DEVELOPMENTAL DYSLEXIA: THE ROLE OF THE CEREBELLUM

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INTRODUCTION: DEVELOPMENTAL DYSLEXIA

Specific developmental dyslexia is normally identified by unexpected problems in learning to read for children of average or above average intelligence — "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 Neurology, 1968, p26). A typical estimate of the prevalence of dyslexia in Western school populations is 4% (Badian, 1984; Jorm, Share, Maclean, & Matthews, 1986), with roughly four times as many boys as girls being diagnosed, though other investigators (Shaywitz, Shaywitz, Fletcher and Escobar, 1990) have reported incidence as high as 10%. Dyslexia is genetic in origin (Smith, Kimberling, Pennington, & Lubs, 1983), and cannot therefore be 'outgrown' in adulthood, even if the reading difficulties are largely overcome.

Substantial progress has been made in the methods for overcoming the reading difficulties of children with dyslexia, but the success of reading remediation depends critically upon how early the support can be provided, with by far the best results being obtained if extra support is given as the child is learning to read, rather than after one or two years of reading failure (Bradley, 1988; Lundberg, Frost &
Peterson, 1988; Strag, 1972; see also Clay, 1993). Unfortunately, the underlying cause has proved frustratingly elusive, to the extent that there is now widespread concern over methods of diagnosis even at 8 years, together with confusion over appropriate methods of theory development (see Lyon, Gray, Kavanagh and Kranegor; 1993 for a series of articles on these issues).

In this article we present the findings of our ten year research program aimed at a fuller understanding of the underlying causes of dyslexia. The initial research was based on the skill learning framework, and discovered symptoms consistent with faulty skill automatisation even in the gross motor skill of balance. The second research phase was deliberately exploratory, aimed at delineating the pattern, severity and incidence of difficulties shown by children with dyslexia across the spectrum of skills. These studies indicated severe and persistent problems in phonological skill, processing speed, balance and motor skill. The third phase attempted to identify possible cause(s) of the range of deficits, focusing on the possibility of cerebellar impairment. The cerebellar impairment hypothesis provides a potential parsimonious explanation of the range of problems and makes a number of specific predictions. Empirical work both with our existing panel of subjects and with further dyslexic subjects confirm these predictions, thereby providing strong evidence that cerebellar impairment may well be one of the underlying causes of dyslexia.

The learning framework and the cerebellar impairment hypothesis run counter to the mainstream of dyslexia research, and it is therefore important to explain not only the rationale for our own work but also the rationale for alternative conceptualisations, attempting to explain that the cerebellar impairment hypothesis is not only compatible with existing approaches, but that it actually provides a coherent, explanatory framework capable of unifying what are currently diverse approaches. We start with a brief survey of current theoretical approaches to the understanding of dyslexia, focusing on the influential phonological deficit hypothesis and the more recent temporal processing deficit. This survey leads into the set of issues that our research program was designed to address. We then outline the findings of our own research program, leading to the establishment of the cerebellar impairment hypothesis. Finally we return to the key issues identified initially, arguing that the cerebellar impairment hypothesis presents a coherent explanatory framework for the underlying cause of dyslexia.

**Dyslexia: The Range of Difficulties**

One of the fascinations of dyslexia for researchers is that, whatever one's interest in human behaviour and performance, children with dyslexia will obligingly show interesting abnormalities in precisely that behaviour. Deficits have now been established in motor skill, in visual processing, in rapid processing, and in memory, together with tantalising links to neuroanatomical irregularities. The body of knowledge on dyslexia is very extensive and growing rapidly. Neurological and genetic background factors are thoroughly discussed in edited works by Galaburda (1989) and Duane and Gray (1990). General cognitive accounts are provided in