# Influences of Processing Suprasegmental Features on Phonological Awareness and Reading Skills of Dyslexic Children

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## ABSTRACT

In an attempt to illuminate some of the underlying causes of phonological deficit in dyslexia we investigated the influences of processing suprasegmental acoustic features on children's phonological awareness and reading and spelling abilities. In the English cohort tested (N=65) the processing of duration but not of intensity in 9-year old dyslexic children was significantly poorer than in age-matched normally-reading controls. Furthermore, the dyslexics were significantly poorer in processing the rise times of amplitude modulations. Although both duration and rise times of amplitude envelope thresholds were correlated with reading and spelling, only rise time thresholds showed a significant relationship with phonological awareness measures. These findings illuminate the importance of processing suprasegmental information for developing reading skills.

## 1. INTRODUCTION

Although a vast majority of children have no difficulties acquiring reading and spelling skills, around 5% of children without obvious sensory/neurological damage find reading/spelling extremely effortful despite adequate intelligence, educational opportunities and social background. Despite a large amount of research on children and adults with developmental dyslexia, there is still no conformity as to the underlying causes of this deficit. The most well-established finding so far is that most dyslexic individuals have a problem not just with literacy skills but also with phonological processing (1). Recently, there has been increased interest in finding an underlying cause for these problems in auditory processing abilities and in particularly in the temporal domain. Accordingly, the most influential claim is that a deficiency in the processing of rapid or brief (shorter than 40ms) temporal information of acoustic signal underlies dyslexia (2). However, there is a growing body of evidence showing that this is not the case (3, 4).

In our recent study, we showed evidence that dyslexic children had problems in an auditory task varying a temporal feature, c.f., the rise-time (RT) of amplitude envelope (AE) of sinusoid (5). This task, however, was not specifically designed to establish the processing of brief temporal information but rather to investigate the processing of larger time frames, which we consider to be more relevant at the earlier stages of reading acquisition due to the findings that syllable is a more salient part of speech than shorter, single segments in the early stages of the development of phonological awareness (6). For the above mentioned study, a stimuli continuum was constructed out of a sinusoid which was modulated in amplitude to a depth of 50% and within this, the rate of amplitude change only was varied by varying the rise time (15-300ms) of the modulation, holding the overall rate of modulation constant. The long rise time end of the continuum yielded the percept of a single sound that varied in loudness and the short rise times were perceived as distinct beats in an otherwise continuous sound (overall duration of each stimulus was 7.857 sec thus including five rise times of amplitude modulation in each). Noticeably dyslexic children did not have specific problems in processing brief temporal information in this task but rather they, in comparison to control children, had problems in consistently labelling stimuli with longer rise times (<120ms) of amplitude envelope as having a beat. Importantly, the performance in the rise time task was highly correlated with both reading and phonological skills. This finding suggests that the inability of dyslexic children to detect differences of amplitude envelope may be an indicator of word segmentation problems.

In the present study we studied the same aspect further in an attempt to establish the specificity of our earlier findings. Specifically, we wanted to ensure that our earlier finding was not due to the differences in simply processing temporal information or intensity as such. Therefore, for the present study we administered several tasks measuring sensitivity to a) durational changes of the acoustical signal as such and b) intensity of the acoustic signal, as well as c) rise times of amplitude modulations in dyslexic children. Our hypothesis is that since suprasegmental features have an influence on the whole structure of speech signal, the ability to efficiently use these cues in order to segment speech into smaller sections may be vital in order to acquire phonological awareness and consequently fluent reading and spelling skills.


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## 2. METHOD

### *Participants*

The study involved 65 children. Twenty-four of the children had a statement of dyslexia from their local education authority. None of the children had dysphasia or suffered from another neurological or psychiatric disorder. Of the 65 children, 24 were chronologically age-matched controls (CA group) with no reading or spelling problems. Another control group (RL group) with no reading or spelling problems comprised 17 of the younger children whose reading age matched that of the dyslexic children. Participant characteristics are shown in Table 1.

