More than words: a common neural basis for reading and naming deficits in developmental dyslexia?

Eamon J. McCrory,1,2 Andrea Mechelli,3 Uta Frith2 and Cathy J. Price3

Summary
Dyslexic individuals show subtle impairments in naming pictures of objects in addition to their difficulties with reading. The present study investigated whether word reading and picture naming deficits in developmental dyslexia can be reduced to a common neurological impairment. Eight dyslexic subjects, impaired on measures of reading, spelling and naming speed, were matched for age and general ability with 10 control subjects. Participants were scanned using PET during two experimental conditions: reading words and naming pictures in the form of corresponding line drawings. In addition, two high-level baseline conditions were used to control for visual and articulatory processes. Relative to the control group, the dyslexic participants showed reduced activation in a left occipitotemporal area during both word reading and picture naming. This was the case even in the context of intact behavioural performance during scanning. Abnormal activation in this region, as reported previously for reading, is therefore not specific to orthographic decoding but may reflect a more general impairment in integrating phonology and visual information. Our investigation points to a common neurological basis for deficits in word reading and picture naming in developmental dyslexia.

Keywords: dyslexia; reading; naming; functional imaging; left occipitotemporal cortex

Introduction
It has long been proposed that the cognitive processes engaged when reading a word overlap considerably with those engaged when naming a known object (Geschwind, 1965; Wolf, 1991). In both instances we perceive and identify a visual stimulus and retrieve its associated lexical form, which is then output during articulation. It is also well established that picture naming provides a means to index literacy skill. Naming performance in kindergarten, for example, represents a powerful predictor of later reading ability (Jansky and de Hirsch, 1972; Wolf and Goodglass, 1986).

It is therefore not surprising that dyslexic children show early impairments on tasks of picture naming in addition to their difficulties with reading. For example, dyslexic children present with impairments on tasks of rapid automatic naming, in which a series of pictures are named sequentially (Denckla and Rudel, 1976). The cognitive complexity of this task has precluded a straightforward explanation of this impairment (Wolf, 1991; Manis et al., 1999). In contrast, their impairments in confrontation naming, in which individual pictures are named discretely, are generally thought to be attributable to a phonological impairment (Katz, 1986; Snowling et al., 1988; Swan and Goswami, 1997).

By adulthood, impairments in confrontation naming have largely resolved, in contrast to continuing deficits in reading (Felton et al., 1990; Hanley, 1997). Yet how can this be accounted for if a common phonological deficit is hypothesized to underlie both impairments? A number of observations suggest that a deficit in lexical retrieval persists into adulthood but at a more subtle level. For example when adult dyslexics must name single pictures in a rapid fashion, impairments do emerge (e.g. Wolff et al., 1990). Similarly, deficits are commonly reported in adult dyslexics when pictures are named sequentially on tasks of rapid automatic naming (e.g. Felton et al., 1990).
During both reading and naming, a stored phonological code is retrieved. This code is likely to consist of phonological segments that are activated and assembled into a sequence that controls production (Levelt, 1989). During reading, orthographic codes are postulated to have direct connections with phonological codes; despite a large amount of empirical research, it is still a matter of debate how these connections are instantiated (Plaut et al., 1996; Zorzi et al., 1998; Coltheart et al., 2001). In contrast, during picture naming, phonology is accessed via the semantic system (Warren and Morton, 1982; Glaser, 1992). Despite these differences, both words and pictures are thought to access the same lexical store of word forms but pictures are thought to show privileged access to semantics and words a privileged access to phonology (Warren and Morton, 1982; Glaser, 1992). So while word reading is faster than picture naming, word classification is slower than picture classification (Segui and Fraise, 1968).

Studies of dyslexic individuals are remarkable in showing a selective deficit in the phonological but not semantic processing of pictures (e.g. Murphy et al., 1988). Such findings support the view that dyslexia is characterized not by a general language or semantic deficit, but one which pertains primarily to phonological representation and retrieval.

Studies of the normal population have investigated the neural basis for the cognitive processes engaged in phonological retrieval. Tasks of letter, colour and picture naming have been shown to implicate a common neural system incorporating the left posterior inferior temporal lobe and the left frontal operculum (Price and Friston, 1997; Moore and Price, 1999). The functional role of these regions remains to be fully specified. Typically, however, frontal regions are associated with later stages of retrieval, including articulation (Murphy et al., 1997) while posterior areas are activated during earlier stages of phonological retrieval (e.g. Salmelin et al., 1996).

