and 5·2 years; the child was monoglot English and teaching was through the medium of English; there were no severe hearing or eyesight deficiencies nor were there signs of physical or mental handicap; the teacher reported that the child had no known emotional or family problems; the socio-economic background must, as far as could be established, have fulfilled the description of 'advantaged'. The children were initially assessed in their first year of school as they reached five years of age and were just beginning to show some reading ability. They were seen thereafter at 12-monthly intervals as six, seven and eight years old. Subject attrition resulted in there being 40 subjects remaining in the study at age seven (22 girls and 18 boys) and just 34 at age eight. Their reading, spelling and IQ scores can be seen in Table 1. (The reading and spelling ages were calculated by averaging the raw scores and then finding the age norm equivalent from this; as the distribution of raw scores is positively skewed the mean is an overestimate of the modal score.)

The large increase in IQ scores between five and six years old may perhaps reflect floor effects with the WISC-R at the youngest age and some of the increase in Performance IQ might result from practice effects on the puzzles. Although six years old is the acceptable lower limit for using the WISC, it was used throughout the study (and therefore at five years old) because it was important to use an intelligence test which would span the four years of development investigated in this longitudinal study.

When the children were eight years old three matched groups of five children were extracted on the basis of their reading and IQ attainments. Group A had high IQ scores but were lagging behind on reading. Group B had similarly high IQ scores but their reading ability was progressing very well. Group C were somewhat below the norm in both their IQ scores and their reading ability. The profiles of reading ability [Schonell single-word reading test (Schonell, 1942) and Neale analysis of reading accuracy, comprehension and rate (Neale, 1958)] and WISC scores can be seen in Table 2. Groups A and B are matched for intelligence but differ in reading ability, Groups A and C are matched for reading ability but differ in intelligence, and Groups B and C differ both in reading ability and intelligence. The children in Group A are thus showing a fairly specific reading disability [although this is somewhat mild following the common usage of the term (Critchley, 1970; Naidoo, 1972) – their reading age is at the overall group average and only a few months below age level] whereas those in Group C seem to have more generalized problems. This can be checked by calculating rough achievement ratios for the three groups. Crane (1959) discusses use of the formula:

Table 1. Chronological age, reading and spelling ages, and IQ scores for the 40 children at the three times of testing: Means (standard deviations)

	Five years old	Six years old	Seven years old
Chronological Age (months)	59·1 (2·4)	71·1 (2·4)	83·1 (2·4)
Schooling (months)	7·8 (3·3)	19·8 (3·5)	31·5 (3·7)
Reading			
Schonell words	3·4 (7·5)	12·8 (12·1)	24·7 (12·6)
Schonell Reading Age 1942 norms	5·3	6·3	7·4
Schonell Reading Age 1971 norms	6·2	6·9	7·6
Spelling Age (Schonell years)	5·4 (0·2)	6·1 (1·1)	7·5 (1·2)
WISC Verbal	95·7 (13·1)	114·3 (12·9)	122·2 (13·0)
WISC Performance	87·9 (14·7)	108·8 (14·8)	114·4 (13·9)
WISC Full	90·7 (12·5)	113·0 (13·8)	115·0 (13·6)

reading age divided by mental age and multiplied by 100. This procedure (which ignores effects of regression to the mean, Yule *et al.*, 1974) results in the following ratios when applied to the seven-year-old data: Group A 86 per cent; Group B 102 per cent; Group C 104 per cent. It appears that Groups B and C are reading at the level predicted by their general intellectual abilities whereas Group A are lagging behind in their reading.

The longitudinal nature of this study permits a retrospective search into the development of these patterns of ability from the very beginnings of reading acquisition. An initial summary can be seen in Table 3 where the WISC profiles and reading scores of the three groups are shown at five, six and seven years old.

Groups A and B are fairly well matched for full IQ at all years of testing but this results from Group B scoring higher on the WISC Verbal items than on the Performance scales whereas Group A develop more on the Performance items than on the Verbal scales. This follows the characteristic WISC profile of children with specific reading disability where there are consistent reports of difficulties on the Information, Arithmetic, Digit Span and Coding subtests (Rugel, 1974; Spache, 1976; Miles & Ellis, 1981; Lawson & Inglis, 1985).

The reading abilities of Groups A and B diverge from age five where performance is at floor level on the Schonell. Over the next three years Group B makes 4·5 norm-years' worth of progress whilst Group A makes a mere 2·5.

Group C is consistently over 20 points behind the other two Groups on the WISC. The Verbal and Performance scores are fairly evenly balanced. The development of reading skill as assessed by the Schonell runs similarly in Groups A and C.

Procedure

At five, six and seven years old the children were individually tested for ability on 44 variables during five sessions which lasted some 30–40 minutes. At eight years old the testing was restricted to a subset of reading, spelling and short-term memory (STM) tests. The Neale test was only administered at eight years old.

The 44 variables, along with a very brief description, can be seen in Appendix 1 where they have been grouped according to a rough Carroll (1976) type of classification. Besides the Full WISC there were a variety of measures of reading, spelling, vocabulary, STM, visual skills, auditory–visual integration ability, auditory–language abilities, language knowledge, and rote knowledge and ordering ability.

For each year's set of data the scores for all 40 children on these 44 variables were normalized by conversion to stanines, a nine-point scale with mean 5·0 and SD 1·96 (Guilford & Fruchter, 1978).

Table 2. Reading characteristics of the three groups at eight years old

	Reading age years/months
Group A: low reading, high IQ	
Neale Accuracy	9:5
Neale Rate	7:6
Neale Comprehension	8:10
Schonell Reading – Words	24·8
– Age 1942 norms	7:6
– Age 1971 norms	7:7
WISC at seven years old	116
Group B: high reading, high IQ	
Neale Accuracy	10:10
Neale Rate	8:9
Neale Comprehension	9:6
Schonell Reading – Words	50·2
– Age 1942 norms	10:0
– Age 1971 norms	9:6
WISC at seven years old	117
Group C: low reading, low IQ	
Neale Accuracy	9:4
Neale Rate	7:2
Neale Comprehension	7:10
Schonell Reading – Words	23·4
– Age 1942 norms	7:4
– Age 1971 norms	7:5
WISC at seven years old	93

The child who had performed best on a particular variable would thus be given the score 9, the worst would score 1. This procedure allows the scores for different tests to become comparable and a child's profile of abilities can thus be produced in the same way as is done on standard attainment tests such as the WISC. It has the additional advantage of ensuring normally distributed scores with equal variances. It also entails that the mean and variability of the scores remains the same year after year. This may seem somewhat absurd – as Thorndike (1966) has pointed out, higher scores and a greater variability of specimens as they mature is an essential feature of growth. Thus any statistical treatment that automatically excludes increasing scores and variability as we go from birth to maturity must be artificial. However, in the present case, where we wish to compare abilities as different as chalk and cheese, the advantages of this scoring method (which is effectively operating like class ordinal position – 'Johnny came top in maths and bottom in French last year but this year...') outweigh the disadvantages.

The stanine scores on each variable for the children in Groups A, B and C were then extracted from each year's data.

Results

These data were analysed as a four-factor ANOVA (3 groups × 3 years × 44 tests with five subjects nested within each group).

