The spatiotemporal deployment of processing resources in developmental dyslexia

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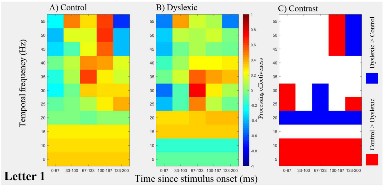

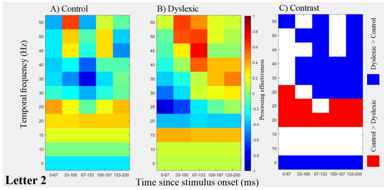

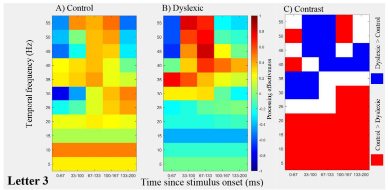

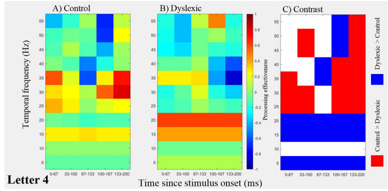

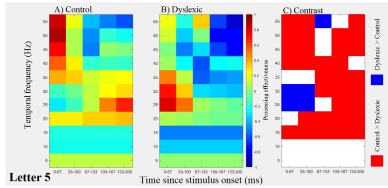

Figures 2 to 6. Time-frequency profiles by group (A) Control, B) Dyslexic) and their contrast (C) for each letter position. Between-group comparisons were performed using t-tests with Bonferonni correction (55 comparisons; $p < 0.00091$). Significant differences are colored either in red (controls > dyslexics) or blue (dyslexics > controls).

Introduction

A visual word cannot be recognized without sufficient attentional resources (Waechter, Besner, & Stolz, 2011). Letters constitute the most important source of information for word recognition (Pelli & Tillman, 2007).

- Yet, the attentional deployment that allows the extraction of information in visual word recognition remains undermined.

Several visual and attentional deficits have been documented in dyslexia (Vidyasagar, 2013), but a demonstration of their causal role in the reading disorder has been elusive.

Objective: Assess the spatiotemporal deployment of processing resources in visual word recognition in a group of adults with dyslexia and in another made of normal readers.

This will be done through a classification image technique whereby each letter of target words is sampled independently on the temporal dimension.

Method

Participants: 16 normal readers, 16 dyslexics. Groups were matched in terms of age, IQ, gender and manual dominance.

Reading speed task: MNRead in RSVP. Presentation durations (in ms/word): 50, 58, 75, 100, 133.

Stimuli: 825 five-letter lowercase French words, without diacritics, sufficiently frequent (Content and al., 1990). The experiment was conducted in two separate sessions. The first session began with 150 practice trials and the second with 75 practice trials. 600 experimental trials were then run in each test session.

Presentation: 200 ms (24 screen frames at 120 Hz refresh rate)

- Signal (word to identify); 5 º x 0,7 º
- Noise (white noise); 10 º x 10 º (centered on the signal)
- Random temporal modulation of signal-to-noise ratio during the target presentation. Independent temporal sampling function for each letter. The area under the curve defining each temporal sampling function was normalized across letters and across words. Temporal sampling functions were made from the integration of sine waves between 5 and 55 Hz in steps of 5 Hz, each with a random amplitude and phase.

Data analysis:

Data analysis was aimed at uncovering the properties of the sampling functions associated with the accurate recognition of the target word.

• Temporal domain: raw signal/noise values across the 200 ms target duration.

• Phase-amplitude domain: representation of the temporal sampling functions in terms of the phase and amplitude values of their constituent frequencies.

• Time-frequency domain: representation of the temporal sampling functions in terms of their detectable temporal frequency content as a function of time. Window size for each temporal frequency to be detected was maximized as much as possible up to 4 cycles of that frequency and the overlap between successive windows was 50%. Prior to smoothing, classification images were segmented to the highest number of windows per frequency.

• For each representation domain for the temporal sampling functions, classification images for individual participants were constructed by subtracting the weighted sum of profiles associated with errors from that associated to correct responses.

