Physiological Bases of Altered Multisensory Temporal-Order-Judgments in Dyslexia

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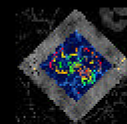


Introduction

Developmental dyslexia is characterized by reading difficulties, and is typically ascribed to disrupted phonological processing. However, recent research suggests that the difficulties observed in dyslexia may not be limited to the linguistic realm, and may also include deficits in basic sensory processes. In fact, recent work suggests that the deficits can span multiple sensory modalities, raising the possibility that multisensory processes may be preferentially altered in dyslexia. To test this, we have recently shown that dyslexic individuals are unusually affected by a slightly delayed auditory stimulus during performance of a visual temporal-order-judgment (TOJ) task. Specifically, these individuals show task improvements even when a significant (>300 ms) delay is introduced between the visual and auditory signals. In comparison, normal readers lose this performance enhancement with long delays.

The goal of this ongoing study is to examine the physiological correlates of the auditory enhancement of visual temporal processing, and how the neural circuits subserving these processes may differ in the dyslexic brain. **Shown here are preliminary data from psychophysical and fMRI testing completed to date.**

Methods

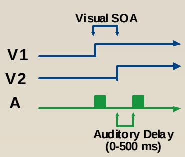
Psychophysical Assessment

Auditory TOJ: Subjects are presented with two tones (440 and 660 Hz, 500 ms total duration) separated by a variable stimulus onset asynchrony (SOA), and are asked to report by keypress which of the two tones occured first. SOAs are varied according to an adaptive staircase procedure to determine auditory TOJ thresholds.

Auditory Pitch Discrimination: Subjects are presented with two 100 ms duration tones separated by a 500 ms gap, and are asked to report which is higher in pitch. One tone is the "base" and is always the same (440 Hz), while the frequency of the other changes according to an adaptive staircase procedure to determine pitch discrimination thresholds. The order of the two tones is randomly interleaved.

Visual TOJ: Subjects view two circles (1 cm diameter) presented 5 cm above and below a fixation cross on a PC monitor (200 Hz vertical scan) with a variable SOA. They are asked to report which appears first, and the SOA varies according to an adaptive staircase to determine visual TOJ thresholds.

Visual TOJ w/ auditory cues: Two identical sound cues (broadband noise, 20Hz-20kHz, 65dB SPL, 10 ms duration) accompanied the visual onsets on most trials. Whereas the first sound was always presented synchronous with the onset of the first visual stimulus, the second sound was delayed behind the onset of the second visual stimulus by 0-500 ms. A no-sound condition provided baseline visual performance. As before, participants reported which ***circle*** appeared first.



Functional MRI

Imaging: All images were acquired with a 1.5T echo speed Horizon LX General Electric scanner with birdcage headcoil (GE Medical Systems, Milwaukee, WI), and are shown in neurological format with the right side of the brain on the right.
Anatomical images: Acquired with multi-slice spoiled gradient inversion recovery (3DSPGR-IR) protocol; matrix 256 x 256; FOV, 24cm; section thickness, 3mm, no gap; 60 sections; in-plane resolution, 0.94mm.
Functional data sets: Acquired with echo-planar imaging (EPI); FOV, 24cm(frequency)x15cm(phase); acquisition matrix, 64 x 40; section thickness, 5mm, no gap; 28 sections; TE=40ms; TR=2500ms; in-plane resolution 3.75 x 3.75mm.
Analysis: Statistical parametric maps (SPMs) were generated using SPM99 (Wellcome Department of Cognitive Neurology, London, UK) in Matlab (The Mathworks, Inc., Sherborn, MA) using an IDL interface. Data from all subjects were processed individually with a fixed-effects analysis using SPM99 software, then random effects analyses were completed. All data shown are set to a threshold of $P \leq 0.01$, with ROIs restricted to occipital and temporal lobes.
Paradigm: During scanning subjects (n=12) performed the multisensory TOJ task. Visual-only, auditory-only, and multisensory trials were randomly interleved in an event-related design. Multisensory trials consisted of auditory delays of 100 ms and 300 ms, chosen because previous behavioral data suggests these delays are the most and least likely to show cross-modal interactions, respectively. Subjects did not have to respond during auditory-only presentations (no task).

Results

Figure 1. In visual TOJ, auditory TOJ and pitch discrimination, dyslexic subjects have higher thresholds than normal-reading control subjects.