Main effects. The groups factor was significant ($F = 27{\cdot}01$, d.f. = 2, 12, $P < 0{\cdot}01$), the group means being A 4·88, B 5·81, and C 3·34. The year factor was not significant ($F = 2{\cdot}64$, d.f. = 2, 24, n.s.), the year means being: five years old 4·89, six years old 4·62, seven years

Table 3. Reading age (years/months) and WISC scores of the three groups at five, six and seven years old

	Five years old		Six years old		Seven years old	
Group A: low reading, high IQ						
Schonell Reading Words	0·0	(0·0)	4·6	(2·8)	14·6	(5·3)
Age 1942 norms	5:0		5:6		6:5	
Age 1971 norms	'below 6:0'		6:5		7:0	
WISC Full	96·4	(5·1)	114·6	(12·3)	115·6	(9·8)
WISC Verbal	98·6	(8·3)	112·0	(8·9)	109·6	(7·2)
WISC Performance	95·6	(8·0)	115·2	(16·6)	119·2	(10·8)
Group B: high reading, high IQ						
Schonell Reading Words	1·4	(2·2)	16·4	(9·6)	33·2	(5·0)
Age 1942 norms	5:2		6:7		8:4	
Age 1971 norms	'below 6:0'		7:1		8:3	
WISC Full	94·8	(12·4)	120·0	(6·9)	117·0	(7·5)
WISC Verbal	100·0	(8·0)	123·8	(10·6)	121·4	(6·0)
WISC Performance	93·4	(14·7)	111·4	(3·9)	108·8	(8·7)
Group C: low reading, low IQ						
Schonell Reading Words	0·0	(0·0)	2·2	(2·9)	11·8	(6·9)
Age 1942 norms	5:0		5:2		6:2	
Age 1971 norms	'below 6:0'		6:0		6:10	
WISC Full	72·2	(5·2)	90·0	(5·2)	93·4	(6·8)
WISC Verbal	83·0	(6·7)	96·6	(6·4)	94·0	(1·7)
WISC Performance	63·6	(9·9)	84·4	(13·0)	92·8	(14·4)

old 4·52. There were no significant differences between the test scores when averaged out over groups and years ($F = 0{\cdot}76$, d.f. = 43, 516, n.s.).

Two-way interactions. The year × test interaction was insignificant ($F = 0{\cdot}83$, d.f. = 86, 1032, n.s.). The group × year interaction was significant ($F = 3{\cdot}67$, d.f. = 4, 24, $P < 0{\cdot}05$) – whereas the average test score for Group B tended to increase from five to seven years old (5·52, 5·91, 5·99), those for Group A (5·31, 4·82, 4·52) and Group C (3·82, 3·15, 4·52) tended to decrease.

The second-order interaction of interest here is that of group × test. This is significant at the 1 per cent level ($F = 2{\cdot}06$, d.f. = 86, 516) and demonstrates reliably different test profiles for the three groups. The interaction means can be seen in Table 4.

Three-way interaction. The group × year × test interaction was significant ($F = 1{\cdot}44$, d.f. = 172, 1032, $P < 0{\cdot}01$). In order to analyse this interaction further we performed separate three-factor ANOVAs (group, within-subjects, year) for each test and categorized them into those where the group × year interaction was significant and those where it was not. This group × year interaction was not significant for the majority of the tests and for these we can therefore conclude that the characteristic test profile which describes the performance of a group at five years old is essentially constant over the following two years and Table 4 is therefore representative of the patterns of abilities of the three groups over the course of development from five to seven years old.

The tests where the group × year interaction was significant, and where this replication of

Table 4. Mean stanine scores for the three groups averaged over the three years (the standard error of the differences between tests when comparing across groups is 0·406)

	Group A High IQ low reading	Group B High IQ high reading	Group C Low IQ low reading
Reading			
1. Phonically Simple D&DA	4·20	5·73	3·60
2. Phonically Complex D&DF	4·07	5·60	3·47
3. Nonsense Words D&DH	4·40	5·93	3·73
4. 'Reversible' Words D&DG	4·33	5·73	3·47
5. Sentence Comprehension D&DR	4·27	5·73	3·80
6. Schonell Reading	3·73	5·73	3·33
Spelling			
7. Schonell Spelling	4·40	6·13	3·67
Vocabulary			
8. WISC Spoken–Spoken	5·47	5·80	3·27
9. Peabody Spoken–Picture	6·47	5·07	2·73
10. D&D Picture–Printed	4·27	6·40	3·00
11. Carver Spoken–Printed	3·93	6·27	2·93
STM			
12. Token Test	5·33	6·07	2·93
13. Auditory Sentence Span	5·07	6·47	3·33
14. Auditory Word Span	4·53	5·87	3·73
15. Auditory Digit Span	4·53	6·60	4·07
16. Visual Digit Span	5·27	6·27	3·07
17. Visual Digit Span and AS	5·87	6·33	3·33
18. Visual Serial Ordering	4·80	6·00	2·87
Visual			
19. Visual Closure	5·33	5·60	3·73
20. Picture Completion WISC	5·80	5·00	2·60
21. Letter Search	5·20	5·87	2·80
22. Coding WISC	5·13	5·27	2·80
23. Block Design WISC	5·87	5·20	3·33
24. Object Assembly WISC	6·47	5·07	3·00
25. Picture Arrangement WISC	5·87	5·80	2·60
Auditory–Visual			
26. Letter Recognition	4·07	5·80	3·07
27. Symbol > Sound Learning	4·73	5·07	3·40
28. Sound > Symbol Learning	4·53	5·40	4·07
29. Colour Naming Rate	4·33	6·20	3·00
Auditory			
30. Syllable Segmentation	4·73	5·73	2·73
31. Phoneme Segmentation	4·60	5·67	3·07
32. Rhyme – Odd One Out	4·47	7·20	3·27
33. Rhyme Generation	4·00	6·67	3·73
34. Sound Blending	4·27	6·13	2·53
Language Knowledge			
35. Grammatical Closure	5·13	5·67	3·33
36. Knowledge of Syntax	5·67	6·67	3·13

Table 4. (*cont.*)

	Group A High IQ low reading	Group B High IQ high reading	Group C Low IQ low reading
Rote and Ordering			
37. Days Forwards	4·53	4·33	4·87
38. Days Backwards	5·00	5·87	4·13
39. Count Forwards	5·20	4·87	4·47
40. Count Backwards	5·13	4·87	4·47
Oddments			
41. WISC Information	4·73	5·80	2·93
42. WISC Similarities	4·73	5·73	3·27
43. WISC Comprehension	5·27	6·40	3·00
44. WISC Arithmetic	5·00	6·00	3·07

Note. For details see Appendix 1.

pattern over time does not hold, were: all of the reading tests, Carver Vocabulary, Schonell Spelling, Auditory Word Span, Letter Search, WISC Coding, Block Design, and Phoneme Segmentation. The characteristic group × year interaction pattern for these tests was that whereas Group B tended to increase their stanine scores from five to seven years old, Groups A and C tended to run parallel in a gradual decline. This pattern holds for all these tests except Coding and Block Design. The fact that it is reading ability which is the determining criterion in distinguishing Group B from Groups A and C suggests that it is the skills involved in these tests where the groups develop divergently that are especially related to reading ability. The group × year interaction means for these tests are shown in Table 5.

We are therefore in a position to compare the groups' profiles of abilities. This process can be fractionated into three traditional pairwise comparisons. The group × test interaction means can be compared to see on which tests two groups differ and on which tests they do not. Bonferoni's procedure is appropriate here since we are making a limited number of comparisons. This determines that if the mean stanine scores of two groups on any particular test in Table 4 differ by more than 1·34 then the groups are significantly different in this ability. Bonferoni's test uses a single-error term for the whole group × test interaction. As it is likely that the between-subject variation in some subtests will be greater than in others we cross-checked the pairwise group differences for each test for significance using separate ANOVAs (2 groups × 5 within-subjects × 3 years) looking for significant group differences. This more conservative procedure confirmed 66 of the group–test differences by Bonferoni but failed to support 14. We will continue to discuss the Bonferoni set but those differences unsubstantiated by ANOVA are marked by * in Table 6 for readers more cautious of Type I error.

