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# PHONEME BOUNDARY PERCEPTION IN DYSLEXIC AND NORMAL-READING ADULTS

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## Abstract

This paper concerns a study on the auditory perception of dyslexic adults compared to normal-reading controls. The stimulus material that was developed for this purpose consisted of three speech continua - the stop-consonant continuum (/bɑk/-/dɑk/), the stop-consonant approximant continuum (/bɑk/-/wɑk/) and the stop-consonant-fricative continuum (/bɑk/-/zɑk/). The speech stimuli were based on natural speech of a woman. The three continua were used in an AX-discrimination test and a classification test with 12 dyslexic adults and 12 normally reading subjects. These categorical perception experiments were done to establish whether dyslexics process phoneme boundaries differently from normal readers. On several aspects the results of the dyslexic group differ clearly from those of the control group. Dyslexic subjects are in general less skilled than the control subjects in discriminating between the stimuli of a speech continuum. Furthermore, classification performance seems less categorical in dyslexic listeners. In both tasks dyslexics are also slower in giving their responses. As for the quality of the three speech continua, the results indicate that the /bɑk/-/dɑk/ as well as the /bɑk/-/wɑk/ continuum is suitable for further experimenting. Both continua are perceived categorically by all listeners. In future research the aim is to use these speech continua for measuring auditory perception and processing in children suffering from or at risk of developing dyslexia.

## 1. Introduction

Developmental dyslexia is a reading disability touching on many aspects of human brain functioning, which makes it a complex matter to study. One of the contributing factors to dyslexia seems to be a deficiency in auditory perception and processing. Auditory perception of speech has repeatedly been found to correlate with reading performance. As compared to normal readers, dyslexic children as well as adults generally show lower discrimination acuity and deviant identification performance on categorical perception tasks on stop-consonants (e.g. Werker & Tees, 1987; Godfrey et al., 1992; Groenen, 1998; Irausquin, 1998; and on some other phoneme contrasts (Richardson, 1998; Hazan & Adlard, 1996). This suggests that dyslexics have less distinct phoneme boundary representations. Multiple questions remain, however, as to what causes this abnormal perceptual organization. Is it a problem in general auditory temporal processing (Tallal, 1980) or is it a problem to be traced to a phonological processing deficit (Mody et al., 1997)? The present paper describes work done for a Masters thesis that fitted within the

framework of the recently started long-term Dutch national research program called "Identifying the Core Features of Developmental Dyslexia: a Multidisciplinary Approach" (NWO, 1996). This Masters thesis project is now continued in a Ph.D. project aimed at elaborating categorical perception and temporal order processing tasks as a tool for studying aspects of dyslexia. In this Ph.D. project (Schwippert, 1998), initially, adult dyslexic subjects are tested but as soon as possible 10-year-olds and pre-reading-age children are to be tested as well. Categorical perception experiments, in combination with additional paradigms and neurophysiological data, can provide a better understanding of what is going on in the brain during speech and language processing in dyslexic individuals. The categorical perception paradigm is merely used as a tool for studying deviant behavior in dyslexic readers compared to normal readers. Therefore, we do not elaborate issues that concern speech perceptual theories as such.

### 1.1 Aim of the study

Many of the categorical perception experiments described in literature have made use of synthesized speech stimuli not nearly approaching the quality of natural speech. One of the objectives of the present study is to develop and test speech material that sounds as natural as possible.

Another aspect concerns the nature of the Dutch language. Subjects may react differently to stop-consonant(-approximant) contrasts than English subjects do. Replications in Dutch of categorical perception experiments with dyslexic subjects done in English speaking environments, are therefore useful, especially with more natural sounding speech stimuli. Studies on the Dutch /bɑ/-/dɑ/ contrast have been done (e.g. Irausquin, 1997; Groenen, 1997) but on the Dutch /bɑ/-/wɑ/ contrast nothing has been reported yet.

A third concern of this study is that data of dyslexic subjects on other than stop-consonant phoneme contrasts is desirable in order to investigate whether or not anomalies in auditory perception are limited to phonemes that are characterized by very brief cues.

