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Brain activity while reading words and pseudo-words: A comparison between dyslexic and fluent readers

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ABSTRACT

In recent years many studies have focused on brain activity differences between fluent and dyslexic readers in order to understand the neural basis of dyslexia. The aim of the current study was to examine the processing of words and pseudo-words in the two hemispheres among dyslexic as compared to fluent readers, using behavioral, and electrophysiological source estimation measures. Two matched groups of university students, fluent and dyslexic readers, performed a lexical decision task in order to examine the processes of word recognition. Dyslexic readers showed overall less activity than fluent readers, mainly during late processing stages. In addition, the distinctive patterns of activity for words and pseudo-words displayed by fluent readers were not apparent in dyslexic readers. In particular, the increased activation of left-hemisphere language areas found in response to pseudo-words was absent in dyslexics. These findings are further evidence of orthographic and phonological impairments in dyslexia.

1. Introduction

Dyslexia is characterized by great difficulty or very incomplete development of accurate and fluent word reading and/or spelling (Lyon et al., 2003). For years, researchers have attempted to determine why 10–15% of the literate population are unable to acquire reading skills despite sufficient intelligence, motivation and learning opportunities, as well as a lack of visual, auditory, mental or primary motor impairment (Vellutino et al., 2004). Over the years, evidence for difficulties among dyslexic readers in several systems relevant to reading has been accumulated. A wealth of studies suggests that the main source of their word decoding deficit lies in difficulties with the phonological system, which is responsible for the use of information of the sound structure of language for processing written and spoken language (Bruck, 1992, 1998; Snowling and Nation, 1997; Snowling et al., 1997; Shaywitz et al., 1999; Shaywitz, 1996; Leong, 1999). Other studies have pointed to impairments in the orthographic system. Orthographic knowledge is related to the visual information of a word, specifically the letters that comprise lexical patterns and their order in a word, which contributes to spelling ability as well as the ability to identify the visual pattern of a word (Corcos and Willows, 1993; Wagner and Barker, 1994).

Recently, attention has been turned to understanding the neural basis of dyslexia and many studies have focused on brain activity differences between fluent readers and dyslexic readers. A significant line of research points to the hemispheric balance of activity as a major distinction. For example, Shaywitz et al. (1998, 2006) found that most of the cerebral activity differences between regular and dyslexic readers are a result of differential hemispheric patterns during reading, with fluent readers showing more activity in the left hemisphere and dyslexics exhibiting more activity in the right hemisphere. The main differences are found in the left occipito-temporal area, including the word form area, which extracts linguistic information from letter strings. Fluent readers show greater activity in this area as compared to dyslexic readers (Shaywitz et al., 2006).

Magneto-encephalography (MEG) studies have also demonstrated such hemispheric differences. Adult dyslexics show normal visual feature-processing but reading is disrupted at the subsequent letter string specific stage (Helenius et al., 1999a,b; Salmelin and Helenius, 2004). These disruptions were accompanied by nonexistent or abnormally weak activation of the left inferior occipito-temporal cortex. Simos et al. (2000a,b) reported, in addition to decreased involvement of the left temporo-parietal regions, increased involvement of the right temporo-parietal regions in dyslexic children while performing a syllable discrimination task. Subsequent studies have found that the degree of right activation is correlated with poor phonological processing (Breier et al., 2003).

A possible way of stressing these differences is by using pseudo-word reading. Pseudo-words are pronounceable letter strings without meaning or semantic representation in the brain. Pseudo-word reading requires phonological decoding, whereas reading regular words relies on the orthographic presentation of the visual form of the letters. As compared to reading regular words, pseudo-word reading was found to increase activation in several language areas such as the left inferior

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frontal gyrus and inferior temporal gyrus (Mechelli et al., 2003; Price et al., 1996). This increased activation is supposedly due to the unfamiliarity of the words which activate the networks searching for meaning as opposed to regular words which are processed automatically and their meaning is accessed easily. In addition to classical left language areas, right hemisphere regions were shown to be more activate when processing pseudo-words as compared to words (Price et al., 1996). The assumption is that the right hemisphere language network is activated automatically when a linguistic stimuli is presented, but is inhibited by the left one if the meaning is found. When a pseudo-word, which has no meaning and is harder to process, is encountered, the right hemisphere is activated to assist in the processing. MEG studies, pinpointing specific time windows of activity, indicate that reading pseudo-words leads to less activation of the left middle temporal gyrus and mesial temporal regions (which are assumed to be responsible for whole-word reading) than reading words, but leads to more activity in the left superior temporal gyrus which is assumed to be responsible for phonological decoding among fluent readers (Hagoort et al., 1999; Simos et al., 2002).