The pairwise group profile comparisons can be seen in Table 6 where the significant group mean differences for each test have been ranked in order of decreasing magnitude. The first column relates to the question '*How do children with specific reading problems differ from their reading-skilled peers?*', the second column to '*How do children with a generalized reading deficit differ from their reading-skilled peers?*' and the third column to '*How do specific and generalized reading-disabled children differ?*'.

Table 5. Group × year interaction means for the few tests where this interaction was significant

Test	Five years old	Six years old	Seven years old
Reading Phonically Simple			
Group A	4·2	4·4	3·2
B	5·4	6·6	6·8
C	3·4	2·4	3·0
Reading Phonically Complex			
Group A	4·6	4·0	3·6
B	5·0	5·8	6·0
C	4·2	3·2	3·0
Reading Nonsense Words			
Group A	5·0	4·0	4·2
B	5·0	6·4	6·4
C	5·0	3·4	2·8
Reading Sentence Comprehension			
Group A	5·0	4·4	3·4
B	5·2	5·6	6·4
C	4·8	3·4	3·2
Reading Schonell			
Group A	4·0	3·8	3·4
B	5·0	5·8	6·4
C	4·0	3·0	3·0
Spelling Schonell			
Group A	5·0	4·6	3·6
B	5·0	6·6	6·8
C	5·0	3·2	2·8
Vocabulary Carver			
Group A	4·2	4·4	3·2
B	5·4	6·6	6·8
C	3·4	2·4	3·0
STM Auditory Word Span			
Group A	5·4	4·8	3·4
B	5·2	5·8	5·8
C	4·0	4·0	4·0
Letter Search			
Group A	6·4	5·0	4·2
B	5·8	5·6	6·2
C	3·2	2·0	3·2
WISC Coding			
Group A	5·6	6·0	3·8
B	5·0	4·6	6·2
C	3·2	2·4	2·8
WISC Block Design			
Group A	5·6	5·6	6·4
B	6·6	4·6	4·4
C	2·4	3·6	4·0
Phoneme Segmentation			
Group A	5·4	4·6	3·8
B	4·8	6·0	6·2
C	3·4	3·2	2·6

Groups: A – low reading, high IQ; B – high reading; high IQ; C – low reading, low IQ.

Discussion

1. *How do children with specific reading problems differ from their reading-skilled peers?*

From the test battery that was used in this study there are 17 variables which significantly discriminate between these two groups. In order of decreasing discrimination the top five are: rhyme – odd one out, rhyme generation, Carver vocabulary, Daniels & Dyack (D&D) vocabulary, and auditory digit span.

This pattern replicates findings current in the literature. There has been considerable interest in the proposition that children with specific reading disability have particular problems with the phonological aspects of auditory language processing. These problems have been identified in a variety of experimental tests. Liberman *et al.* (1977) and Gleitman & Rozin (1977) have shown that dyslexic children have difficulty in segmenting auditorily presented words into phonemes or syllables. Newton & Thomson (1976) found that a sound blending test, in which discrete phonemes were spoken to the child who then had to say the word which these phonemes constituted, was a better predictor of later reading performance than were tasks involving the sequencing of visually or auditorily presented material. Rhyming and spoonerism tasks, which require implicit use of phoneme segmentation, are reliable discriminators between dyslexics and adequate readers in group studies (Snowling *et al.*, in press), and they are reliable predictors of later reading difficulty (Bradley & Bryant, 1983). Training in sound categorization improves progress in reading acquisition (Bradley & Bryant, 1983). Such results have underpinned a number of theories of developmental dyslexia where phonological deficits take a causal role (Vellutino, 1979; N. C. Ellis, 1981; Frith, 1981; Bradley & Bryant, 1983).

It is not surprising that the two vocabulary items come next on the list of predictors. Both of these tests assess vocabulary through the printed word, and, since they were designed to tap a wide vocabulary, they may be serving as more discriminating tests of reading ability than reading tests themselves. It is worth noting that the other vocabulary tests which do not involve reading do not discriminate between the groups – it is read vocabulary which discriminates not vocabulary *per se*. Such findings prompt concern over the usage of widely available tests which are all supposed to measure the same ability because they share the same name. Similarly they devalue the validity of crude categorization of psychometric tests according to their supposed information-processing demands (Carroll, 1976, and that system used here). The taxonomy of information processing functions is an empirical matter.

The final strong discriminator is auditory digit span. This must be the most common finding in the developmental dyslexia literature (see Vellutino, 1979; Ellis & Miles, 1981, and Jorm, 1983, for reviews, and Torgeson & Houck, 1980, for exceptions).

All of these top five abilities are more discriminating than the actual reading abilities which were used to initially separate and define the two groups. As stanine conversion gives all the measures the same *a priori* discriminating power (it is a differential design – Chapman & Chapman, 1973; Baron & Treiman, 1980) this suggests that abilities at phonological discrimination and manipulation, and auditory STM play an important and perhaps causal role in specific reading disability. (This argument is analogous to that where a whole group of poor readers, matched in reading ability to a control group, nevertheless shows lower levels of a particular skill. This is described further in section 3 of this discussion.)

When the weaker discriminators are included the list grows by another 12 tests. The six tests of reading ability feature next among other tests of STM for verbal material (auditory sentence span, auditory word span), and of phonological processing (sound blending). In addition, however, we find that some poorer readers are still having difficulty

Table 6. Analysis of the group × test interaction: Pairwise group comparisons of stanine score differences

Stanine differences between Group A low reading, high IQ and Group B high reading, high IQ		Stanine differences between Group B high reading, high IQ and Group C low reading, low IQ		Stanine differences between Group A low reading, high IQ and Group C low reading, low IQ	
Rhyme – Odd One Out	2·73	Rhyme – Odd One Out	3·93	Peabody Spoken–Picture Vocab	3·74
Rhyme Generation	2·67	Sound Blending	3·60	Object Assembly WISC	3·47
Carver Spoken–Printed Vocab	2·34	Knowledge of Syntax	3·54	Picture Arrangement WISC	3·27
D&D Picture–Printed Vocab	2·13	D&D Picture–Printed Vocab	3·40	Picture Completion WISC	3·20
Auditory Digit Span	2·07	WISC Comprehension	3·40	Visual Digit Span and AS	2·54
Schonell Reading	2·00	Carver Spoken–Printed Vocab	3·34	Knowledge of Syntax	2·54
Colour Naming Rate	1·87	Colour Naming Rate	3·20	Block Design WISC	2·54*
Sound Blending	1·86*	Visual Digit Span	3·20	Token Test	2·40
Letter Recognition	1·73	WISC Picture Arrangement	3·20	Letter Search	2·40
Schonell Spelling	1·73	Auditory Sentence Span	3·14	Coding WISC	2·33
Phonically Simple D&DA	1·53*	Token Test	3·14	WISC Comprehension	2·27
Nonsense Words D&DH	1·53	Visual Serial Ordering	3·13	WISC Spoken–Spoken Vocab	2·20
Phonically Complex D&DF	1·53	Letter Search	3·07	Visual Digit Span	2·20
Sentence Comprehension D&DR	1·46*	Visual Digit Span and AS	3·00	Syllable Segmentation	2·00
Auditory Sentence Span	1·40*	Syllable Segmentation	3·00	Visual Serial Ordering	1·93
Reversible Words D&DG	1·40*	Rhyme Generation	2·94	WISC Arithmetic	1·93
Auditory Word Span	1·34*	WISC Arithmetic	2·93	Grammatical Closure	1·80
		WISC Information	2·87	WISC Information	1·80
		Letter Recognition	2·73	Auditory Sentence Span	1·74*
		Phoneme Segmentation	2·60	Sound Blending	1·74*
		Auditory Digit Span	2·53	Visual Closure	1·60*
		WISC Spoken–Spoken Vocab	2·53	Phoneme Segmentation	1·53
		WISC Coding	2·47	WISC Similarities	1·46
		WISC Similarities	2·46		
		Schonell Spelling	2·46		
		Schonell Reading	2·40		