The importance of the temporal aspect in speech processing in dyslexia is a matter of debate. As mentioned above, the duration of a cue that is necessary to distinguish between two stimuli may influence speech processing. However, it has been suggested that the speed with which cues follow one another may also play a role in processing difficulties in dyslexic individuals. When two stimuli are rapidly presented one after the other, in other words, when the interstimulus interval (ISI) is short, this may cause problems in processing them (Mody et al, 1997; Reed, 1989; Tallal, 1980). For this reason the ISI was kept short in the experiments presented here. To detect possible influences of ISI duration, the discrimination performance of the subjects was tested at two different ISIs, namely 25 and 400 ms.

## 2. Methodology

### 2.1 Stimulus material

Earlier studies on categorical perception with synthetic or natural /bɑ/-/dɑ/ continua have shown that this stop consonant contrast is perceived particularly categorically (Repp,

1984). The phoneme boundary between these two phonemes is sharply defined. This characteristic makes the contrast very well suited for the study of phoneme perception in people with more diffuse phoneme representations, as is assumed for dyslexics. Therefore numerous studies on the auditory perception of dyslexics using the /ba/-/da/ contrast exist. It was logical to use this stop-consonant continuum in the present study as well, to be able to relate our results to earlier findings. We also used a stop-fricative (/ba/-/za/) and a stop-approximant (/ba/-/wa/) contrast. We chose to implement the phoneme continua in the existing one-syllable words /bak/, /dak/, /zak/, and /wak/, all being normal Dutch words, meaning *'tray'*, *'roof'*, *'bag'*, and *'hole in the ice'*, respectively. This resulted in a /bak/-/dak/ continuum, a /bak/-/wak/ continuum and a /bak/-/zak/ continuum. In addition to preserving the link to earlier studies, the /bak/-/dak/ continuum served as a reference to the /bak/-/wak/ continuum and to the /bak/-/zak/ continuum. On the /bak/-/wak/ continuum no literature on categorical perception exists with respect to dyslexia; on the /bak/-/zak/ continuum no literature is available at all. Our hypothesis was that the /bak/-/wak/ contrast is more difficult to discriminate than the /bak/-/dak/ contrast and that the /bak/-/zak/ contrast is easier to discriminate. This hypothesis was based on Dutch consonant confusion matrices (Pols, 1983; Tielen, 1992). We expected that the degree of difficulty would influence the difference between the performance of the dyslexics and normal readers, the difference becoming more pronounced if the contrast is harder to perceive.

The continua were constructed by doing formant manipulations using LPC in Praat (Weenink & Boersma, 1996) and/or signal editing. All continua consisted of 10 items, the total duration of each item was 600 ms. For details the reader is referred to Schwippert (1998).

## 2.2 Subjects

Twelve adult dyslexic subjects (8 male and 4 female) and twelve adult control subjects (4 male and 8 female) participated in the listening tests. Except for 3 dyslexics all subjects were students; they were paid for their participation. None of the subjects reported auditory problems.

## 2.3 Experimental procedure

Subjects' reading skills were evaluated in a screening test for dyslexia consisting of 7 tasks (Koopmans-van Beinum et al., 1998). The auditory perception experiments were done at the Max Planck Institute for Psycholinguistics (MPI) using the experimental environment NESU (Nijmegen Experiment Set-up; more information can be found at the MPI website http://www.mpi.nl/world/tg/experiments/nesu.html). The perception tests were conducted in a room with sound-attenuated booths. Each booth contained a computer screen, headphones, and a panel of buttons that the subjects had to press to indicate their responses. The buttons were labeled with words and with a corresponding picture or symbol, to avoid lexical confusions. Each session began with a same-different discrimination task followed by a forced choice classification task. For both discrimination and classification the continua were presented separately. The order of presentation of the continua was balanced across subjects.

