Children with dyslexia show deficits on most primitive skills[1]

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Abstract

Anomalies have been found in a range of skills for children with dyslexia. The study presented here investigated performance on the full range of primitive skills for with dyslexia and normal children at ages 8, 11 and 16 years. Unexpectedly severe deficits were revealed in a range of skills, including motor skill, phonological skill, and processing speed. Overall, the performance of the 16 year old children with dyslexia was no better than that of the 8 year old normal children, with some skills being significantly worse, and some better. The results are interpreted in terms of a developmental progression in which children with dyslexia suffer from general deficits in primitive skill learning, but are able to consciously compensate in many skills. We believe that a connectionist learning framework may provide a parsimonious account of the range of deficits, providing a potential link between these difficulties in skilled performance and the underlying neuroanatomical abnormalities.

Introduction

Specific developmental dyslexia, or dyslexia for short, is formally defined as "a disorder in children who, despite conventional classroom experience, fail to attain the language skills of reading, writing and spelling commensurate with their intellectual abilities" (from the definition by the World Federation of Neurologists, 1968). In other words, children of normal or above normal intelligence who, for some otherwise inexplicable reason, have severe problems learning to read and spell. Dyslexia research has seen more than its share of passion and controversy — not surprisingly, given its close links with that very emotive topic, reading failure; its high incidence in Western populations (around 5% is a typical estimate, Badian, 1984; Jorm et al, 1986); and high financial stakes, given the statutary requirement in many Western countries to provide educational support for children with dyslexia. Over and above these aspects, however, dyslexia provides a challenging paradox to a wide variety of researchers — why do these articulate, intelligent people show such a problem in one of our most routine skills? These background factors have resulted not only in the continuing high public profile of dyslexia research internationally but also in a wide range of research studies aimed at the better understanding, diagnosis or remediation of dyslexia.

Early research suggested that visual deficits were important, but around 20 years ago, there was a gradual realisation that problems of language must be, at least in part, responsible for the reading deficits. This general hypothesis has been refined over the years (Vellutino, 1979; Miles, 1983; Snowling et al, 1986; Stanovich, 1988) to provide what was until recently the consensus theoretical belief of most psychology researchers, namely that children with dyslexia suffer from an early impairment in their phonological skills, and this impairment prevents them from acquiring the word decoding and blending skills necessary for normal acquisition of the skill of reading. By contrast, however, many American researchers have studied the biological substrate. Again, dyslexia has provided intriguing abnormalities. Large scale twin and familial studies (e.g., Smith et al, 1983) has established specific abnormalities both of chromosome 15 and, more recently, chromosome 6 (Lubs et al, 1991). Studies of brain electrical activity in response to different types of stimulus have shown abnormalities for the processing of linguistic stimuli (Duffy et al, 1980; Hynd et al, 1990). Most directly, comparative studies of dyslexic brains have established neuroanatomical anomalies (Galaburda, Rosen and Sherman, 1989, p383). One significant recent development has been the re-establishment of visual deficits, in this case in rapid visual processing, specifically the threshold for the detection of flicker (Lovegrove et al, 1990), and in an interdisciplinary project involving both psychophysics and neuroanatomical analysis, this deficit has been linked to neuroanatomical abnormalities in the magnocellular pathway linking the eye to the visual cortex via the lateral geniculate nucleus (Livingstone et al, 1991).