Table 6. (*cont.*)

Stanine differences between Group A low reading, high IQ and Group B high reading, high IQ		Stanine differences between Group B high reading, high IQ and Group C low reading, low IQ		Stanine differences between Group A low reading, high IQ and Group C low reading, low IQ	
		WISC Picture Completion	2·40		
		Grammatical Closure	2·34		
		Peabody Spoken–Picture Vocab	2·34		
		'Reversible' Words D&DG	2·26		
		Nonsense Words D&DH	2·20		
		Auditory Word Span	2·14		
		Phonically Complex D&DF	2·13		
		Phonically Simple D&DA	2·13		
		WISC Object Assembly	2·07*		
		Sentence Comprehension D&DR	1·93		
		Visual Closure	1·87*		
		WISC Block Design	1·87*		
		Days Backwards	1·74		
		Symbol > Sound Learning	1·67*		

Note. The group differences on each test shown here are significant using Bonferoni's multiple comparison test following ANOVA of the whole data set. Asterisked differences are not significant on conservative test using separate ANOVA on the data relevant to the single test score difference for two groups. See text for details.

finding the names of letters, and the rate at which children can access the articulatory equivalents for colours is a good discriminator (slow naming rate for objects, pictures and colours is another oft-quoted dyslexia-associated phenomenon: Denckla, 1972; Spring & Capps, 1974; Denckla & Rudel, 1974, 1976; Audley, 1976; Ellis & Miles, 1981; but see Torgeson & Houck, 1980, for exceptions). The groups also differ in spelling ability (reading and spelling ability are so tightly associated that it is a surprise when they are not: Bryant & Bradley, 1980).

None of the other tests, the larger part of the battery, significantly discriminate between Groups A and B – the children with specific reading problems do not seem to show strong and reliable patterns of problems of visual processing (tests 19–25), nor syntactic skills (35, 36), nor rote knowledge and ordering (37–40). Neither are the groups different in terms of their ability on tests of visual digit span with or without articulatory suppression (tests 16, 17) – this suggests that at this young age visual STM is not behaving in the same way as auditory STM and it is perhaps more like the 'visual tasks' (19–25). This finding accords with those of Keeney *et al.* (1967) who suggest that four- to six-year-old children use visual representations for remembering nameable pictures whereas older children use articulatory rehearsal.

The strong discriminators concern phonological processing, verbal STM, and some aspects of accessing the articulatory equivalents of visual material. The age × group interaction was significant for all the reading tests, spelling, and auditory sentence span. The specific reading disability group lags further and further behind the good readers on these abilities as they develop.

The age × group interaction was insignificant for the abilities of phonological processing, speed of lexical access and articulation, and auditory word span. This tells us that the profile of these abilities associated with specific reading disability at age eight is relatively unchanging in the three previous years: it is essentially the same at age five. The facts (i) that the two groups were more strongly differentiated on these abilities than on reading itself, and (ii), that they were differentiated on these abilities before any large differences in reading ability at age five, implicate these abilities as causal factors associated with specific reading disability. Furthermore they imply that if we wish to determine how such disabilities in phonological processing arise then we must look to developmental events prior to five years old.

And the matter of group homogeneity is an empirical issue. In terms of this relatively coarse-grained analysis, the ANOVA tells us that the five children here identified as showing specific reading disability are behaving in a relatively homogeneous fashion on these discriminating variables. So do the five single-subject profiles shown in Fig. 1.

2. *How do children with a generalized reading deficit differ from their reading-skilled peers?*

They do so in almost every way. Of the 44 variables used in this study 40 (91 per cent) are significant discriminators. Remember that these results come from a low-powered design with only five subjects per group – with a larger *n* we would reasonably expect even more contrasts to be significant. These are shown ranked in decreasing order of magnitude in the middle column of Table 5. Tasks involving phoneme segmentation, STM, and rate of access and articulation of the lexical equivalents of visual stimuli still appear high in the list of strong discriminators, and the correlation between the magnitudes of the Group A/Group B and Group A/Group C differences is 0·49. But here, with the two groups differing in reading *and* intelligence, almost all of the tests are significant discriminators and we cannot tell if a test is a strong discriminator because of its association with reading or its association with general intelligence.

As you seek so shall you find, and if you look for associates of general reading ability in

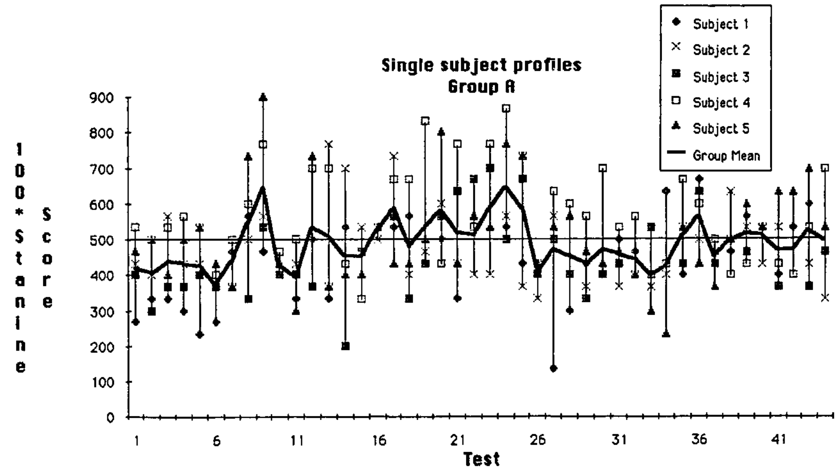

Figure 1. Single subject test profiles of the children in Group A (specific reading disability). The test numberings are shown in the Appendix.

a fairly heterogeneous population then just about any ability will correlate to a significant degree. Such findings are reminiscent of those from psychometric studies of general intelligence which have been summarized thus:

> Any battery of cognitive tests given to a sample of subjects from some reasonably heterogeneous population results in a set of positively correlated scores, the principal component of which accounts for at least one fourth of the variance of the original measurements (Cooley, 1976, pp. 57–58).

> The almost ubiquitous occurrence of positive correlations among scores on various tests and scales... (Estes, 1976, p. 297).

The body of psychometric research shows that with variables which tap fairly gross cognitive abilities there is ample evidence of a deviation from the null hypothesis of totally unrelated abilities. Should there be any deviation from the null hypothesis, however small, a sufficiently large number of observations will lead to rejection of the null hypothesis (Bakan, 1967). So if we pick a random subset of a small number of cognitive abilities and test whether people who are good at these are also good at an important, ecologically valid, gross cognitive ability such as reading, then we find, should we run a sufficient number of subjects, that they are.

And this is exactly what happens in a large proportion of the educational and psychological literature which concerns reading. It may not appear to be correlational because the analyses use ANOVA or *t* tests which remind us of experimental designs, but most of the work is *ex post facto*. But the associations tested are not random – the researcher only tests those predictions made by the 'levels of dual working (or somesuch) model'. However, whether the research is guided by a correct or an incorrect model, it is no less of a fishing expedition. With this population of data and a small enough mesh size ensured by a reasonably large *n* then there is bound to be a bounteous haul.