For visual and (more notably) auditory TOJ, dyslexic subjects require more time between stimulus onsets to achieve threshold performance (**A**). Additionally, the dyslexic subjects require a larger percent difference to discriminate between two tones of differing frequency (**B**).

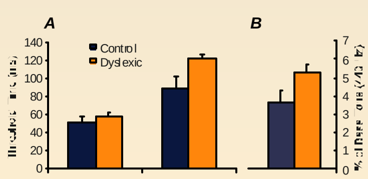


Figure 2. Dyslexic subjects are differentially affected by a delayed sound during visual temporal-order-judgments.

A. In all subjects, the addition of the delayed auditory cue improves accuracy on the visual TOJ task. However, this benefit is typically larger and seen at longer temporal intervals (i.e., 400 ms, 500 ms A/V delay) in dyslexics when compared with controls.

B. Even though the auditory signal is uninformative for the task, response times are significantly shorter when the second auditory cue is presented simultaneously or at short delays (e.g., 50 ms, 100 ms) to the second visual stimulus. Notice for each condition that dyslexic subjects require significantly more time to respond.

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C. However, the response time benefit appears to be larger in dyslexic subjects than in controls. Note that for both groups, large delays (i.e., 500 ms) result in an inhibition of response times.

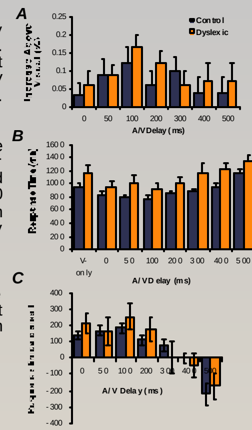
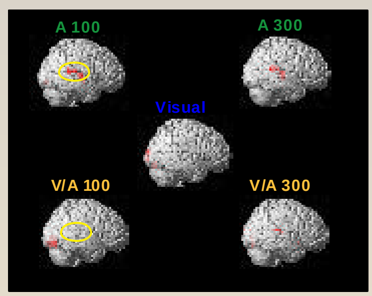


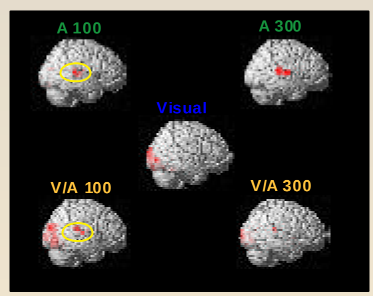
Figure 3. In normal-reading subjects, there is an inhibition of the BOLD response in temporal cortex for short but not long visual-auditory delays.



Performance of the visual TOJ task results in activation of occipital cortex (**Visual**). Passively listening to only the paired auditory stimuli results in similar temporal cortical activations (**A100**, **A300**). Intriguingly, when the visual TOJ task is paired with these sounds, strikingly different patterns of activation are seen. Whereas the short delay pairing (**V/A100**) results in a slight increase in occipital cortical activation and no BOLD response in temporal cortex, the long delay pairing (**V/A300**) results in temporal cortical activation and a decline in the response in occipital cortex.

Figure 4. Dyslexic subjects do not show the same modulation of the auditory response with short delay stimuli.

Unlike normal reading control subjects, dyslexic subjects show a clear activation within auditory cortex under both cross-modal conditions, as well as a somewhat larger BOLD response within visual cortex.



Conclusions and Summary

1. Dyslexic individuals have alterations in their perceptual thresholds for discriminating simple, non-linguistic stimuli in both the visual and auditory realms, and these alterations are seen for both temporal-order and frequency discrimination tasks.

2. Although both dyslexic and control subjects show an improvement in accuracy and response times when a task-irrelevant auditory stimulus is added to the visual TOJ task, the magnitude and temporal profile of these changes differ between the two groups.

3. In control subjects, temporal (i.e., auditory) cortical activations are inhibited when the auditory delay is short, and this inhibition is not seen in dyslexic subjects.

It remains unclear as to the mechanism of the decrease in auditory cortical activitation during the short-delay multisensory condition, particularly in light of the behavioral enhancements seen under these conditions. Regardless, dyslexic subjects do not show this modulation in auditory cortical activation, perhaps explaining the greater behavioral benefit seen at thse short intervals when compared with controls. Taken together, these results lend additional support to a model of altered multisensory processing in dyslexia - alterations which may play an important role in the development and maintenance of reading skills.

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