**Table1. Participant characteristics**

| | **Standardised tests** | | |
|---|---|---|---|
| Group | Dyslexic | CA match | RL match |
| *N* | 24 | 24 | 17 |
| Age in years and months | 8,9 (9) | 8,9 (10) | 7,3 (6) |
| Reading level (age)* | 7,6 (9) | 11,0 (23) | 7,8 (12) |
| Reading standard score* | 89.5 (5.4) | 118.8 (9.7) | 110.4 (10.8) |
| Spelling level (age)* | 7,9 (9) | 11,3 (27) | 8,5 (17) |
| Spelling standard score* | 90.5 (6) | 119.4 (13) | 116.1 (12) |
| Nonword reading/20† | 8.9 (4.7) | 18.6 (1.7) | 10.5 (5.1) |
| IQ‡ | 110.6 (11.3) | 111.6 (15.4) | 110.8 (12.3) |
| Block design/19 ‡‡ | 9.3 (3.0) | 9.5 (3.5) | 9.8 (2.3) |
| Vocabulary standard score** | 107.5 (14.2) | 106.9 (10.6) | 103.0 (10.6) |

Standard deviations are shown in parentheses.

* British Ability Scales

† Graded Test of Nonword Reading

‡ WISC

‡‡ WISC nonverbal subtest

** British Picture Vocabulary Score

### *Auditory Processing Tasks*

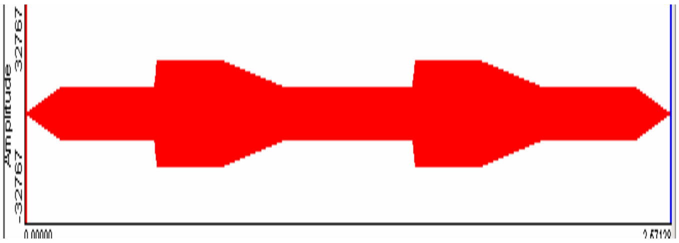
All the auditory processing tasks were administered by using the child friendly Dino program (created by Dorothy Bishop) that presents auditory stimuli in a forced choice paradigm, adaptively selecting stimulus values thus enabling efficient threshold measuring. Two types of paradigm were utilized here. In the two-interval forced-choice paradigm two sounds are presented consecutively (500ms IOI) and the child is required to choose the target sound. In the AXB task three sounds are presented consecutively (500ms IOI) where the middle stimulus is always the standard stimulus and either the first (A) or the last (B) is different from the standard. The more virulent PEST (Parameter Setting by Sequential Estimation, 7) method was used adaptively to control which stimulus was presented according to the subject's previous performance.

**Intensity detection (AXB) task**. A 500Hz sinusoidal with liner onset and offset envelopes (50ms) and fixed steady state duration of 700ms was used as a starting point for creating a stimuli continuum for the intensity detection task. A continuum of 40 stimuli was constructed by varying the intensity of the steady state logarithmically, values ranging from 0dB to 29.25dB. The stimulus with 29.25 dB steady state was used as a standard, and the child's task was to choose the stimulus that was different (which in this case was the quietest of the three sounds).

**Duration discrimination (2IFC) task**. A continuum of 100 stimuli was constructed of the naturally produced nonword *ata* in which the duration of the silent closure of the word medial stop (varying from 65 ms to 265ms) was augmented in stepwise fashion with increments of 2 ms. The stimulus with a 65 ms closure duration was used as a standard stimulus. The child listened to two nonwords and was required to tell which of them was longer.

**Rise time of amplitude envelope detection (AXB) task**. A continuum of 40 stimuli was created from 500Hz sinusoid with 0.7Hz amplitude-modulation (depth of 50%), varying the linear rise time envelope logarithmically from 15 ms to 300 ms. The steady state of the stimuli had a fixed duration of 700ms. Also the linear fall time envelope was fixed to 50 ms. Thus the overall duration of the stimuli varied from 765 to 1050 ms. The stimulus with the shortest rise time (15ms) was used as a standard stimulus. The child was required to choose the stimulus that sounded different at the beginning (which in this case had the longest rise time; hence insensitivity to the rise time parameter would predict poorer detection of differences of rise times).

**Rise time of amplitude envelope discrimination (2IFC) task.** A 3573ms sinusoidal carrier at 500Hz which was amplitude-modulated at the rate of 0.7Hz (depth of 50%), was used as a starting point in creating a continuum of 40 stimuli. The underlying modulation envelope was based on a square wave. The rise time was varied from 15 to 300ms (logarithmically spaced) but the fall time was fixed at 350 ms (Figure 1). The stimulus with the longest rise (300ms) was used as a standard stimulus. The task was to tell which one of the two stimuli had a clearer beat (which in this case had the shorter rise time; hence dyslexic insensitivity to this parameter would predict poorer perception of a beat in the stimuli with longer rise times).




a)

b)

**Figure 1**. The stimulus wave forms for the rise time of amplitude envelope (2IFC) discrimination task with 15 (a) and 300ms (b) rise times.