The discrimination task required subjects to discriminate between two stimuli that were always three continuum steps apart (e.g. 1-4, 2-5, 3-6, etc.). The 7 stimulus pairs were presented 12 times. The internal order of a stimulus pair was balanced. In addition to 'different' trials, ten 'same' trials (1-1, 2-2, etc.) were presented, each pair twice. The stimulus pairs were presented in four blocks of 52 stimuli ($6 \times 7 + 1 \times 10$), while the interstimulus interval remained constant within one block. The first and third block always contained the stimulus pairs separated by a 25 ms ISI, the second and fourth block stimuli were separated by 400 ms ISI. So there was a short-long-short-long ISI-pattern for each continuum. Within blocks stimuli were randomized. The task was preceded by 24 practice stimuli. No direct feedback was given. Subjects were instructed to listen to the two words presented and to determine whether they sounded 'the same' or 'different'. They were urged to react as adequately and as quickly as possible by pushing the corresponding button. The discrimination task took about 45 minutes.

The classification task required subjects to classify a stimulus as being "bak" or "dak", "bak" or "zak", "bak" or "wak", respectively. Again neither training nor feedback was given, 15 practice trials were presented to accustom the subjects to the task. Each stimulus was presented 12 times, the 120 stimuli of each continuum were randomized not allowing more than 3 identical stimuli in a row. Subjects were instructed to label the words as quickly and as adequately as possible.

# 3. Results

## 3.1 Discrimination

Figure 1 displays the results of the same-different discrimination experiment with the /bɑk/-/dɑk/ continuum, the /bɑk/-/wɑk/ continuum and the /bɑk/-/zɑk/ continuum. These are the average scores of the dyslexic and the control subjects on both the long and short interstimulus interval condition. The dyslexic group performs significantly less well than the control group on the /bɑk/-/dɑk/ continuum and the /bɑk/-/wɑk/ continuum. The dyslexic subjects less often than the control subjects indicate hearing a difference between two different stimuli. The /bɑk/-/zɑk/ continuum yields unexpected results probably due to the structure of the stimulus material. Further experimenting is needed to correctly interpret these results.

The average scores as presented in Figure 1 provide a clear indication of the effects that are found. To get the full picture, of course, it is important to inspect the individual scores as well. An ANOVA was conducted for each continuum, the independent variables being subject group (control and dyslexic), interstimulus interval (25 and 400 ms), and stimulus pair (seven 3-step pairs) and the dependent variable being the same-different discrimination scores. Significant main effects ($p<.001$) were found for subject groups (dyslexics performing worse) and for stimulus pairs, whereas the main effect of ISI was moderately significant ($p<.05$). The interaction between ISI and subject groups, however, was not significant. This indicates that for both control subjects and dyslexic subjects a longer ISI yielded better discrimination scores to the same degree. This result is interesting since we expected that varying the ISI would influence dyslexics more than controls.

Reaction times were on average longer for the dyslexic subjects as compared to the control subjects. The reaction times show no marked differences between within-category

and between-category stimulus pairs. An ANOVA with reaction times as the dependent variable confirmed that the difference between the dyslexic and the control group is significant, dyslexics reacting on average 100 ms slower. Table 1 displays the group means, all stimulus pairs taken together.