• A bootstrap procedure (1000 iterations) served to transform the raw classification images into Z scores.

• Processing effectiveness: Finally, for each letter position and each participant, the Z scored classification images were normalized in the range 0 to 1.

Results

Reading speed was significantly less in dyslexics (464 words/minute) than normal controls (677 words/minute).

Mean signal-to-noise ratio (Controls: *Mean* = 0.57; *SD* = 0.16; Dyslexics: *Mean* = 0.65; *SD* = 0.19) and average success rate (Controls: *Mean* = 61.76 %; *SD* = 6.91; Dyslexics: *Mean* = 59.64 %; *SD* = 6.58) did not differ significantly between controls and dyslexics ($t_s(30) < 1.2$; *ns*).

Temporal domain: There was no significant difference between groups on these classification images.

Phase-Amplitude domain: The classification images for both groups showed no significant effect (i.e. were perfectly uniform), thus indicating that no Phase x Amplitude feature impacted performance.

Time-frequency domain: The comparison of time-frequency profiles revealed complex interactions. Figs. 2-6 illustrate the results for each group as well as the between-group contrasts for each letter position.

The averages of all possible pairwise correlations of the individual time-frequency classification images (i.e. between-subject consistency) were remarkably high within groups but very low between groups (Table 1).

Table 1

Average correlation coefficients (r) of the time-frequency classification images for all possible pairs of participants within and between groups.

	Letter 1	Letter 2	Letter 3	Letter 4	Letter 5
Controls	0.79	0.84	0.78	0.90	0.87
Dyslexics	0.82	0.82	0.90	0.89	0.92
Between groups	0.41	-0.10	0.22	-0.20	0.29

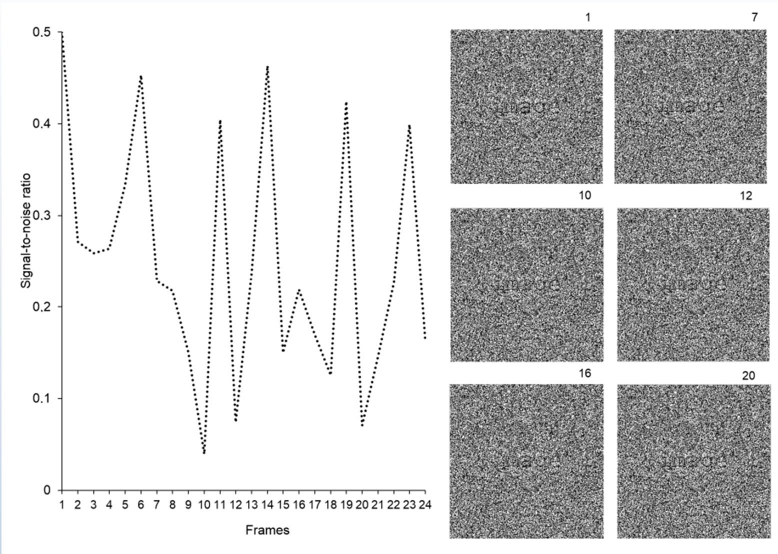

Figure 1. Example of a temporal sampling function applied on letter 3 of the word image throughout the 200 ms (24 screen frames) exposure duration. The images on the right illustrate six instants of the target word display.

Discussion

• The classification images obtained in the temporal domain revealed no significant difference between the control and dyslexics groups.

• The uniform Phase x Amplitude classification images suggest that this code is inappropriate to capture how visual processing effectiveness unfolds through time.

• The comparison of time-frequency classification images between groups reveals a complex pattern of structural interactions. For each letter position, we find distinct patterns of group differences in the time-frequency profiles of information extraction.

The correlation analyses of the time-frequency classification images indicate that each group seems to apply a common process of visual information extraction to achieve visual word recognition and that this process differs between groups.

Conclusion

The present findings demonstrate a markedly distinct spatiotemporal distribution of processing resources in adult dyslexics compared to matched controls.

This supports previous proposals suggesting that developmental dyslexia may originate from an ineffective or impaired deployment of attention on the stimulus (Vidyasagar, 2013).

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