Studies of generalized reading disability derive a large set of discriminators. Some of these may have nothing at all to do with reading. The finding of a correlation between two performances might arise for any number of reasons. The abilities might have been learnt together for some quite arbitrary reason (like they were both stressed in the curriculum at the same time), or the child may be interested in both skills independently, or home and school environment may generally nurture or retard the variety of abilities, or learning one of the abilities may indeed be a prerequisite to learning the other, or the performances might indeed both depend on some trait or capacity.

The grand trawl is there to see in review works such as Gibson & Levin (1975). But to attempt to analyse such collections of significant discriminators in terms of shared information-processing functions (as is done for specific reading disability) may well be misguided on a number of counts: (i) the trawl reflects what researchers have looked for and is therefore model-justifiable and plausible, but the quotes above tell us that totally misguided models would similarly be 'validated' with significant results; (ii) the review efforts pile together results from different studies of different numbers of children from different backgrounds – we thus have no way of directly comparing the importance of the discriminators (whereas in this current study we can – see 1 above); (iii) it may be more appropriate to leave the fine-grained information-processing level of analysis behind when considering general ability and to think on a wide range of different levels such as socio-economic background, home environment, educational opportunity, cultural factors, 'a good brain' and possible innate factors, personality variables, general cognitive strategies, etc.

To be fair, it is often nowadays acknowledged that a significant association between one ability and reading does not imply shared processes. There has been growing advocacy for differential studies (Chapman & Chapman, 1973; Baron & Treiman, 1980) and the preponderance of studies of specific reading disability involve 'matching for intelligence'. (But in the light of what has just been said, this matching must be tight – it is no good to have two groups, both of 'average or above-average intelligence' but where the control children average out some 10 or 20 points higher than the dyslexics. And just what test do we use for matching? – groups matched on a Full WISC will show different test discriminators than those matched on the WISC Performance scales or Ravens – see Bishop & Butterworth, 1980.) Unfortunately this remedy has adverse side-effects. IQ matching forces retarded readers to be no different from normal readers on some skills which might have been associated with their reading problems. This latter point has been championed by Singer (1982) who reminds us that 'intelligence, socioeconomic status, and family and school environment explain much of the variation in reading ability (Jencks, 1979). These factors usually predict an individual's reading ability. Investigations of variation in reading ability that control for these factors *necessarily examine a small proportion of the variation in reading ability*' (p. 41). At the extreme of this approach lie those studies which only consider the abilities at which specific reading-disabled children are worse than children who are matched for intelligence *and reading ability* (e.g. Bradley & Bryant, 1978; see section 3 below). Studies of specific reading disability or dyslexia tell us very little about reading.

It appears that neither is the correct methodology. We are in a dilemma, forced to choose between two evils: studies of generalized reading disability give us too many discriminators, studies of specific reading disability give us too few. Whether we follow an idiographic or a nomothetic approach we are still in this bind. We make our choice depending on our interests:

Specific interest. If we are interested in the limiting ability factors which underlie specific reading disability, with the child having all other prerequisite abilities (prerequisites which we cannot determine), then the specific disability vs. ability comparison with matching for intelligence and even reading ability is appropriate. But the ability discriminators which arise are a very limited subset of those involved in reading.

General interest. If we are interested in reading then the general reading disability vs. ability comparison is appropriate. But the larger list of ability discriminators which arise here are a mixture of things which are and things which are not associated with reading – they are factors associated with general intellectual ability of which reading is but a part. There are two possible research strategies here:

(1) We can investigate reading development as an aspect of general intellectual development and look for factors which promote this. [The fact that the majority of factors which promote general intelligence *are* relevant to reading is demonstrated by the predictive power of intelligence on reading (Yule *et al.*, 1974; Stanovich *et al.*, 1984) and by current experiment where it was possible to derive from the 40 children the following three groups of five children: high reading/high intelligence, low reading/low intelligence, low reading/high intelligence; children who are good at reading but of low intelligence (from IQ tests) are few and far between. The correlations between Schonell Reading and Full WISC IQ for the 40 children were 0·54 at five years old, 0·72 at six, and 0·65 at seven, giving a rough average of 0·64.]

(2) We can try to highlight reading by attempting to differentiate between the close associates of reading and the more general factors. This is a compromise position between the specific and general designs. One way of going about it is to identify the general abilities which are not associated with reading; an example follows in section 3. Another is a psychometric study of reading in the general population looking for the patterning of associations of abilities using correlational and factor/cluster analytic techniques. There are, of course, well-documented criticisms of this approach with regard to heterogeneity of reading ability (Lewin, 1933; Doehring, 1978; Singer, 1982), linear mathematical models being applied to highly non-linear combinations of abilities (Hunt, 1976; Kagan, 1976; Sternberg, 1977), and subjectivity in choice of analysis method (Green with Carroll, 1976; Horn, 1967) but there is some benefit when such methods are used to complement other approaches. Ellis & Large (submitted) take the data for all of the 40 children for the first three years of this study and analyse them in this fashion.

3. *How do specific and generalized reading-disabled children differ?*

There is a traditional distinction between children who show generalized reading backwardness (low attainment in relation to age but consistent with intelligence) and those who show specific reading retardation (a specific disability in reading not explicable in terms of the child's general intelligence). However, there has been little work where these two subgroups of reading retardation have been directly compared. Rutter & Yule (1975) compared two such subgroups (roughly 80 children in each group, ages nine to 11 years) and found that the specifically retarded children differed in terms of a much greater male preponderance, less overt neurological disorder, a more specific association with delays in the development of speech and language (rather than in motor and praxic skills as well as in the general backwardness group), and in coming from a roughly average social background. A detailed analysis of the development of the cognitive abilities of these two types of reading disability has not, however, been undertaken.

This novel comparison is informative about the nature of abilities associated with reading – it is the obverse of comparison 1 between good readers and children with specific reading disability. Comparisons of the first kind, where the groups are matched for intelligence but differ in reading ability, are undertaken driven by the belief that any differences in ability between the groups are direct associates of reading and, problems of causality notwithstanding, the type of conclusion drawn is 'these are the sorts of things that good readers are good at'. If we accept this type of argument then in this comparison of the third kind, where groups are matched for reading ability but differ in intelligence, any group differences *are not* specifically associated with reading. We can identify the chaff because the conclusion is of the type: 'you can still read as well as these other children even if you have difficulty with these things'. This is the interpretation for group differences

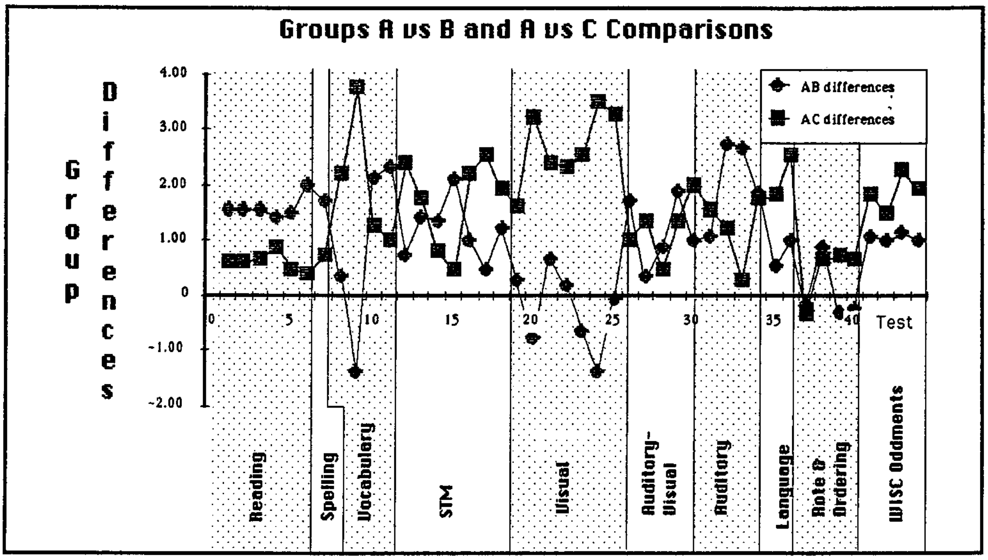

Figure 2. Mean group differences on each of the tests for the two comparisons: A vs. B (high IQ, low reading vs. high IQ, high reading) and A vs. C (high IQ, low reading vs. low IQ, low reading). Numbering as in Appendix.

where the generalized reading-disabled children are scoring worse than the specific reading-disability group and these differences are shown in the right-hand column of Table 5.