Over the past decade, functional imaging studies have made significant advances in identifying the neural basis of word reading in developmental dyslexia (for reviews see Habib, 2000; McCrory, 2003). In general, dyslexic participants have been reported to show a pattern of differential activation relative to normal readers that have clustered in three key left hemisphere regions: (i) a set of left frontal regions largely centred on the inferior frontal gyrus; (ii) the left temporoparietal region, including the supramarginal gyrus and the posterior aspect of the superior temporal gyrus (Wernicke’s area); and (iii) the left posterior inferior temporal lobe (BA 37), now more commonly referred to as the occipitotemporal region.

A consensus is emerging that the most robust differences in activation arise in the left occipitotemporal area in dyslexic participants (Salmelin et al., 1996; Rumsey et al., 1997; Brunswick et al., 1999; Paulesu et al., 2001; Shaywitz et al., 2002) even when behavioural performance has been matched (Brunswick et al., 1999) and across different orthographies (Paulesu et al., 2001). These differences have been consistently interpreted in the context of impaired phonological processing in dyslexia (Rumsey et al., 1997; Brunswick et al., 1999; Paulesu et al., 2001; Shaywitz et al., 2002). Yet while these studies have employed a variety of paradigms they share one common feature: the use of orthographic stimuli. Therefore, we cannot exclude the possibility that reduced activation in this area reflects orthographic rather than phonological processing.

Studies of skilled reading have not provided a consistent account of the role of the left occipitotemporal area. Recently, the emphasis has been on the association of this area with visual word form processing (Cohen et al., 2000; McCandliss et al., 2003). However, although this left occipitotemporal area is activated during reading, it is also activated by a range of tasks that do not engage visual word-form processing, such as naming colours and pictures (Moore and Price, 1999; Chao et al., 2002), reading Braille (Buchel et al., 1998) and making manual responses to pictures of meaningless objects (Phillips et al., 2002). This response profile suggests the left occipitotemporal area has a more general function (Price and Devlin, 2003). Nevertheless, we still need to consider whether the area is more involved in reading than non-orthographic processes. Our functional imaging experiments have suggested that activation is higher during picture naming than reading in normal participants (Price and Devlin, 2003). However, Hasson and colleagues found greater activation for written words than pictures of tools during a one back task (i.e. is present stimulus identical to previous stimulus?) (Hasson et al., 2002). Thus, the degree to which left occipitotemporal activation is engaged during the processing of orthographic and non-orthographic stimuli may depend on the nature of the task and the differential demands on a shared processing function. If the left occipitotemporal activation reflects phonological retrieval, then abnormal activation is more likely to be detected by dyslexics who are engaged in phonological tasks such as reading. A recent MEG study (Tarkiani et al., 2003) showed that face stimuli elicited normal left occipitotemporal activation in dyslexic participants, which contrasts with the reduced left occipitotemporal activation that has been observed in dyslexic participants during reading. However, the face stimuli and task used by Tarkiani and colleagues did not require any phonological processing. Thus, abnormal left occipitotemporal activation might be abnormal if faces or objects had to be named.

Previous imaging studies that have used tasks which explicitly entail phonological processing have had to contend with impaired behavioural performance by dyslexic participants (e.g. Rumsey et al., 1997; Shaywitz et al., 1998). The difficulty here is how one interprets differences at the neural level, if at the behavioural level the performance of the two groups differs. Poor behavioural performance alone may be sufficient to explain some, if not all, of the observed activation differences. Picture naming, for several reasons, may represent an ideal paradigm to overcome these concerns. While picture naming is markedly impaired in dyslexic children (e.g. Katz, 1986; Swan and Goswami, 1997), confrontation naming is normal in dyslexic adults (e.g. Felton et al., 1990). When naming proceeds in rapid succession, either in a sequence (e.g. Felton et al., 1990) or singly (Wolff et al., 1990), dyslexic
adults manifest a performance deficit. This pattern suggests that although dyslexic adults manifest a developmental improvement in picture naming, a cognitive impairment in phonological retrieval persists—and this impairment is behaviourally manifest under speeded conditions. In this way picture naming may allow us to engage the cognitive component of interest (phonological retrieval) while not giving rise to detectable behavioural impairments.

The present study aimed to investigate the neural correlates of picture naming and word reading in developmental dyslexia, using PET. Dyslexic individuals are thought to have a common deficit in phonological retrieval that extends beyond literacy to encompass picture naming (e.g. Katz, 1986; Swan and Goswami, 1997). It is hypothesized that this deficit persists into adulthood and is detectable at the neural level. We propose that the atypical left occipitotemporal activation in developmental dyslexia reflects an impairment in phonological retrieval beyond that implicated by orthographic decoding. Specifically, the dysfunction in this region should be manifest during both word reading and picture naming since both tasks require phonological retrieval. The alternative possibility is that atypical activation in the occipitotemporal region is specific to orthographic stimuli. This would be inconsistent with the idea that impaired performance during reading and naming can be reduced to a common phonological deficit.

