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Executive functioning in adults and children with developmental dyslexia

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Abstract

The performance of developmentally dyslexic children and adults was studied upon a range of tasks that involved executive functioning. Both adult and child samples of dyslexics were found to under-perform on the group-embedded figures test. This test required the identification of constituent parts from within complex visual arrays, with good performance necessitating the inhibition of the processing of the surrounding context. A general deficit on visual–spatial tasks was eliminated as an explanation as dyslexics performed normally upon a range of other non-verbal assessments. The dyslexics consistently demonstrated a deficit in digit span tasks, a decrement that was increased with distractors, again suggesting difficulties in inhibiting the processing of the surrounding context. A deficit was also identified upon a verbal fluency task without a deficit in vocabulary level. Additionally, a specific deficit in the recollection of the temporal order of the presentation of items was in evidence, without a deficit in the recognition of the items themselves. The findings taken as a whole suggest that dyslexic individuals show deficiencies in executive functions relating to inhibition of distractors and to sequencing of events, a set of tasks associated with left prefrontal cortex functioning in the acquired neuropsychology literature.

Keywords: Group-embedded figures test; Inhibition of distractors; Left prefrontal cortex

Developmental dyslexia (DD) is defined by the World Federation of Neurology [85] as a disorder manifested by difficulty in learning to read despite conventional instruction, adequate intelligence and sociocultural opportunity. This definition is consistent with the DSM-IV classification of specific reading difficulty, for which prevalence is estimated to be around 5–10% in the school-aged population [1], although some estimates are as high as 20% of schoolchildren [72]. The earliest theorising of DD has implicated possible abnormalities in cerebral lateraliation, specifically a failure to acquire left hemisphere specialisation for language [57]. Evidence that hemispheric specialisation may play a role is suggested by the relatively high incidence of left-handed or ambidextrous individuals within the dyslexic population [51]. Geschwind and Behan [31] hypothesised that left-handedness and DD are related to a common factor affecting the development of the left hemisphere in utero, which results in right hemisphere dominance. Neuroimaging studies consistently reveal that the dyslexic brain is distinguished from the non-dyslexic brain in the degree to which language areas in the brain are asymmetric (see [35]; Table 20.1, p. 624–5 for a summary, see [61] for a meta-analysis). In the most comprehensive MRI study of brain anatomy in DD, Eliez et al. [17] report a significant decrease in grey matter on the left side and a (possibly consequent) non-significant greater-than-normal rightward symmetry of grey matter.

A rightward symmetry is significant as the right hemisphere primarily subserves the processing of the relatively global level, whilst the left hemisphere primarily subserves the processing of the relatively local level [37]. With respect to reading, initial reading processes focus on the (relatively global level) word, or 'logographic' [25] level (primarily undertaken by the right hemisphere) with a developmental shift to a focus on the processing of (relatively local level) letters (and the subsequent formation of grapheme–phoneme correspondences subserved mainly by the left hemisphere) occurring at around 7 years of age. This refocusing of processing onto local level elements requires the inhibition of global level processing [9]. A major theory of DD [3–6] suggests that the abnormal cerebral symmetry underpins a failure to shift from the word level to the letter level of processing, arresting reading development at the (relatively more global) logographic level [25]. Unlike normal readers, dyslexic individuals do not show increased left hemisphere activation when processing language nor a right ear advantage on dichotic listening tasks [6,51,78] highlighting that the DDs' reading strategies are less phonemically based [50,56].

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Thus, DD can be described as a deficit in the inhibitory processes required to shift from the logographic level of reading and as such we would expect the abnormal symmetry described above to be evident in the prefrontal regions, which are associated with the control of inhibition. Whilst most neuropsychological studies focus on more posterior areas of the brain associated with language, Hynd et al. [36] found that atypical symmetry of the prefrontal regions correlated with deficits in reading skills. Abnormal symmetry has been found to be evident in the prefrontal cortex in language impaired children, in the absence of such abnormalities in more posterior areas associated with language [28,39]. This would suggest that the hemispheric symmetry underpinning the deficit in DD would be manifest in other cognitive assessments not directly related to reading, such as tasks benefiting from inhibitory control. The main aim of the four studies reported here is to evaluate this hypothesis by assessing dyslexic individuals on a series of tasks that are not specifically associated with assessments of reading. Given the prefrontal symmetry that has been identified in DD, we would predict biases in assessments of executive functioning, which include the capacity for inhibition.

