Dyslexia : a new evidence of the articulatory deficit

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ABSTRACT

Articulatory disorders have been occasionally associated with developmental phonological dyslexia. This study used acoustic and aerodynamic data to investigate to what extent developmental dyslexia is associated with potential disorders in the fine-grained control of articulatory movements in voiced and voiceless bilabial stops /b/ and /p/ production in a repetition task. Our results reveal more deviations from the target consonant for the dyslexic than for the control. This study shows also differences in the timing of the articulatory movements between dyslexics and controls. These observations are consistent with recent findings pointing to a general deficit in fine motor control in dyslexia.

1. INTRODUCTION

One currently attends an important debate around three main theories. The phonological theory proposes that a deficit in phonemic awareness brings out difficulties in manipulating sounds of speech [2]. According to the magnocellular theory [9], a deficit of the auditive and visual magnocellular ways perturbs development of phonemic awareness and leads to difficulties in visual and phonetic code analysis. Developmental phonological dyslexia has been also occasionally associated with a variety of motor disorders in the production of speech: dyslexic children showed irregular reading tempo and rhythm [4], more sequencing errors and deviate more from the specified rate than control groups in a syllable repetition task at a prescribed metronome rate [12]. These findings are consistent with an increasing number of studies suggesting that fine-grained motor control can be impaired in dyslexics: they often showed deficits on tests of postural stability, muscle tone, coordination and dexterity which could be attributable to a cerebellar dysfunction [8]. According to the motor-articulatory feedback hypothesis [5], dyslexic children are unaware to associate their own articulatory gestures with speech sounds [1, 6]. This latter theory attributes a main part to the speech production mechanisms in the phonemic awareness development in suggesting that phonemic deficit would be the result of poor articulatory control skills, attributable to cerebellar dysfunction. Indeed, the most recent work makes it possible to consider this deficit either like a disorder specific to the reading but like a more general deficit being able to affect cognitive, sensory, motor and linguistic competences. This study focused on the articulatory and acoustic characteristics of speech in dyslexic children in a repetition task. We asked to what extent developmental phonological dyslexia is associated with potential disorders in the fine-grained control of articulatory movements in voiced and voiceless bilabial stops /b/ and /p/ production. We focused on the voicing opposition because of the well-known difficulties dyslexic children encounter with. Moreover, there is a well recognized difficulty in maintaining voicing during a stop, because the air flowing through the glottis accumulates in the vocal tract, causing supra-glottal pressure to approach subglottal pressure and air flow to diminish [11]. Consequently if an articulatory deficit exists it can be all the more visible as the task is difficult. Articulatory movements are inferred from the time course of oral air pressure and air flow.

2. METHOD

Three groups of subjects took part in the study. The first group (DY) was made up of nine children aged 10-14 with a severe developmental phonological dyslexia. The second group (RA) comprised ten 7-year-old control children matched with the dyslexics on reading age. The third group (CA) was composed of ten children aged 10-11, and matched with the dyslexics on chronological age. The material was composed of VCV sequences, where C was a bilabial stop (/b/, /p/) and V /a/ or /i/. Each sequence occurred in the following carrier sentence “C’est CVCV peut-être” (“It’s CVCV perhaps”). All subjects had to achieve a repetition task : they heard each sentence through a pair of headphones and had to repeat it. The whole set of sentences had been recorded previously for that purpose by a male native speaker of French (Southern variety), aged 60. Each sentence appeared has five recoveries in the home record.

Aerodynamic and acoustic data were collected with the EVA2 multichannel recording system [10]. This system simultaneously recorded oral air flow and intra-oral air pressure together with the speech signal. The air pressure is measured with a probe tube with an outside diameter of 3.5 mm, and the airflow via a silicone face mask. The mask is placed on top of a tripod with an adjustable height, and the subject firmly applies the mask on his face. The aerodynamic and acoustic signals were low-pass filtered and digitized. The sampling rates and resolutions were as

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follows : audio signal : 25000 Hz, 12 bits; air flow/pressure: 6250 Hz, 12 bits. The entire recording session took about 30 minutes per subject. The acoustic and aerodynamic signals were processed on a workstation using MES, a software for the display and analysis of multichannel speech data [3]. In a first step, the signals were edited and annotated by hand. A detailed phonetic transcription of all the recording was made using IPA and ExtIPA symbols. Turning to the phonetic transcription of the recordings, we examined to what extent each target stop had been judged as being correctly realized by the speaker; We also examine which type of realizations the speakers could produce. In a second time, markers were placed for each stop to identify from the acoustic signal the beginning (V1_off) and the end (V2_on) of the consonant segment. We derived from these acoustic markers the overall consonant segment durations (tcons). Using the annotation criteria proposed by Müller &Brown (1980), markers were placed for each stop at the following locations : the instant of complete articulatory closure (dt) and release (dr), identified on the air flow trace; the onset of articulatory closure (do), the end of release (fr), and the peak pressure (pm), identified on the pressure trace. Figure 1 shows the position of the markers for the sequence /aba/ as produced by a RA subject.