In sum, there is evidence of distinct hemispheric activity while reading among dyslexic and fluent readers. Reading pseudo-words stresses the pattern of hemispheric differences in processing, and can be used to emphasize such differences in dyslexics. Therefore, the aim of this study was to investigate in depth the time course of reading in each hemisphere among dyslexic and fluent readers while reading words and pseudo-words. Brain activity was measured by source estimation of event-related potentials (ERPs), in order to disentangle in time the contribution of the LH and RH at the various stages of processing. Previous studies have demonstrated the advantage of using ERP and source localization methods to assess and clarify the functional activity during the different stages of information processing (Arzouan et al., 2007; Michel et al., 1999; Sotillo et al., 2005). We expected to find different patterns of hemispheric activation for words and pseudo-words among fluent readers with bilateral activation for pseudo-words, and left-hemisphere dominance for words. In contrast, for dyslexic readers we expected more right-hemisphere involvement in processing both words and pseudo-words.

2. Method

2.1. Subjects

Twenty dyslexic university students (mean age = 29.1; SD = 5.07) volunteered for the experiment. All were diagnosed as dyslexic in childhood, and as adults approached the university to receive special academic accommodations on the basis of their reading deficit. All scored at least one standard deviation below average on word decoding measures (criterion for the definition of dyslexia, NICH, 2001; Ministry of Education Report, Breznitz, 2001). In addition 20 fluent university students readers (mean age = 24.53; SD = 3.43), displaying average and above average reading abilities were used as controls. Groups were matched for age, gender, IQ, and socio-economic status. All participants were right-handers, native speakers of Hebrew, with normal hearing and vision and without known neurological problems or history of developmental attention disorder. None of the subjects were taking prescribed medication and all were paid volunteers.

2.1.1. Group validation measures

A battery of tests was administered in order to validate the allocation to the experimental and control groups. Measures included background measures of general ability [Raven Standard Progressive Matrices, (Raven, 1965)] and attention [D2 test, (Brickenkamp, 1981)], reading decoding [one minute tests of reading accuracy of words and pseudo-words (Shatil, 1997), reading text in context (The National Center for Evaluation, 2000)], and a reading comprehension test (The National Center for Evaluation, 2000). The comprehension test consisted of reading of two text passages, one silently and one orally, followed by multiple choice questions on each passage. Total comprehension score for each subtest ranged from 0–5. See Table 1 for the means and standard deviations for reading measures and IQ.

2.2. Reading task

In the lexical decision task the subject was required to decide whether a visually-presented letter sequence constituted a real word or not and to press, as fast as possible, one of two joystick-buttons accordingly. All letter strings were presented in the native language of the participants — Hebrew. All stimuli were presented using a HP Pentium 4 computer. The stimuli were presented to the center of the screen and were 3 cm in height and 4–5 cm in length. The subjects were seated at a distance of 0.5 m in front of the computer. The task included 120 stimuli, half of which were words (nouns describing objects, 2–3 syllables, 4–6 letters) and half pseudo-words. Pseudo-words were created by replacing a letter or syllable in each real word and creating a new meaningless stimulus.

2.3. EEG recording and processing

Thirty-two electrodes were placed according to the International 10/20 system (Jasper, 1958) by means of an Electro-cap. Recordings were acquired using a Bio-Logic Brain Atlas IV system at 256 Hz referenced to an electrode on the tip of the nose and grounded to the right mastoid. Electrode impedance was kept below 5 KΩ. One electrode was applied diagonally below the left eye to monitor eye movements. Recordings were segmented into 2 s epochs beginning 450 ms pre-stimulus. Segments were corrected for eye-movement artifacts by an automatic software algorithm (Orgil, 1997). Segments with excessive artifact were rejected. The EEG data were filtered (lowpass: 25 Hz and highpass: 0.1 Hz), and epochs of trials with a correct response were averaged by condition and baseline corrected (200 mesc pre-stimulus). In addition the global field power (RMS) was calculated for each subject in each condition which reflected the global activity of all 31 electrodes.

In order to estimate the neural sources of the waveforms for each condition, the average ERPs for each condition and subject were subjected to LORETA analysis (Pascual-Marqui et al., 2002, 1994). LORETA calculates the three-dimensional current density distribution of the neural generators in the brain under the assumption that for each voxel the current density should be as close as possible to the average current density of the neighboring voxels ('contiguity'). Computations

Table 1
Means and standard deviations for reading measures and IQ.

Measure	Fluent readers (N = 20)		Dyslexic readers (N = 20)		T
	Mean	S.D.	Mean	S.D.	
Words per minute					
Correct	110.8	12.61	73.00	23.19	−6.40***
Errors	0.85	1.26	2.05	1.76	2.44**
Pseudo-words per minute					
Correct	70.95	20.56	35.20	13.27	−6.15***
Errors	3.45	4.78	10.55	9.05	3.10**
Oral text reading					
Reading time (sec)	92.01	12.36	129.21	33.2	4.69***
Reading errors	0.75	0.96	5.55	3.57	5.79***
Correct (out of 5)	4.15	1.30	3.95	0.94	−0.55
Silent text reading					
Reading time (sec)	84.04	40.70	119.93	51.46	2.45*
Correct (out of 5)	3.00	1.16	3.00	1.25	0.00
I.Q					
Raven	55.25	4.24	55	2.15	−0.24

* $p<0.05$.
** $p<0.01$.
*** $p<0.001$.