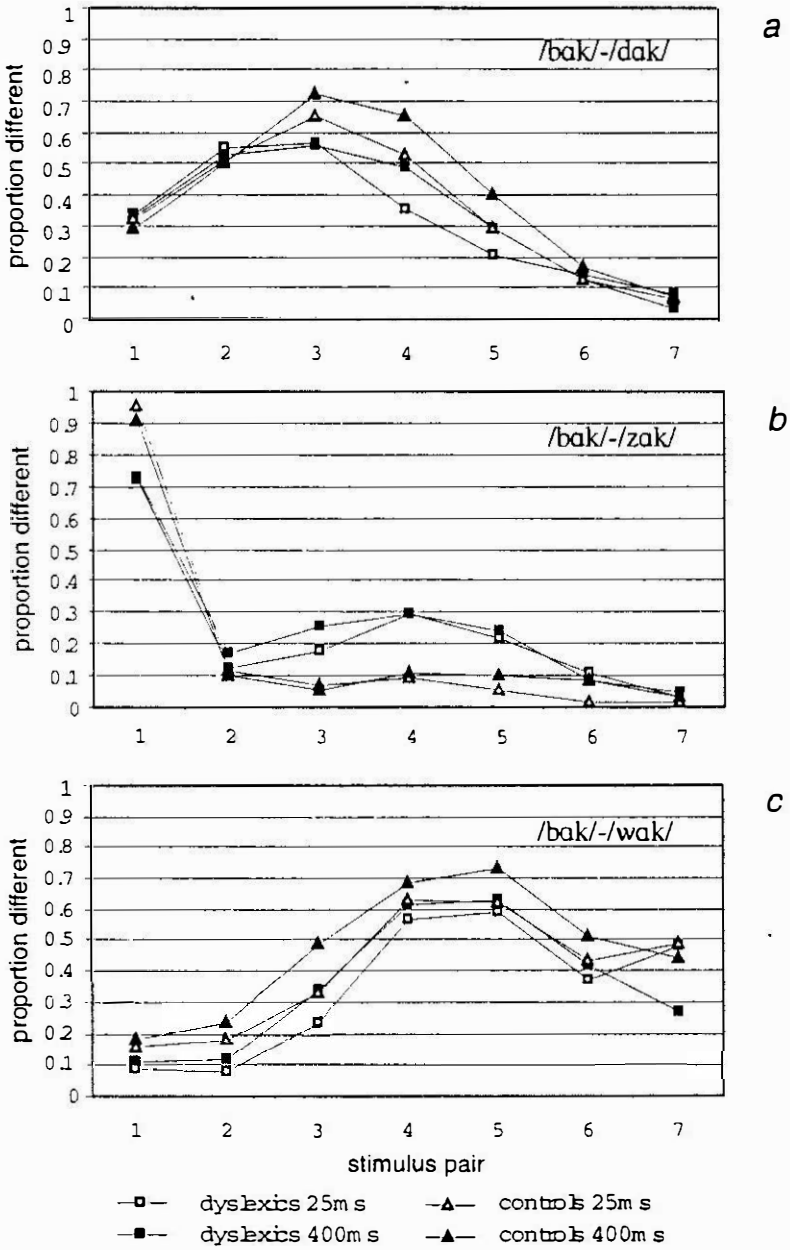


Figure 1: Mean discrimination functions of the dyslexic and control group plotted for the /bak/-/dak/ (a), /bak/-/zak/ (b) and /bak/-/wak/ (c) continuum. The stimulus pairs were presented with either 25 ms or 400 ms between the two words (ISI=25 ms or ISI=400 ms).

Table 1: Mean reaction times (RT) and standard deviations for the dyslexic group and the control group on the discrimination task. The reaction times are averaged for ISI condition and for stimulus pair.

| | /bak/-/dak/ | | /bak/-/zak/ | | /bak/-/wak/ | |
|---|---|---|---|---|---|---|
| | RT (ms) | stdev. (ms) | RT (ms) | stdev. (ms) | RT (ms) | stdev. (ms) |
| dyslexics | 854 | 211 | 776 | 252 | 844 | 226 |
| controls | 767 | 166 | 586 | 174 | 740 | 172 |
| *Δ dyslexics-controls* | **87** | 45 | **190** | 78 | **104** | 54 |

