Phonemic Perception in Children with Developmental Dyslexia: An FMRI Study
Lisa L. Conant¹, Einat Liebenthal¹,², Anjali Desai¹, Jeffrey R. Binder¹
¹Department of Neurology, Medical College of Wisconsin, Milwaukee, WI
²Department of Physiology, University of Manitoba, Winnipeg, MB, Canada

BACKGROUND

Developmental dyslexia is a learning disability characterized by difficulties reading words accurately and/or fluently. Impairments in phonological processing, particularly phonological awareness, are widely considered to represent the core deficit in most cases of dyslexia. However, several behavioral studies in individuals with dyslexia have suggested the presence of a deficit at an earlier stage of processing, when the complex spectrotemporal patterns in the speech signal are analyzed and assigned to phonemic categories (1), which may underlie a phonological awareness deficit in at least a subset of individuals with dyslexia. This FMRI study was used to compare brain responses associated with discrimination of CV syllables (P) and nonphonemic nonsense syllables (N) in 5 children with dyslexia and 12 typically developing (TD) children between the ages of 8 and 17 years.

METHODS

• Subjects:
  - 21 right-handed, native English speaking children with normal hearing, aged 8-17. All children had an estimated Full Scale IQ>90 and no history of significant neurological illness or injury, ADHD, or psychiatric disorder. The 5 children with dyslexia had a history of reading difficulties and performed below 90 on a composite measure comprised of tests of timed and untimed single-word and nonword reading as well as a spelling task. The 12 TD children all performed above this cut-off.
  - Neuropsychological testing:
    - As part of a larger battery, participants completed selected subtests of the Wechsler Intelligence Scale for Children-IV (2) or Wechsler Adult Intelligence Scale-IV (3); Woodcock-Johnson III Tests of Achievement (4); Test of Word Reading Efficiency (5), and Comprehensive Test of Phonological Processing (6).
  - FMRI Task Stimuli:
    - Phonemic (P) stimuli – a 7-token continuum from /ba/ to /da/ cued by the F2 transition.
    - Nonphonemic (N) stimuli – a 7-token continuum created by spectral rotation of F1 in the syllables

• FMRI Task:
  - The task involved a 2-alternative forced-choice AX discrimination. Three types of 2-step token-pairs, equidistant in acoustic space, were presented. For P items, two of the pairs fell within a phonemic category (1-3, 5-7) and one crossed the phonemic category boundary (3-5). There were also two types of across category (in P) token-pairs that were separated by 4 continuum steps (1-5, 3-7), and two types of identical token-pairs (3-3, 5-5).
  - P and N stimuli were presented in blocks of 24 discrimination pairs, with one block of each condition within a run. There were two runs containing these conditions, alternating with runs containing contrasts not presented here.

• Categorical Perception Index (CPI):
  - The average percentage of 2-step, within-category P items perceived as different was subtracted from the percentage of 2-step, across-category P items perceived as different.

• Image Acquisition
  - Functional Data:
    - 32 EPI: TE=35 ms, TR=7.5, Acquisition Time=2a
  - Anatomical Data:
    - 3D SPGR, TR=8, TE=3.8

• Image Analysis
  - Multiple linear regression with reference functions of condition (P, N) and trial-wise RTs as a regressor of no interest. General linear tests to obtain condition contrasts.
  - Missed trials and trials with greater than 10% movement from baseline were removed from the analysis.
  - Individual SPMs resampled in standard stereotaxic space and smoothed with a 4mm FWHM.
  - Random effects analysis, thresholded at voxelwise p<.025 and cluster extent of 650 vox for a corrected magwise p<.05

FMRI RESULTS

Group activation maps for the TD group, the dyslexia group, and the group comparison

TD Group

Dyslexia Group

Demographic and Behavioral Data Means and Standard Deviations

<table>
<thead>
<tr>
<th></th>
<th>Dyslexia Group</th>
<th>TD Group</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>11.89 ± 1.58</td>
<td>12.95 ± 2.04</td>
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<tr>
<td>Sex (% F)</td>
<td></td>
<td>33.33</td>
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<tr>
<td>Estimated Full Scale IQ*</td>
<td>87.00 ± 13.66</td>
<td>119.17 ± 9.32</td>
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<tr>
<td>Estimated Neurovis IQ</td>
<td>85.17 ± 17.4</td>
<td>116.33 ± 10.74</td>
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<tr>
<td>Reaction Time</td>
<td>54.15 ± 13.92</td>
<td>53.75 ± 2.54</td>
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<tr>
<td>CTOPP Phonological Awareness**</td>
<td>53.29 ± 7.83</td>
<td>53.29 ± 7.83</td>
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<tr>
<td>CTOPP Rapid Naming*</td>
<td>86.33 ± 14.74</td>
<td>103.75 ± 14.02</td>
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<tr>
<td>CEREBRAL EFFICIENCY</td>
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<tr>
<td>1st Step Accuracy</td>
<td>72.20 ± 24.03</td>
<td>91.32 ± 8.42</td>
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<tr>
<td>2nd Step Accuracy</td>
<td>58.33 ± 26.59</td>
<td>78.13 ± 18.56</td>
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<tr>
<td>Same Trials  P (% Correct)</td>
<td>65.64 ± 15.88</td>
<td>80.97 ± 10.64</td>
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<tr>
<td>Same Trials  N (% Correct)</td>
<td>76.39 ± 25.35</td>
<td>84.38 ± 11.39</td>
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<tr>
<td>Response Time</td>
<td>221.56 ± 229.44</td>
<td>229.17 ± 289.38</td>
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<tr>
<td>Response Time N</td>
<td>221.17 ± 208.89</td>
<td>324.08 ± 263.89</td>
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REFERENCES


DISCUSSION

Similar to previous findings (7,8), an area extending along the left posterior superior temporal sulcus (pSTS) was found to be more responsive to phonemic sounds than to nonphonemic sounds of comparable acoustic complexity in the TD children. In contrast, the children with dyslexia showed greater activation in the left pSTS for N relative to P.

In the group comparison, the difference in the pSTS for P-N was seen bilaterally, while, in the left hemisphere, there was also significantly greater activation for the TD group in an occipitotemporal cortex in the vicinity of the putative “visual word form area.” Activation in this area was unexpected in our study given the use of purely auditory stimuli. However, greater activation in this region was recently reported in association with performance of a phonological relative to a melody judgment task on chimeric auditory stimuli comprised of words and tone triples (9). In addition, some studies have suggested that this region may be activated in association with auditory word processing in children (10) or in bilingual adults when the stimuli are heard as less proficient language (11). Thus, it is possible that, in TD children, this region plays a role during some auditory phonological tasks, and this is disrupted in children with dyslexia.

In contrast, the dyslexia group showed greater activation than the TD children in the bilateral insula, precentral gyrus, and supplementary motor area. This pattern of overactivation may suggest recruitment of articulatory processes to aid in performing the phonemic discrimination task.

These findings are generally consistent with several previous neuroimaging studies using print stimuli that are associated with dyslexia that have found reduced activation in left temporoparietal and occipitotemporal regions and, more variably, increased activation in insular and motor/ premotor cortex (12,13).

Thus, at this early stage of speech processing, group differences are already apparent in many of the regions associated with reading disability suggesting that the primary deficit in at least a subset of children may lie earlier in the processing stream than phonological awareness and that categorical perception may be an important target of early intervention in children at risk for dyslexia.

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