The same idea underpins studies which compare children with specific reading disability with younger normal children who have the same reading ability and which look for differences in the opposite direction – where the specific reading-disability children are still scoring worse than the younger children who are matched for reading ability. Bradley & Bryant (1978) claim that the direction of the causality of associations between abilities can be disentangled by this method: 'if, as in our design, the two groups have reached the same reading level, and yet the backward readers are worse on a perceptual task, the fact that the two groups have the same reading ability rules out the possibility that the backward readers' perceptual failure is merely the result of a lack of reading experience' (Bradley & Bryant, 1978, p. 746; see also Frith, 1980; Nelson, 1980; Seymour & Porpodas, 1980; Baddeley *et al.*, 1982). In the present experiment, however, there was no instance of the specifically disabled readers scoring lower than the generalized disabled readers.

The argument in the penultimate paragraph leads to the prediction that the differences between Groups A and B (comparison 1) and those between Groups A and C (comparison 3) will be essentially mutually exclusive. This is confirmed in Table 5. There is no overlap between the strong, unstarred, discriminators from the two comparisons. (The only variables common to both lists are auditory sentence span and sound blending which scrape in at the botton of the AC comparison list. This may reflect the fact that Group C, although adequately matched to Group A for reading ability at age eight, is somewhat behind at earlier ages.) In Fig. 2 the AB and AC differences are shown for each of the tests. Visual inspection shows that when a Group AB difference is large then the Group AC difference is small. There does appear to be an inverse relation if you imagine a mirror going across the page at $y = 1{\cdot}55$ (the mean AC difference), but further analyses are needed to test its significance.

In the scatterplot in Fig. 3 the magnitudes of the differences between Groups A and B

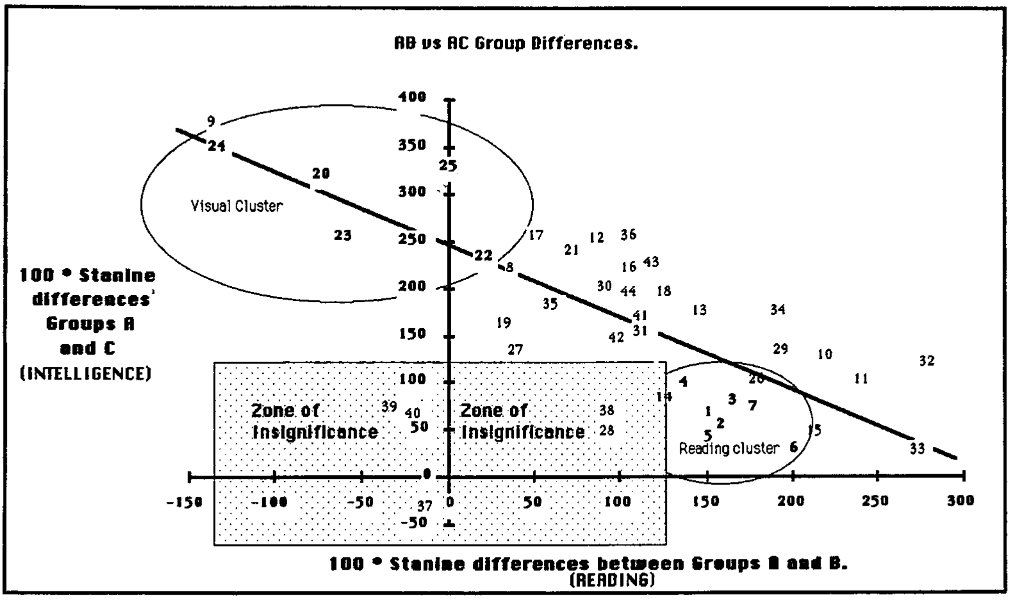

Figure 3. The 44 test variables represented in a space of reading (AB differences) vs. intelligence (AC differences). Numbering as in Appendix.

are plotted against those between Groups A and C for each test (these are identified according to the numbering system used in Appendix 1). The points are well described by a decreasing linear function except for five outliers (the rote and ordering tests and sound > symbol learning) which all lie in the 'zone of insignificance': none of these tests was a significant discriminator in either comparison 1 or 3. When the outliers are excluded the product moment correlation between the two comparisons is $-0{\cdot}83$, the slope of the regression line is $-0{\cdot}76$. Belief in this method of analysis is also strengthened by the clusters of related variables which emerge: they broadly correspond to those used in the initial categorization [see, e.g., the cluster of reading variables (1...7) (this cluster is of course determined vertically by the matching of Groups A and C for reading, even so it is free to vary in width), the cluster of visual tests (20, 22, 23, 24, 25), and the rote and ordering tasks in the zone of insignificance (these latter two clusters are not directly constrained by the AB/AC matching procedures – in the absence of association with reading or IQ they would be randomly distributed about the plot)]. It is as if we were plotting against two principal components of reading and intelligence.

Figure 3 therefore merges comparisons 1 and 3; we have both sides of the coin visible at the same time. Those variables that emerge towards the bottom right of the plot are strongly related to reading with little contribution from general intelligence, and as we move upwards and left the tests become more related to intelligence and less to reading *per se*.

We can conclude that those variables which are specifically and strongly related to reading ability at these ages are, in decreasing order of magnitude:

	Tests directly involving reading	Non-apparent reading associates
33		Rhyme Generation
32		Rhyme—Odd One Out
11	Carver Vocabulary	

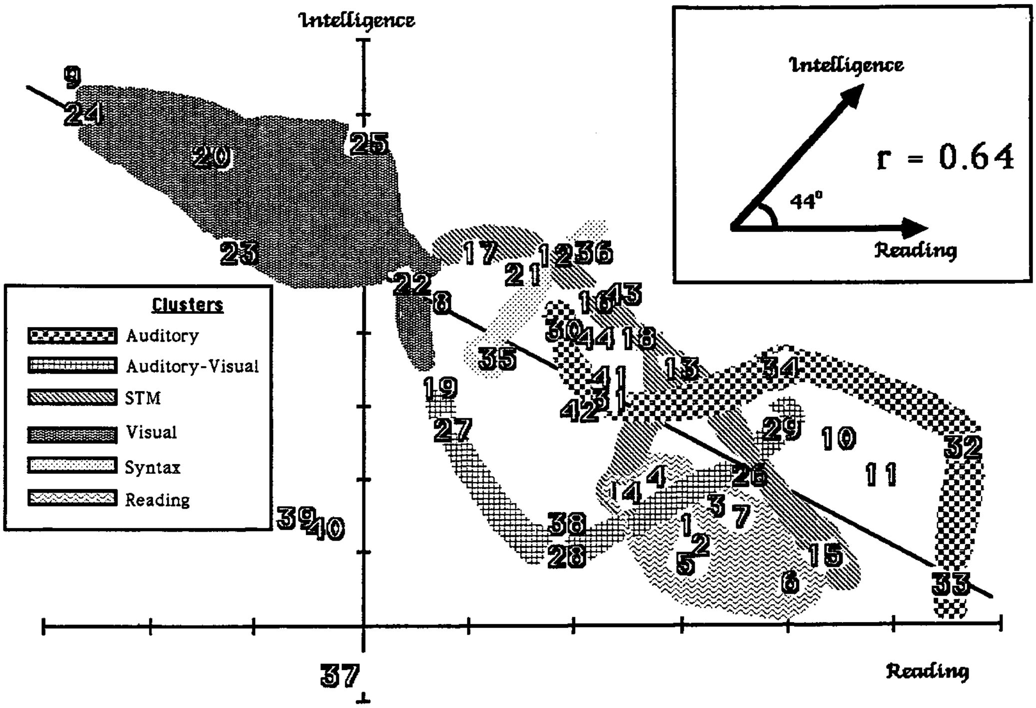

Figure 4. The clustering of visual, syntactic, STM, reading, auditory–visual association, and auditory abilities in the space defined by reading and intelligence. Test numbering as in Appendix. The orthogonal relationship between reading and intelligence is true for the present data, but in general these two factors are oblique as is shown in the inset graph.