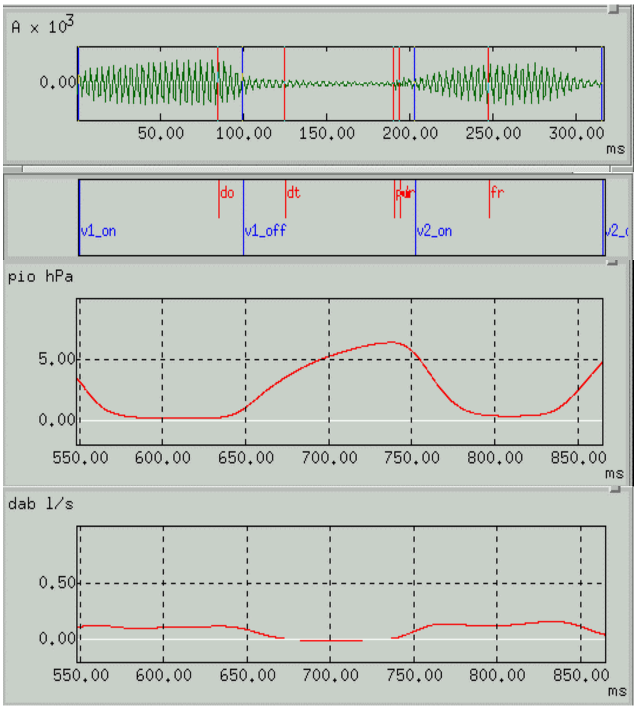

Figure 1: Tracings of audio, air pressure and air flow recordings in the production of /aba/ by a RA child.

From these aerodynamic annotation points, were derived four temporal measures : 1) duration of the closing phase (dt-do), 2) duration of the full closure phase (dr-dt), 3) duration of the release phase (fr-dr) and 4) the time between peak and release closure (pm-dr); this last duration was used as index of escape of airflow during the full closure phase. We also compared peak pressure values between dyslexic and control groups.

3. STATISTICAL RESULTS

3.1 ANALYSIS OF PHONETIC TRANSCRIPTIONS

Turning to the phonetic transcription of the recordings, we carried on an Anova to test to what extend each target stop had been judged as being correctly realized by the speaker. Figure 2 shows the proportion of correct realization for /b/ and /p/. The results show that the percent correct is higher for the voiceless stop than for the voiced stop ($p<.05$). We also observe more deviations from the target consonant for the dyslexics than for the RA for /b/ and /p/ ($p<.05$) and for the CA for /b/ ($p<.05$). Lastly, in all groups, the phonological segment /b/ is often realized like a phonetic voiceless segment [b̥] or like an incomplete closure (Bl.).

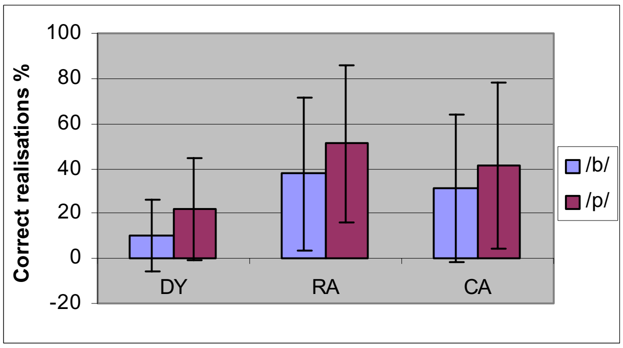

Figure 2 : Average percentages of correct realization for /b/ and /p/ for the three groups DY, RA and CA

3.2 TEMPORAL ANALYSIS

All statistical analysis for temporal and aerodynamic data were carried on with the R software

- **Overall consonant segment duration (tcons)**

Table 1 gives average duration of the overall consonant segment /b/ and /p/ respectively.