## 3.2 Classification

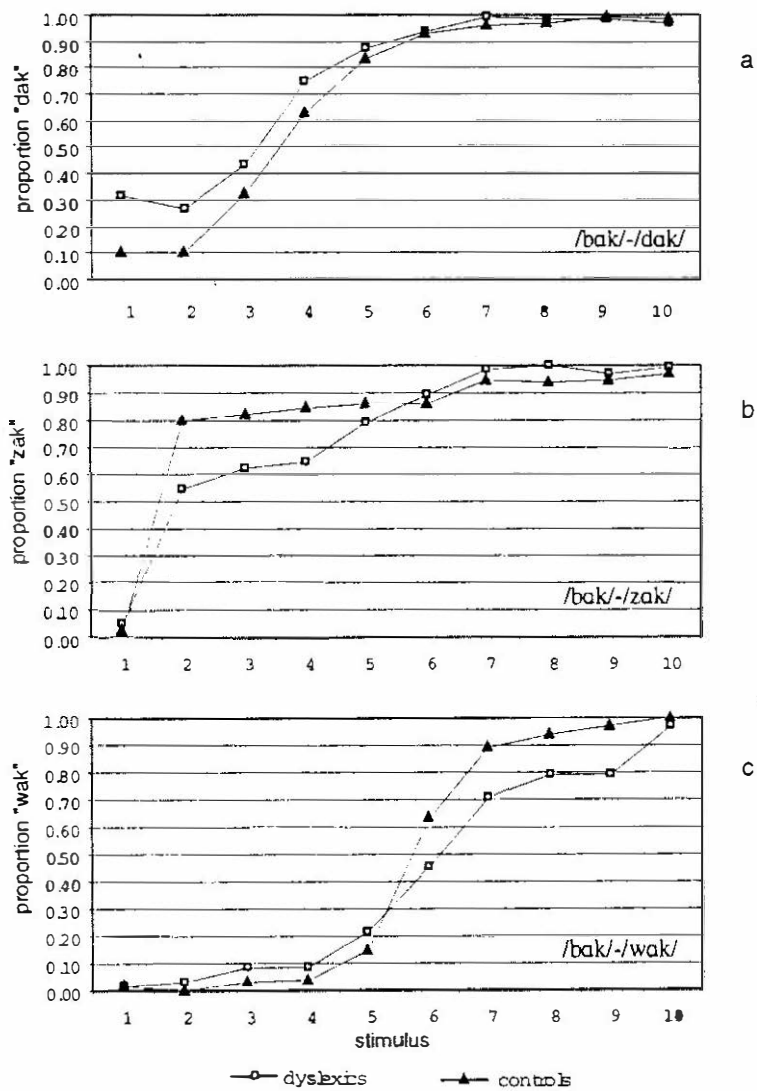


Figure 2: Mean classification functions of the dyslexic and control group plotted for the /bak/-/dak/ (a), /bak/-/zak/ (b) and /bak/-/wak/ (c) continuum.

In Figure 2 the mean classification functions of the dyslexics and controls are presented for each of the three continua. ANOVA on each continuum separately across subject groups (control and dyslexic) and stimuli (10 in each continuum), with the dependent measure being the forced choice classification scores, revealed significant main effects ($p<.001$) for both subject groups and stimuli.

If we compare the functions of the three continua, it is obvious that dyslexics and controls are more similar for the /bak/-/dak/ than for the /bak/-/wak/ continuum, which could be explained by our assumption that the /bak/-/wak/ continuum has a higher degree of difficulty than the /bak/-/dak/ continuum. A contrast that is more difficult to perceive would accentuate the differences between control subjects and dyslexic subjects. As for the /bak/-/zak/ continuum, which was constructed by manipulating the second formant and by adding fricative noise of increasing intensity, it turned out that only the presence or absence of fricative noise determined the phoneme identification for the control group as well as for half of the dyslexic group. The other half classified the stimuli in a different way and indicated perceiving the phoneme boundary in the middle of the continuum.

Like in the discrimination experiment, reaction times were in general shorter for the control subjects than for the dyslexic subjects.

To take a closer look at the observed differences between the dyslexic group and the control group, the individual classification curves of the 24 subjects are examined for the /bak/-/dak/ and the /bak/-/wak/ continuum. The information that each curve contains about the perceptual behavior of a subject is reduced to two values. The first indicates the steepness of the category transition slope. Steepness is defined as the difference in the proportion /dak/ or /wak/ classifications caused by one step on the ten point continuum measured around the 50%-point, i.e. the crossover point from one phoneme category to the other. The second indicates the position of the 50%-point on the 10 stimuli scale. The group means for these values for steepness of the transition and crossover point are displayed in Table 2.