15		Auditory Digit Span
6	Schonell Reading	
10	D&D Vocabulary	
29		Colour Naming Rate
7		Schonell Spelling
26		Letter Recognition
2	D&DF Phonically Complex	
1	D&DA Phonically Simple	
3	D&DH Nonsense Words	
5	D&DR Sentence Comprehension	
34		Sound Blending
4	D&DG 'Reversible' Words	
14		Auditory Word Span

There seems to be a noticeable gap (a levelling of the scree) at this point as we move back along the regression line. And we are leaving the reading tests behind, so it is probably time to stop the listing. Where exactly we stop is determined by the generality of our interest (Specific or General above).

The present analyses, with only five subjects per group, are of low power. They are conservative and they only consider strong effects. As such they may be missing less robust associations and changes with age. Ellis & Large (submitted) analyse the data for all 40 children and tease out some of these less obvious developmental changes in reading skill.

The representation of all of the abilities in the space defined by intelligence and reading demonstrates a number of other phenomena. Whereas the visual and reading tests form fairly well-defined circular clusters, the other categories used in the Appendix form long chains. In Fig. 4 we have highlighted these clusters.

The 'chequered snake' of *auditory abilities* show that some of these skills (like rhyme generation and 'odd one out') are much more related to reading than others (like syllable segmentation) – whereas all of these tests demand phonological awareness, some aspects of such awareness are much more involved in reading than others. Such findings have been reported previously. Thus syllable segmentation is acquired prior to phoneme segmentation, perhaps because syllables, unlike phonemes, are clearly marked in speech and are therefore easier to identify (Liberman *et al.*, 1974). Phoneme segmentation is the better predictor of present and later reading ability (Helfgott, 1976; Lundberg *et al.*, 1980), presumably because it is phonemes which serve as poles in the grapheme–phoneme conversion rules used by 'Phoenician' readers (Treiman & Baron, 1981). Rhyme production tasks were more highly associated with reading than other phonemic awareness tasks in the Lundberg *et al.* (1980) study. Whereas the segmentation tasks demand perception of phonological units, sound blending and rhyme generation require perception, manipulation and generation. It is these phonemic skills which are most related to reading in Fig. 4, and we suggest that this is because whilst phoneme perception must be involved in the early stages of reading development, reflecting as it does the acquisition of the relevant sound categorization system, thereafter it is the use of this system in the production and manipulation of phonemes which is the stuff of Phoenician reading.

The *auditory–visual* cluster spans from the visual abilities to the auditory ones, crossing verbal STM and reading on its path. The tests having most in common with the visual tasks concerned the learning of paired associates (consonant–vowel–consonant names and nonsense geometrical shapes). Letter naming appears on the edge of the reading cluster. The position of the test of rapid naming of overlearned colour patches suggests that this ability is essentially as much constrained by output phonology production as is sound blending. As the auditory demands of the auditory–visual tasks increase and outweigh the visual demands, so the task becomes more associated with reading. At this stage of reading development reading seems much more limited by phonological skills than visual ones.

This is confirmed in Fig. 4 where *visual* and *syntactic* skills are more related to intelligence than to reading at this stage of development.

The 'STM' cluster similarly spans visual, auditory and reading clusters. It comes as no surprise that visual digit span and articulatory suppression and visual digit span are the span tasks most associated with abilities in the visual cluster. The token test's demands on STM to remember the instructions, on complex syntactic decoding, and on representation and manipulation of the identity and position of shapes in an array, explain its conjunction with the STM, syntax and visual clusters. Auditory digit span is associated with phonological perception and production abilities, and this supports the view that phonological codes have to be perceived and generated for the purposes of digit storage in the same way as they have to be accessed in order to set up motor programmes for the articulation of unfamiliar words or to make rhyme judgements (Snowling *et al.*, in press). Low STM span and poor reading or aphasia may all reflect problems in phonological processing in certain individuals (Conrad, 1972; Baddeley, 1979; A. W. Ellis, 1979*b*; Allport, 1983). Auditory word and sentence spans, where the demand is on the production and manipulation of the phonemes of the words of the language (rather than digits) are those with the greatest association with reading.

There is moral to the spreads of these chain-like clusters. We develop tests of ability and put them in the same category if they seem to be tapping the same essential information processing element. Once these tests have been so labelled it is all too easy to think of them as pure tests of this element. Yet very few of these tests are 'clean' (Calfee, 1977) and measure this element alone. There are numerous examples in Fig. 4: the tests of vocabulary fall into two distinct types; the STM and auditory–visual tasks range from the visual to the pure auditory; the tests of syntax have strong STM elements. The categorization of information-processing abilities is an empirical matter to be addressed using psychometric approaches of the type used here, it does not automatically follow from first-sight labelling. There are well-documented cases of misinterpretation of associations between abilities because of miscategorization of test, for example Vellutino (1979) suggests that the documented relationship between 'visual problems' and dyslexia is attributable to the 'visual' tests being contaminated with verbal factors. The degree of spread of the clusters in Fig. 4 makes it quite likely, however, that such errors of interpretation are much more wide ranging. Thus, to consider just one example, tests of syntactic ability must also have elements of language understanding and STM functioning; therefore any association between scores on such tests and another ability can only be discussed in terms of syntactic skills if a differential design is used and the groups are shown not to differ on these other contaminating components.

This list of reading-associated abilities that is generated by following the line which relates reading to intelligence is in fact little different from that which results from following just the reading axis which results from a comparison of two groups who are matched for intelligence but differ in reading ability (column 1 of Table 5). The significance of the present analysis, however, lies in the emphasis that it ascribes to those abilities which are not high on the list of reading associates. These abilities are not something to be discounted as they would be as non-significant correlates from comparisons of the first kind. Rather it should be emphasized that they are abilities that are intimately associated with general intellectual ability. The matching procedures used in this study where Groups A and B were matched for intelligence but differed in reading ability and Groups A and C were matched for reading ability but differed in intelligence entail that reading ability and intelligence are unrelated and orthogonal in Fig. 4. But in the general population intelligence is a good predictor of reading ability. This is shown in the inset graph in Fig. 4 where the degree of relationship is that for all 40 subjects in this study. Therefore it is likely that those factors which promote general intelligence also promote reading ability in all but those relatively infrequent individuals who suffer from a specific reading retardation. There are numerous such factors: family environment (Rowe & Plomin, 1981; Bradley & Caldwell, 1984), parental socio-economic status (Kagan & Moss, 1959; Marks & Klahn, 1961), nutrition and health care (Birch & Gussow, 1970), parent–child interaction (Bayley, 1976; McGowan & Johnson, 1984), parental interest and encouragement (Douglas, 1964), culture (Olson, 1976; Goodnow, 1976), general education (Cole & Scribner, 1974), teacher (Bennett, 1976), teaching method (Snow & Yalow, 1982), general cognitive strategies (Baron, 1978), personality (Baron, 1982), environmental accident (Kollerstrom, 1982), innate factors (Plomin & DeFries, 1980), etc. We have to jump between levels to consider them all but they are as relevant to reading as to intelligence.