Executive functions refer to a collection of cognitive abilities such as planning, sequencing, organisation and inhibition, associated with the functioning of the prefrontal cortex [27,49]. DDs have been shown to demonstrate poor strategy formation and a lack of planning and organising [11,12,41,52,62]. DDs, for example, under-perform on Tower of Hanoi (ToH) assessments of planning and strategy formation. Despite the potentially significant role of inhibition in the development of reading, this executive function has been largely neglected in the assessment of DD. The potential significance of inhibitory processes is highlighted by the consistent deficit that has been identified in verbal digit span tasks, which assess aspects of working memory. Increasingly taxing working memory resources results in increased difficulty in controlling inhibition [60]. Working memory demand and the demand for inhibition have been identified as the two dimensions critical for understanding the breadth of executive functioning tasks. Tasks with a high demand for either or both of these dimensions are sensitive to prefrontal function and may be mediated by a single cognitive mechanism (see [64] for a review).

This is consistent with a large body of research that argues the capacity for inhibition (or 'resistance to interference') within the perceptual domain is a major factor in cognitive development that is intimately associated with the operation of the prefrontal cortex; young children 'find it difficult to resist misleading, irrelevant visual and auditory stimuli' ([14], p. 224). This sensitivity to interference declines throughout the school years through increased effectiveness in inhibiting or suppressing stimuli or associations that are not relevant to the task at hand [27,49]. This sensitivity also increases again during the ageing process, beginning in the 50s [46]. A task that assesses the effectiveness of these inhibitory processes and mirrors this developmental trend is the group-embedded figures test (GEFT; [84]). The GEFT requires participants to identify a simple shape (such as a cube) within a complex visual array, designed to provide distracting context. Effective inhibition of the distracting context allows for successful completion of the task. The poor GEFT performance of young children and elderly individuals is similar to the performance of frontal lobe patients. Frontal lesions affect the ability to control interference from external and internal sources, without affecting established IQ [75] and ERP studies have confirmed the role of the frontal lobes in GEFT performance, specifically the left prefrontal cortex [19,20]. This is particularly pertinent to reading as most text passages contain abundant sources of interference (e.g. ambiguities, see [14,15] for a full account). Some text processing difficulties exhibited by DDs maybe due to inefficient inhibition as they are with frontal patients, as 's/he will have difficulty remaining "... within the selective system of connections given by the text" ([49, p. 286]; [14, p. 62]). Thus, in addition to its impact on reading strategies, inhibition plays a significant role in learning—particularly in the presence of interference from distractors [14].

Whilst the prefrontal cortex is not a homogeneous structure, having several distinct cytoarchitectonic regions, the capacity for inhibition is an intrinsic property of the prefrontal cortices as a whole [65]. The abnormal cerebral symmetry in dyslexia discussed above is particularly relevant to this aspect of executive functioning as the left prefrontal region inhibits the processing of the right prefrontal region [24] raising the possibility that a deficit in the control of inhibition in the left prefrontal cortex may underpin DD. ERP studies have identified the left frontal lobe as particularly important for the selective processing of the local level [86], a process that requires the inhibition of the global level processing (as described above). These inhibitory processes mediate selective attention and the inability to inhibit distractors may underlie the distractibility frequently found in frontal patients [24] and is also reported in dyslexics [83].

In normal processing, increased blood flow in the left prefrontal cortex is associated with efficient planning and organisation [54]. The verbal fluency task, for example, is associated with left prefrontal cortex functioning which requires the generation of words that begin with a specified letter (F, S). Patients with bilateral or left frontal lesions but not right frontal lesions have been found to generate significantly fewer words than matched controls [38,53]. These findings from the acquired literature are comparable to the study of developmental dyslexics who also display a deficit on this task [44,47]. Whilst it is probable that the representations of words are stored in the temporal lobes, the left prefrontal cortex is involved in generating appropriate responses and inhibiting inappropriate responses [26].

As Bakker's [3–6] proposal of abnormal symmetry in DD extends to the prefrontal cortex, we would predict deficits in executive functions associated with the left prefrontal cortex, one of which is a failure to inhibit the processing