There is, therefore, a wealth of research evidence about abnormalities in dyslexia. Unfortunately, there

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is a fundamental weakness in dyslexia research, namely the diagnostic method. The traditional definition, given earlier, depends both on a *discrepancy* (between actual and expected reading performance), on *exclusion* (of alternative explanations of a discrepancy in terms of low IQ, low opportunity, emotional factors and so on), and on a *learned skill* (reading). Taking the reliance on reading first, it is well-established that extensive support in learning to read helps a child with dyslexia to read at normal or even above normal levels (Bradley & Bryant, 1983; Lundberg & Høien, 1989), and in general the level of reading depends upon amount of practice as much as underlying aetiology. The use of exclusionary criteria has been roundly criticised by many researchers (Miles, 1983; Wood et al, 1991) with the link with intelligence proving the most problematic (Siegel, 1989; Stanovich, 1991). Clearly what is needed in dyslexia research is a better operational definition, based on positive indicators rather than exclusionary factors, on objective tests rather than clinical judgement, and on intrinsic factors rather than learned skills. Probably the ideal for many dyslexia researchers would be the development of a screening procedure usable before a child tried (and failed) to read. Unfortunately, progress towards this goal has been largely disappointing, with truly predictive studies (as opposed to retrospective) generally achieving relatively poor prediction of poor readers (Badian, 1990). It seems inevitable that development of better diagnostic methods awaits better understanding of the underlying causes of dyslexia. Our research program has been aimed in the first place at providing a body of reliable cognitive data linking research in phonological processing, motor skill, processing speed, and working memory. We hoped that availability of this corpus would prove a stimulus to researchers from all the disciplines of cognitive science to attempt to provide integrative theories linking the cognitive deficits with the underlying neurological abnormalities.

Skills, Age and Dyslexia

The study reported here derives from early research (Nicolson and Fawcett, 1990) in which we identified problems in motor balance for a group of children with dyslexia, but only when they were required to undertake a secondary task while balancing. Subsequent work extended these findings to a deficit in blindfold balance (Fawcett and Nicolson, 1992) and in choice reactions but not simple reactions (Nicolson and Fawcett, 1993). Given the established deficits in phonological skill, it was clearly important to undertake a wide ranging study in which as many primitive skills as possible were tested for as large a range of children with dyslexia as practicable, in order to establish the relative severity of the deficits in these various skills. Furthermore, given the developmental nature of skill and of the symptoms of dyslexia, it is important to study performance at several ages.

Participants

We wished to study 'pure' dyslexia, uncontaminated by factors such as low IQ, economic disadvantage and so on. Consequently, we used the standard exclusionary criterion of 'children of normal or above normal IQ (operationalised as IQ of 90 or more on the Wechsler Intelligence Scale for Children), without known primary emotional or behavioural or socioeconomic problems, whose reading age (RA) was at least 18 months behind their chronological age (CA). In addition to our initial groups of 15 year olds, we recruited two further groups of children with dyslexia, mean ages 11 and 8 years, together with two groups of normal children matched for age and IQ. This gave us six groups: D15, D11 and D8; and C15, C11 and C8 for the three age groups of children with dyslexia and control children respectively. This three-age-group design allows performance to be compared with children of the same age, children of around the same reading age (D15 vs C11; D11 vs C8) and children of around half the age (D15 vs C8). The numbers of participants and mean IQ for the groups were 12, 8, 9, 11, 10, 10 and 105, 110, 114, 107, 11.6, 114 for the groups D15, D11, D 8, C15, C11, C8 respectively. These six groups had all been monitored for around two years, and the experiments reported here took place over a period of around one year.

Tests Used

A variety of tests intended to tap performance on primitive cognitive and motor skills was used. Wherever possible these were implemented on an Apple Macintosh computer using digitised sound for instructions and stimuli and using automatic event recording and data analysis techniques in order to standardise testing techniques and to facilitate replication by other researchers. Five generic types of test were used: psychometric tests, motor skill tests, working memory tests, tests of speed of processing, and phonologically-based tests. The psychometric tests used the WISC-R scales, with spelling age and reading age based on the Schonell tests of single-word reading and spelling. The motor skill tests included the balance tasks and tests of bead threading and pegboard peg moving. The working memory tests included nonword repetition (repeating nonsense words of 2, 3, 4 and 5 syllables, based on Baddeley and Gathercole, 1990), the mean Memory Span for words of 1, 2 and 3 syllables, the 'Corsi Span' for spatial sequential memory, and articulation rate (the mean time to repeat five times 'bus', 'monkey' and 'butterfly'), which is included in this category because memory span and articulation rate are known to co-vary (Baddeley, et al, 1975).