Methods

Participants

Eight dyslexic participants and 10 control participants with no history of language difficulty were recruited. All participants were right-handed, physically healthy males and none reported a history of neurological or psychiatric disorder. The dyslexic readers all had a documented history of reading difficulty identified in childhood or adolescence; all participants had gained entrance into university. Both groups were well matched for educational level, age and full-scale, verbal and performance IQ, as shown in Table 1.

Neuropsychological measures

General ability

General intellectual ability was assessed with the administration of a full Wechsler Adult Inventory Scale—III (Wechsler, 1997). Full-scale, verbal and performance IQs were calculated across groups.

Reading and spelling

Literacy skills were assessed using the Wide Range Achievement Test—Revised (Jastak and Wilkinson, 1984).

Naming

Naming ability was evaluated using two tasks of rapid automatic naming. In a picture naming task, five pictures were repeated 10 times along five rows, each 10 items in length (after Denckla and Rudel, 1976). Participants were asked to name each picture, working as fast as possible across each row until the end. The mean time was calculated across two trials. The same procedure was used for the digit version. Participants were asked to read aloud, as fast as possible, strings of 50 single-syllable digits (the number 7 was excluded as the only digit with a two-syllable name). Digits were chunked into blocks of five (e.g. 68248 83542 99634), although participants were told to read each digit as a single number, i.e. the string 51368 had to be read as ‘five, one, three, six, eight’. The task was presented twice with different strings of 50 digits. Again, a mean score, in seconds, was calculated.
PET stimuli and tasks

Stimuli

In total, 120 names were selected from the Snodgrass and Vanderwart set of pictures (Snodgrass and Vanderwart, 1980), and were presented as either words or line drawings [Fig. 1(i) and 1(iii)]. Word length ranged in length from one to four syllables (mean = 1.72; SD = 0.8) and from two to nine phonemes (mean = 4.73; SD = 1.77). Mean word frequency was calculated as 399 occurrences per 17.9 million for combined written and verbal frequency (Celex database). A set of published norms (Morrison et al., 1997) for the Snodgrass and Vanderwart (1980) picture sets indicated a high mean name agreement score (0.92) and a relatively early mean age of acquisition, of 51 months (SD = 16.72). The stimuli were divided into two sets, A and B. Half the participants saw set A as pictures and set B as words; the remaining participants saw set A as words and set B as pictures. In this way no participant read and named the same items. Pictures were all scaled to measure 5–8 cm in width and 5–8 cm in height. Words were presented in lower case Courier font, size 72 points.

In addition, meaningless control stimuli were carefully designed for both reading and naming tasks [Fig. 1(ii) and 1(iv)]. For words, two sets of false fonts were created, one short and one long, to match for word length. For pictures, a set of nonsense line drawings was also created to control for the visual features of each object. The rated visual complexity of these non-objects was matched with published ratings (Morrison et al., 1997) of visual complexity of the real objects.

Experimental paradigm

The experimental paradigm comprised four conditions: word reading, picture naming, false fonts and nonsense shapes. In the reading and naming conditions, subjects were asked to read or name aloud each item when it appeared on the screen. The false fonts were either short strings or long strings. For the short strings, participants were instructed to respond ‘yes’, and to the long false font condition they responded ‘okay yes’. Similarly, there were two types of nonsense shape trial. In one, participants responded ‘yes’ and in the other they responded ‘okay yes’. The false font and nonsense shape tasks were designed to control for visual processing, articulation processes and auditory feedback. These baselines are similar to those employed in previous studies to control for the visual processing of the words and pictures (e.g. Bookheimer et al., 1995; Moore and Price, 1999). Fifteen stimuli were presented per scan, each for 500 ms, with a fixed interstimulus interval of 2000 ms.

PET scanning

Regional cerebral blood flow was measured using a CTI Siemens Ecat HR+ PET scanner. Each activation scan involved the intravenous administration of 5 mSv of 15O-labelled water at the constant rate of 10 ml/min. From the start of each scan, background radiation was measured for 30 s, after which the infusion was given. The activation task was started approximately 30 s later, 10 s prior to the onset of the 90-s acquisition period. This protocol conforms to guidelines established by ARSAC UK and was approved by the Medical Ethics Committee of the Institute of Neurology. A total of 12 scans were acquired: four for the word reading task, four for the picture naming task, two for the false font task (one long, one short) and two for the nonsense shape task.