***Phonological Processing Tasks***

In the oddity task the child listened to sets of three words and had to select the word that had a different sound at the end of the word, c.f., coda (e.g., *coal, pole, TONE).* In the segmentation task the child listened to a word and were required to say the first sound of the word (e.g., [k] in *cat*).

***Standardised Psychometric Tests***

The children received several standardised test. The subtests of word reading and spelling of the standardised British Ability Scores were administered, along with the Graded Test of Nonword Reading test (8). The children received four subsets of the Wechsler Intelligence Scale for Children (WISC): block design, picture arrangement, similarities, and vocabulary. Receptive vocabulary was measured using the British Picture Vocabulary Score, in which the child is required to point to the one of the pictures that best represents the word read out loud by the experimenter.

## 3. RESULTS

The mean scores obtained by each of the experimental groups are shown in Table 2. A significant difference was found between the group of dyslexic children and their chronological age controls in the duration, rise time of amplitude envelope detection (AXB) and rise time of amplitude envelope discrimination (2IFC) thresholds, with the dyslexics having higher thresholds [mean duration threshold 41.9 for dyslexics and 22.6 for controls, $P<0.05$; mean RT threshold of AE in the AXB task for dyslexics 27.3 and for 21.1 for controls, $P<0.05$; mean RT threshold of AE in the 2IFC task for dyslexics 21.5 for dyslexics and 13.9 for controls, $P<0.05$]. As predicted, higher thresholds in the AXB task meant that dyslexics were poorer at detecting rise time differences in stimuli with less than 104ms difference in rise times, whereas higher thresholds in the 2IFC task meant that dyslexics found it hard to perceive stimuli with longer than 55 ms rise time (c.f., the corresponding experimental value for the mean threshold 21.5) as having a beat. The reading age match controls had intermediate thresholds in both of the rise time tasks and similar or slightly higher thresholds in duration and intensity tasks. The thresholds in the intensity task did not differ significantly between the groups. Thus, auditory thresholds for duration and for RTs of AE (both detection and discrimination) were poorer in the dyslexic children than in their controls and seemed to vary with reading level.

**Table 2. Mean performance for the dyslexics and CA and RL controls on the behavioural tasks**

| Group | Dyslexic | CA match | RL match |
|---|---|---|---|
| Oddity, % correct | 61.0 (15.2) | 88.5 (7.3)*** | 75.6 (14.5)** |
| Segmentation, % correct | 69.4 (27.1) | 95.4 (9.4)*** | 95.3 (7.2)*** |
| Intensity threshold level | 4.0 (2.6) [3dB] | 3.3 (1.7) [2.25 dB] | 4.5 (3.6) [3.25dB] |
| Duration threshold level | 41.9 (36.3) [84ms] | 22.6 (22.1)* [44ms] | 46.4 (36.3) [92ms] |
| Rise time of AE threshold (AXB) level | 27.3 (9.9) [104ms] | 21.1 (6.1)* [60ms] | 25.0 (9.6) [87ms] |
| Rise time of AE threshold (2IFC) level | 21.5 (11.3) [245ms] | 13.9 (9.9)* [198ms] | 16.8 (9.7) [219ms] |

Standard deviations are shown in parentheses.

The detectable differences are shown in squared brackets.

P<0.001***

P<0.01**

P<0.05*

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To explore the relationship between the performances in both the duration and rise time of amplitude envelope tasks and phonological processing, reading and spelling, partial correlations controlling for age and WISC IQ (short form) were calculated (Table 3). Although both duration and RTs of AE thresholds were correlated with reading and spelling, only RTs of AE thresholds showed a significant relationship with phonological awareness measures.

**Table 3. Partial correlations between the basic auditory-processing measures and the experimental variables controlling for age and WISC IQ**

| | Duration | Rise time (AXB) | Rise time (2IFC) |
|---|---|---|---|
| Reading std | -.32* | -.29* | -.28* |
| Spelling std | -.29* | -.18 | -.34** |
| Nonword | -.38** | -.37** | -.30* |
| Vocabulary | .04 | -.04 | 0.01 |
| Oddity | -.2 | -.27* | -.35** |
| Segmentation | -.12 | -.27* | .30* |

P<0.01

P<0.05

## 4. CONCLUSIONS

The results of this study indicate that perception of some but not all suprasegmental features is reliably related to reading development. More importantly, this study demonstrated that although the perception of temporal aspects of suprasegmental features as such seems to have an important role in reading/spelling development, the detection of rise times of amplitude envelopes seems to have an expansive influence on both reading/spelling and phonological processing.

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