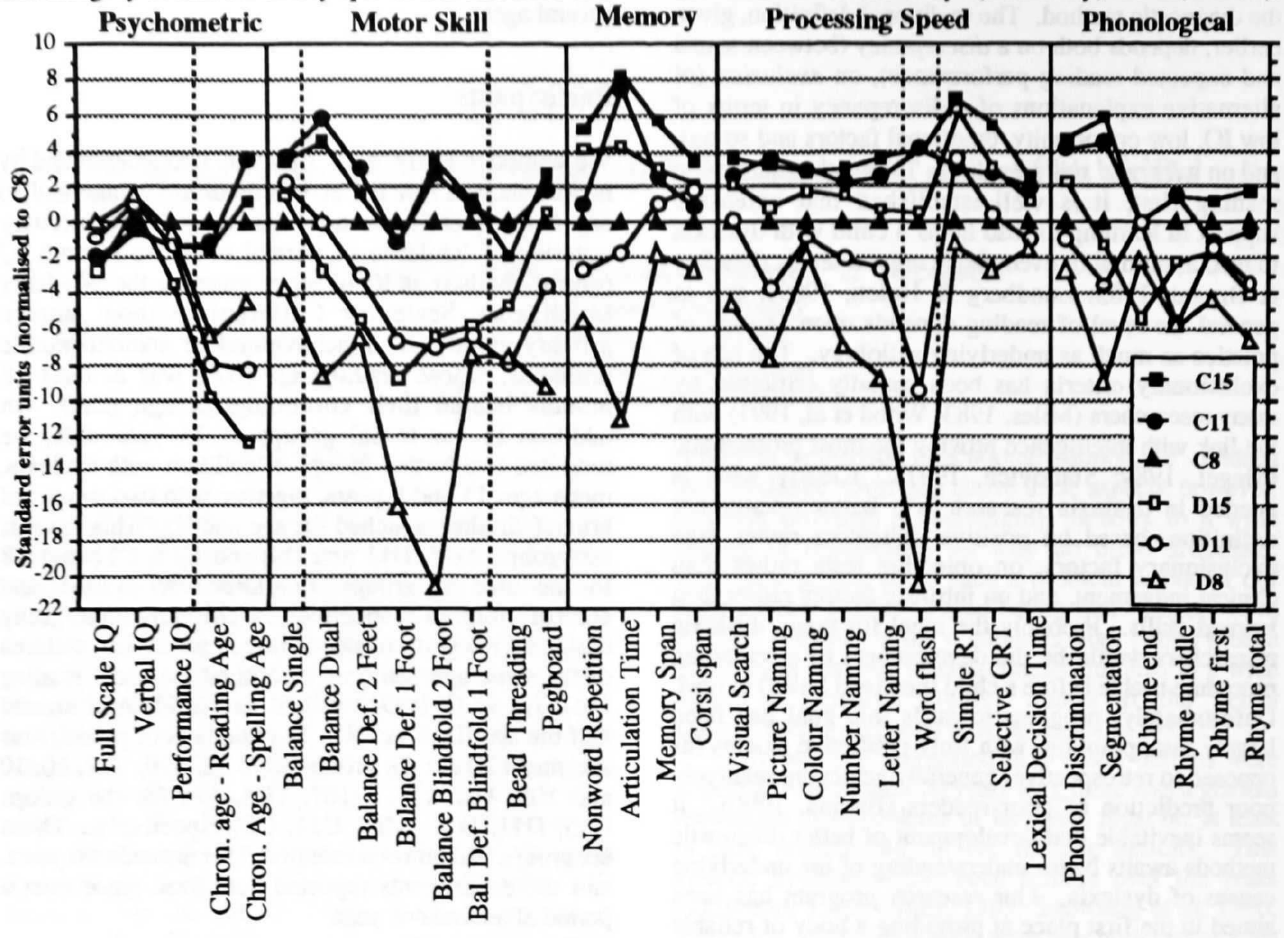

Figure 1. Data for three age groups of children with dyslexia and normal children normalised to the data of the 8 year old normal children