Data analysis

Behavioural measures were quantified and compared between groups using factorial analyses of variance. The PET data were analysed using SPM99 (Friston et al., 1995a) implemented in MATLAB Version 4.2 (MathsWorks, MA, USA) on a SPARC1 workstation (Sun Microsystems, UK). Head movements that occurred during the course of the PET scan were corrected by realigning the time series with the first scan. The reconstructed transaxial PET images were spatially normalized for brain size and shape with 2 × 2 × 2 mm voxels (Friston et al., 1995b). These images were subsequently smoothed in three directions with a Gaussian filter (full width, half maximum) of 16 × 16 × 16 mm. This smoothing had the effect of increasing signal-to-noise ratio and allowing for normal between-subject variation in gyral anatomy. Statistical analyses were performed at the single subject level, to examine the effects of reading > false fonts and picture naming > nonsense shapes in each subject independently. These contrasts were then used in second-level analyses in which unpaired t-tests modelled between-subject variance and compared the effects in the control and dyslexic groups (Holmes and Friston, 1998). Statistical significance was inferred at P < 0.05 corrected for multiple comparisons across the whole brain.

Results

Behavioural data

Accuracy and latency of response for both reading and naming tasks were recorded during PET scanning and compared between groups using factorial analyses of variance (see lower part of Table 1). The two groups performed with comparable levels of accuracy. Likewise, reading and naming latencies did not differ significantly between the control and dyslexic groups. Significant phonological deficits, however, characterized these dyslexic participants when performing more sensitive standardized literacy and verbal memory tasks outside the scanner (see upper part of Table 1).

PET data

For picture naming relative to nonsense shapes, the control group activated the left occipitotemporal region (x = −46, y = −52, z = −16; Z-score = 5.2; P < 0.01 corrected for multiple comparisons across the whole brain) but the dyslexic group showed a much smaller effect in this region (x = −46, y = −52, z = −16; Z-score = 2.8). For reading relative to false fonts, the control group activated the left occipitotemporal area (x = −48, y = −54, z = −16; Z-score = 3.7), but no activation was detected in this region for the dyslexic group even when lowering the statistical threshold to P < 0.1.


Fig. 2 Reduced activation in the dyslexic group relative to the controls in the left occipitotemporal region for word reading and picture naming.

(uncorrected). No frontal activation was detected for either reading or naming; this is likely to reflect the fact that articulation was also required in the baseline task.

Direct comparison of the two groups identified reduced left occipitotemporal activation in the dyslexic group relative to the control group for both word reading relative to false fonts ($x = -46, y = -52, z = -16; Z$-score = 5.4; $P < 0.05$ corrected for multiple comparisons across the entire brain) and picture naming relative to nonsense shapes ($x = -48, y = -54, z = -16; Z$-score = 4.8; $P < 0.05$ corrected for multiple comparisons across the entire brain) (Fig. 2). Critically, there was no significant interaction between task and group, even when lowering the statistical threshold to $P < 0.1$ (uncorrected). No other areas expressed differential activation for the control and the dyslexic group.

Discussion

The primary aim of this study was to investigate whether two tasks of lexical retrieval—reading and naming—were characterized by a common pattern of neural activation in dyslexic adults. Our findings confirmed this prediction: both tasks elicited significantly reduced activation in the left occipitotemporal region in dyslexic participants, even in the context of matched behavioural performance.

At the neural level, abnormal activation during word processing in dyslexia in the left occipitotemporal was expected on the basis of previous studies (Salmelin et al., 1996; Rumsey et al., 1997; Brunswick et al., 1999; Paulesu et al., 2001; Shaywitz et al., 2002). However, the observation that a similar pattern also emerges during picture naming sheds light on the interpretation of these results. Specifically, we have shown reduced occipitotemporal activation in the absence of any orthographic decoding. This suggests that abnormal neural activation in dyslexic individuals reflects a more general impairment in retrieving phonology from visual input. In other words, reduced activation in the same occipitotemporal region may underlie the reading and naming deficits observed in developmental dyslexia.

It appears that, by adulthood, naming impairments become behaviourally manifest when items are named rapidly either in a serial format, as in the rapid automatic naming tasks reported in the present study (Table 1), or when named rapidly in a discrete trial format (Wolff et al., 1990). It may be the case that such rapid naming stresses phonological retrieval in a way that results in slowed behavioural performance. There may, for example, be a refractory period which limits performance. The finding of a common neurological impairment during both picture naming and word reading strongly supports this view, that a common deficit in phonological processing underpins the behavioural impairments observed developmentally in word reading and picture naming (Swan and Goswami, 1997). That is, the dyslexic’s difficulties in lexical retrieval are most parsimoniously accounted for by a single underlying cognitive deficit, without the need to postulate additional deficits (cf. Wolf and Bowers, 1999).