These conclusions may be rephrased in practical terms. If we are concerned with children who apparently have a good brain, who are neither socially nor economically deprived, who have no emotional or personality problems, who have had the benefit of a good education, and yet still they have specific problems with reading, then we should be looking to their problems in phonological processing. This is interest in dyslexia or specific reading retardation. If, however, we are concerned with the promotion of reading ability in the general population then we must consider all of these factors. This is interest in reading.

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Appendix 1: Summary of tests

Reading

1. Phonically Simple D&DA
   Daniels & Dyack subtest 7A. A word-recognition test involving phonically regular two- and three-letter words.
2. Phonically Complex D&DF
   Daniels & Dyack subtest 7F. A word-recognition test involving irregular words like 'who', 'any'. Extra items were added to this test and D&DA from Coltheart, Besner, Jonasson & Davelaar's (1979) Exception and Regular words to overcome ceiling effects.
3. Nonsense Words D&DH
   Daniels & Dyack subtest 7H. A test of the pronunciation of phonically simple non-words like 'bim'.
4. 'Reversible' Words D&DG
   Daniels & Dyack subtest 7G. A test of the recognition of words which can be read backwards like 'saw', 'net' and words high in content of 'reversible' letters like 'b/d'.
5. Sentence Comprehension D&DR
   Daniels & Dyack Standard Test of Reading Skill. A series of 36 questions like 'Can a dog run?'. The order of difficulty of the sentences reflects phonic complexity. The child must comprehend the sentence in order to answer the question.
6. Schonell Reading
   A word-recognition test for ages five to 15. It is composed of 100 words, 10 for each year. The words are arranged in continuous order of difficulty.

Spelling

7. Schonell Spelling
   A spelling test comprising 100 words, 10 for each year from five to 15. The first 10 are regular three-letter words. Thereafter there are both regular and irregular words ordered according to difficulty.

Vocabulary

8. WISC Spoken–Spoken
   The WISC-R vocabulary test where the child has to describe the meaning of words spoken to him.
9. Peabody Spoken–Picture
   Lloyd Dunn's Peabody Picture Vocabulary Test Form A. This tests the child's comprehension of spoken single nouns, verbs and adverbs. No reading is involved, the child being asked to select from among four pictures the one which he feels represents the word spoken by the investigator.
10. D&D Picture–Printed
    Daniels & Dyack subtest 9. The printed word which matches a picture must be chosen from five alternatives.
11. Carver Spoken–Printed
    This requires the child to choose from a set of five or six alternatives the printed word which represents that spoken by the examiner.

STM

12. Token Test
    Warrington *et al.* (1971) shortened form of the Token Test. The child is given three shapes each in four colours and is asked to perform 15 instructions such as 'Put the red circle on the green square'.
13. Auditory Sentence Span
    The child is asked to repeat 20 sentences ranging in length from two to eleven words.
14. Auditory Word Span
    The child is asked to repeat a series of words ranging in length from two to five syllables.
15. Auditory Digit Span
    The child is asked to repeat a string of numbers after the experimenter has said them. The initial sequence comprises two digits. The length is stepped up until there are two successive errors at the same length.

16. Visual Digit Span
Cards containing a series of digits are presented for the same number of seconds as there are digits on the card. The child has to recall the digits in the correct order once the card has been removed. There are three trials per length from two up to eight digits.
17. Visual Digit Span and Articulatory Suppression
As Visual Digit Span except that the child was to say 'hello, hello, hello,...' all the time when studying the card. This was to suppress articulatory rehearsal.
18. Visual Serial Ordering
VSO from the Illinois Test of Psycholinguistic Abilities (McCarthy & Kirk, 1961). Sequences of from two to six chips bearing graphic designs must be duplicated from memory having just seen the test series in a booklet.

Visual

19. Visual Closure
ITPA visual closure test. The child must find 'hidden' objects in a picture strip.
20. Picture Completion WISC
WISC-R subtest of picture completion (Wechsler, 1976). The child must detect and name the missing elements from simple line drawings.
21. Letter Search
Two visual search tasks: (1) find the 10 instances of the target letter among a page of random letters; (2) the same for word targets and foils. A rate of search score is calculated.
22. Coding WISC
WISC-R coding subtest. The child must remember paired associates of geometric symbols and use these to decode a passage.
23. Block Design WISC
WISC Block Design subtest. The child must arrange small geometric blocks to copy geometric shapes shown in the booklet.
24. Object Assembly WISC
WISC Object Assembly subtest. The child is to assemble the parts of a jigsaw-like puzzle.
25. Picture Arrangement WISC
The child must arrange a set of still pictures so that they relate a sequential story.

Auditory–Visual

26. Letter Recognition
The child is asked to name the letters indicated one by one.
27. Symbol > Sound Learning
Nonsense names must be learnt for nonsense shapes. The shapes were presented and the child had to name them. Scores were the inverse of the number of trials taken to learn the complete set.
28. Sound > Symbol Learning
As Symbol > Sound Learning except that here the names were given and the child was to point to the corresponding shape.
29. Colour Naming Rate
The child was to name the colour patches on a card of 40 random instances of eight colours as quickly as possible. A mean rate score was calculated over four trials.

Auditory

30. Syllable Segmentation
Liberman *et al.* (1977). The child was to tap out with a stick the number of syllables which he could hear in each word of a list.
31. Phoneme Segmentation
As Syllable Segmentation but tap out the number of phonemes.
32. Rhyme – Odd One Out
Bradley & Bryant (1978). Sets of four monosyllabic words were spoken to the child. Three of the words had a sound in common which the other did not share. In one series the odd sound was the final phoneme, in the other it was the middle phoneme. The child was to say the 'odd one out'.

33. Rhyme Generation
Ten words were spoken to the child and he was to give more words rhyming with each.
34. Sound Blending
ITPA Sound Blending Task. Words and non-words are spoken to the child as successive, separate sounds and the child must blend them into whole words.

Language Knowledge

35. Grammatical Closure
ITPA subtest. Thirty-three orally presented items are accompanied by pictures portraying the content of the verbal expressions. Each statement consists of a complete statement followed by one that the child must complete – 'Here is a bed, here are two...'. The items test syntax and grammatical inflection.
36. Knowledge of Syntax
Geitman *et al.* (1972). A glove puppet is used and the child is required to say whether the sentences spoken by the puppet are 'all right' or silly. There is then a request to help him say it properly. The sentences tap a wide range of syntactic rules.

Rote and Ordering

37. Days Forwards
Time taken to say the days of the week forwards. This is then converted into a rate score. (Accuracy only at five and six years old.)
38. Days Backwards
As above, but backwards.
39. Count Forwards
As days forwards but 1 to 10.
40. Count Backwards
As above but 10 to 0.

Oddments

41. WISC Information
WISC-R subtest. 'What is the main material used to make glass?', etc.
42. WISC Similarities
WISC-R subtest. 'In what way are an *apple* and a *pear* alike?', etc.
43. WISC Comprehension
WISC-R subtest. 'Why do people pay bills by cheque instead of cash?', etc.
44. WISC Arithmetic
WISC-R subtest. Counting trees, and mental arithmetic. A fairly mixed bag.