Tests of information processing speed included tests of speed of naming of pictures, colours, digits, letters presented unpaced, together with simple reaction and selective choice reaction time to pure tones, visual search (locating a distinctive 'spotty dog' on each of several crowded pages in a child's puzzle book), lexical decision (saying 'Yes' or 'No' as fast as possible to auditorily presented words and nonwords), and tachistoscopic word recognition on a graded series of words presented for gradually decreasing times. The tests of phonological skill included phonological discrimination ability for phonologically confusable stimuli (Bishop, 1985), segmentation ability (Rosner, 1971) and 'rhyming' ability for phonemes at the beginning, middle and end of words (a simplified version of the tests used in Bradley and Bryant, 1983). The computer-based versions of the tests are available in the COMB set (Nicolson, 1992).

Results

Surprisingly large deficits were obtained in a surprisingly wide range of tasks. In order to facilitate comparison of the results, the results were normalised relative to mean and standard error of the corresponding performance of the eight year old controls, with the sign of any differences adjusted so that a positive difference always reflected a better score. A score of 0 therefore indicates performance equivalent to that of the C8 group, a score of +1 indicates one standard error better than C8, a score of -1 one standard error less, and so on. If the data were normally distributed, with 12 children in the C8 group, significance levels are distributed as Student's t with 11 degrees of freedom. Consequently, taking two-tailed values, the appropriate criteria for $p < .05$, $p < .01$, and $p < .001$ are $t > 2.2$, $t > 3.1$ and $t > 4.4$ respectively. Given the likely deviations from the normal distribution it would be appropriate to set these criteria somewhat higher. The normalised results are shown in Figure 1. The C8 group, naturally, have zero score on every measure.

Looking just at the other two control groups (filled symbols), there are few differences on the psychometric tests, better performance on the single task balance, but roughly equivalent fine motor skill (beads and pegs), better performance on the memory, and especially articulation rate, faster processing, better phonological discrimination and segmentation, and roughly equivalent rhyming performance. Whenever there is a difference, the oldest controls perform the best, and the youngest controls the worst. In other words, the results for control groups are largely as one would expect, with some of the skills still developing in the teens, and some already at ceiling (at least on the tests used).

Now consider the performance of the groups with dyslexia. The psychometric data are largely as expected, since the pairs of groups were matched for IQ and age. All three groups with dyslexia show a higher verbal than performance IQ. As expected, reading age and spelling age lag further and further behind chronological age. Phonological skills show the expected deficits, with the D8 group showing the expected lag, and surprisingly poor performance for the D15 group, well below that even of the C8 group. The memory and processing skill scores for the three groups with dyslexia show a heartening developmental trend, with the abysmal performance of the D8 group making way to merely poor performance of the D11s and near-adequate performance of the D15s. Indeed, in contrast to the other tests, the D15s consistently outscore the C8s on these tests. Most notable overall is the extraordinarily poor motor skill performance of all three groups with dyslexia on the dual task balance, the blindfold balance, and the bead threading tasks, with performance at least 5 standard error units below that of the youngest controls. Note that the most marked balance discrepancies are for the deficit data, that is the difference in balance performance in the target condition from that under normal 'single task' balance conditions.

Discussion

It is perhaps worth emphasising that in almost all tests of naming speed, phonological skill, motor skill, and also nonword repetition and articulation rate, the children with dyslexia performed significantly worse even than their reading age controls. It may also be seen that the performance of oldest children with dyslexia is by no means better overall than that of the youngest controls, despite the advantage of around 7 years' experience. Space precludes a more detailed analysis here (see Nicolson and Fawcett, 1993b for a fuller discussion), and we must limit the discussion to the major issues motivating these studies.