The picture naming paradigm employed in the present study demonstrates the possibility of developing tasks which tap neural differences in dyslexia, without eliciting behavioural confounds that can interfere with the interpretation of results. Here, the measurement of neuronal activation indexes subtle differences in cognitive processing not captured by traditional behavioural measures.

The reduced left occipitotemporal activation found in the dyslexic participants for word reading ($x = -46, y = -52, z = -16$) and for picture naming ($x = -48, y = -54, z = -16$) corresponds almost precisely to the peak of the ‘word form area’ proposed by Cohen and colleagues ($x = -43, y = -54, z = -12$; McCandliss et al., 2003). These findings are not consistent with the hypothesis that dysfunction in this region is specific to the processing of letter strings (Tarkiainen et al., 2003). Rather, the pattern of reduced activation in certain tasks (picture naming and reading) and not others (face processing; Tarkiainen et al., 2003) indicates that (i) this region is engaged by non-orthographic stimuli, and (ii) the neurological deficit in this region is an emergent property of the interaction of multimodal (in this case visual and phonological) information (Buchel et al., 1998). We suggest that it is the strategic location of this region, between the visual cortex and the more anterior temporal cortex, in addition to its connections with frontal regions that endows it with a role in the integration of visual, phonological and semantic information (Price and Friston, 2004).

The precise nature of this role remains to be fully delineated. From an evolutionary perspective, the shared effect of reading and object naming in the left occipitotemporal area reported here is not surprising, given that reading is a relatively recent (and still by no means universal) human activity. The difficulties shown by dyslexic individuals during picture naming are too subtle to impact on their performance within a non-literate context. However, the interaction of visual and phonological information needed to read a non-symbolic alphabetic script leads to evident deficits at the behavioural level. We need to characterize more precisely the nature of the deficit in dyslexia in order to explain why a common neural deficit differentially taxes reading in this way.
Future imaging studies are needed to characterize the nature of the dysfunction in the left occipitotemporal area at the neural level. For example, do dyslexic participants show reduced activation in this region when naming environmental sounds—a process requiring lexical retrieval in the absence of visual input? Or are differences confined to those tasks in which the processing of verbo-visual associations are required? It will also be important to delineate the function of the left occipitotemporal area in relation to the left frontal operculum, which can show overactivity in dyslexic readers. It has been suggested that these two regions may represent aspects of the same phonological retrieval system in non-impaired readers (Price and Friston, 1997). In addition, future studies will need to continue to employ new paradigms to evaluate neural function in other brain areas. These may elucidate the role of activation differences in the right hemisphere and the left frontal region in dyslexia (e.g. Shaywitz et al., 2002).

Typically, regional differences in brain activation are implicitly assumed to reflect causal factors in dyslexia (McCrorry, 2003). However, current neuroimaging techniques do not allow causal direction to be established. One proposal is that a lack of reading experience could account for observed differences in the left posterior inferior temporal lobe, given that reading acquisition and ability influence activity in this region (Petersson et al., 2000). Matching adult dyslexics with younger controls for reading age, and the use of longitudinal designs are two ways in which this hypothesis might be tested. The present study indicates differences in the left posterior inferior temporal lobe on a non-reading task; this suggests that differences here may be independent of reading experience. The use of illiterate or unschooled participants is another way to explore the impact of experience on the language system (e.g. Castro-Caldas et al., 1999; Reis et al., 2001). One strong prediction could be made on the basis of the present findings: on a task of picture naming adult illiterates, like adult readers, should show enhanced activation in the left inferior temporal lobe compared with adult dyslexics. Such a finding would support the view that dyslexics are characterized by a specific neural abnormality.

On the basis of our study, novel predictions can be made that are relevant to the diagnosis and treatment of developmental dyslexia. Children can put a name to a picture even before they learn to read. This elementary process in the use of language provides an early measure of a child’s semantic and phonological knowledge. We provide support for the hypothesis that word reading and picture naming deficits share a common neurological basis and speculate that the diagnosis and treatment of picture naming skills in preschool children may impact upon later reading performance.

Acknowledgements

This work was funded by the Wellcome Trust and the Medical Research Council. A. M. is supported by MH64445 from the National Institutes of Health (USA).

References