Table 2: 50%-point and steepness of the transition slope of the classification functions, group means.

| **control group** | /bak/-/dak/ | /bak/-/dak/ | /bak/-/wak/ | /bak/-/wak/ |
|---|---|---|---|---|
| subject | 50%-point | steepness | 50%-point | steepness |
| mean(N=12) | **3.33** | **0.35** | **5.71** | **0.55** |
| stdev(N=12) | 1.21 | 0.15 | 0.43 | 0.18 |

| **dyslexic group** | /bak/-/dak/ | /bak/-/dak/ | /bak/-/wak/ | /bak/-/wak/ |
|---|---|---|---|---|
| subject | 50%-point | steepness | 50%-point | steepness |
| mean(N=12) | **2.79** | **0.33** | **6.40** | **0.43** |
| stdev(N=12) | 1.86 | 0.26 | 1.36 | 0.20 |

As mentioned above, the steepness of the transition was determined around the 50% point. In general, the proportion /dak/ or /wak/ classifications around the 25% point and around the 75% point were determined. The difference between the proportions at these two points divided by the distance in continuum steps between these two points yielded the steepness coefficient.

The individual data show that the category transition slopes in perceiving the /bak/-/dak/ continuum are shallower than in perceiving the /bak/-/wak/ continuum.

Furthermore, the data show that for the /bak/-/dak/ continuum there is hardly any difference between the steepness of the slopes of the dyslexic subjects on the one hand, and those of the control subjects on the other hand (0.02). A more pronounced difference, however, is found for the /bak/-/wak/ continuum (0.12), confirming the pattern of the group means as shown in Figure 2c. When perceiving the /bak/-/wak/ continuum dyslexic subjects show a shallower category transition slope than the control subjects.

## 4. Discussion

The present study has yielded a vast amount of data, containing valuable information on the speech perception of Dutch dyslexic adults. The results show considerable differences between dyslexics and normal-reading controls in the perception and processing of three speech continua. However, the expected differences between dyslexics and controls concerning the effect of manipulating the interstimulus interval were not found. Both subject groups reacted in the same way to reducing the duration of the interval from 400 to 25 ms, which suggests that this particular temporal processing aspect is not correlated to dyslexia.

The results are best understood for the stop-consonant place continuum /bak/-/dak/ and for the stop-consonant approximant continuum /bak/-/wak/. The results on the stop-consonant fricative continuum /bak/-/zak/ are interesting but additional testing is necessary to understand what caused the differences between dyslexics and controls on this continuum. The /bak/-/dak/ continuum and the /bak/-/wak/ continuum are both perceived categorically by the dyslexic subjects and control subjects. The /bak/-/wak/ continuum seems to contain smaller perceptual distances between the stimuli than the /bak/-/dak/ continuum. Both the /bak/-/dak/ and the /bak/-/wak/ continuum are well suited for research on speech perception in dyslexia.

Discrimination and classification experiments both reveal differences between dyslexic and control subjects. The results suggest, though, that the behavior on a discrimination task is a better correlate of dyslexia than the behavior on a classification task with respect to these two continua. Dyslexic subjects are slower and less accurate at discriminating between three-step pairs of both 10-point continua. Classification behavior clearly differs on the /bak/-/wak/ continuum, and to a lesser extent on the /bak/-/dak/ continuum. Dyslexics are less consistent in classifying the stimuli from the ambiguous middle part of the continuum. On both classification and discrimination, on all three continua, dyslexic subjects generally need more time to respond than the control subjects.

In summary, the present study clearly confirms the presence of differences in speech perception of dyslexic adults as compared to normal-reading controls and shows that differences are not limited to perception of stop-consonant place contrasts. Interestingly, the present study does not confirm earlier findings that dyslexic subjects have more trouble processing signals rapidly presented one after the other than normal readers do.

This research is continued in a newly started Ph.D. project aimed at studying the auditory perception of dyslexic adults and, in a later stage, of children at risk of developing dyslexia. In this project aspects of temporality in and between speech signals in relation to dyslexia will be explored more extensively. Perception at a conscious level will be measured using discrimination and classification paradigms. At an unconscious

level perception is evaluated by measuring event related potentials (ERP), which reflect brain activity related to a certain auditory input. In this way we hope to come to a better understanding of the underlying mechanisms of dyslexia.

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