Let us first consider our hope was that the study might help to suggest diagnostic procedures less susceptible to environmental factors and maybe applicable at an earlier age than the current reading-based approach. Note that none of the cognitive tests shown in figure 1 involves reading accuracy. It appears from Figure 1 that dual task balance impairment, together with naming speed and phonological skill do potentially discriminate children with dyslexia from normal children (though it should be emphasised that these tests may not discriminate dyslexic children from non-dyslexic slow learners, in that we have not yet completed studies on the latter). It seems very likely that some suitable combination of these tests may be employed, using discriminant function analysis to provide a series of scores: one for dyslexia, one for specific language delay, another for general learning disability, and so on. This hope rests on research as yet unstarted, with perhaps the greatest need being to identify the qualitative performance of 'slow learning' children on the battery of tests developed above. Turning now to predictive screening, again we see reason for optimism, with perhaps scope for a multi-purpose battery of tests, providing a vector 'at risk' score for several childhood disorders. Many of the tests may be used, in suitably simplified form, with five year old children. Indeed we are half way through a three year screening study, having tested children at age five and six on many of the tests noted above, and we are now waiting to see which of our sample of children will prove dyslexic by the normal criteria, thereby allowing a retrospective analysis to be carried out (Fawcett et al, 1992).

Now let us turn to the theoretical interpretation of the results. It is important to note that the results do appear to provide a link between the motor skill deficits, speed deficits and phonological deficits which have been established in previous research, confirming that a number of disparate findings apply jointly to these groups of children with dyslexia. The expected deficits in phonological skill (cf. Bradley and Bryant, 1983) remain at all ages, with the oldest children with dyslexia performing significantly worse even than the youngest controls, despite the fact that the former are around twice as old. Similarly, the naming speed deficits (cf. Denckla and Rudel, 1976) are robust, though the deficit on the visual search (for a pictorial target in a crowded picture) is perhaps unexpected. There are some working memory deficits (cf. Gathercole and Baddeley, 1990), though these appear less severe than the other deficits, and may even be explicable purely in terms of the unexpectedly slow articulation rate (Baddeley et al, 1975). The deficits on bead threading and on dual task balance are particularly marked (cf. Nicolson and Fawcett, 1990), with the oldest children with dyslexia performing much worse even than the youngest controls. Overall, then, the results appear compatible with the existing literature but they are particularly valuable in that they provide not only an opportunity to compare directly the relative severity of the deficits across the different skills, but also because they provide the opportunity to assess the developmental progression of the acquisition of the skills. Regardless of the specific interpretation of these results, we believe that this corpus of data should prove valuable, as hoped, to cognitive science researchers of all sub-disciplines who are interested in dyslexia.

It is perhaps important to stress that the dyslexic children tested here were matched for IQ with the control children. Consequently, despite their marked deficits in skill acquisition, their intellectual functioning appears to be unimpaired. Consider Anderson's suggestion (1990) that the human brain may be best seen as a hybrid computer, partly a highly efficient, highly evolved massively parallel connectionist processor which is shared in essence with higher mammals, but upon which is overlaid a slow and inaccurate 'serial symbol manipulator' which holds the key to the evolutionary advantage of humans. It is tempting to speculate that, for dyslexic people their brain abnormalities may lead to 'noise' within their 'parallel' system, their neural networks, whereas their symbolic processing capabilities (and hence 'intelligence') remains unaffected. While this hypothesis is at present too vague to provide any explanatory power, it suggests a range of novel investigations, with some aimed at identifying the locus or loci of the 'noise' within the processing system, and others investigating purely symbolic learning capabilities. In the longer term, it may afford an intriguing link between the neurophysiological substrate, cognitive science modelling techniques, and cognitive performance which could form a significant tool in the investigation and modelling of cognitive function.

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