/b/	N	Mean	Sd
DY	85	65.65	16.10
RA	98	86.23	23.30
CA	98	71.35	13.18

/p/	N	Mean	Sd
DY	86	85.88	24.79
RA	100	110.30	24.50
CA	100	92.70	21.72

Table 1 : Average duration of the overall consonant segments /b/ and /p/(ms)

Figures 3 shows the overall shape (using boxplot displays) of the tcons data for the 3 groups, for each of /b/ and /p/ consonant. The central box shows the data between the quartiles, the dot is the median; Very extreme points are shown by themselves.
We used regression analysis instead anova, because our data were unbalanced. The dependent variable was the tcons variable, the predictor was the qualitative variable group, ie a three level factor: DY, CA, RA. Separate analysis were carried on for each consonant. For both analysis, the DY group was the reference level; so each model respectively test the difference between the DY and the CA groups, and the difference between the DY and the RA group.

For /b/, the results show that there is a very significant difference for tcons between the DY group and the RA group (*p*<<.001); the difference is marginally significant between the DY group and the CA group (*p*<.05).
For /p/, there is a very significant difference for tcons between the DY group and the RA group (*p*<<.001); the difference is not significant between the DY group and the CA group.

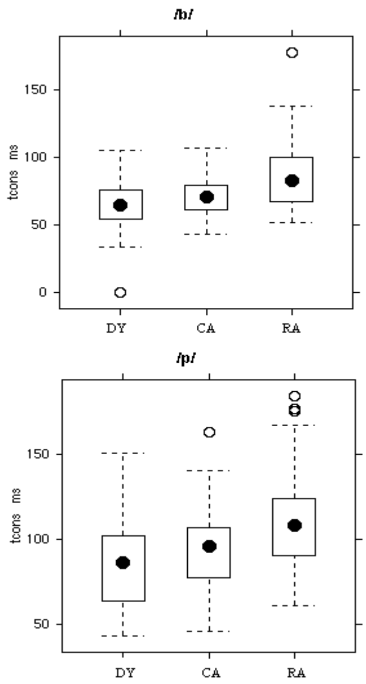

Figure 3 : Boxplots of tcons data

- **Articulatory closing, closure and release phases durations**

Figures 4 and 5 show average durations for the three articulatory phases (closing, closure and release phase) for the production of each of /b/ and /p/ consonant.

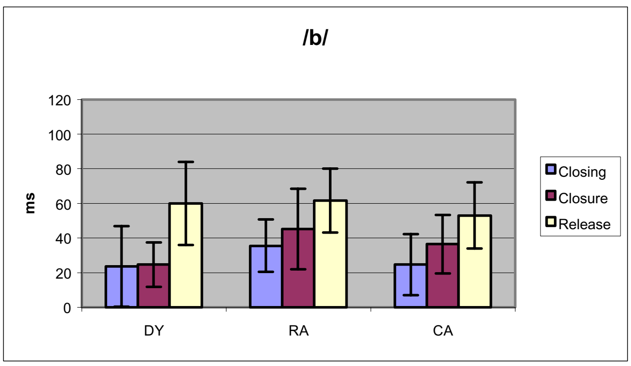

Figure 4 : Average durations of the articulatory closing, closure and release phases of /b/, in ms, for the three groups DY, RA and CA

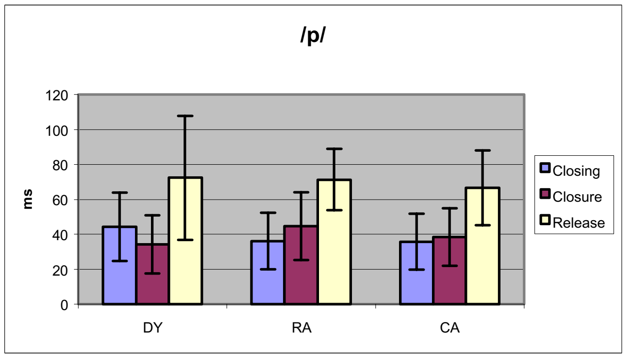

Figure 5 : Average durations of the articulatory closing, closure and release phases of /p/, in ms, for the three groups DY, RA and CA

We used logistic models to explore the relationship between each of the four measured intervals (parameters tdtdo, tdrdt, tfrdr, tdrpm) and the subject's group. The binary dependent variable is the DY vs control groups variable; the predictors were the four durations, and a two-level factor (cons) coding the consonant /b/ or /p/.
We carried on an analysis of deviance (each predictor is added sequentially, starting from the null model) of the model DY vs CA. Only tdrdt (closure duration) is significant (*p*<.01); the significant interaction term tdrdt:cons shows that the slope (on logit scale) for /b/ is different from the slope for /p/ (*p*<.01). Examination of a separate model regression for each consonant shows that indeed only the slope for /b/ is significant. The analysis of deviance of the DY versus RA model shows that only the closure phase is significant (*p*<<.0001); there is no significant interaction term tdrdt:cons. Examination of a separate model regression shows that only the slope for /b/ is markely significant and that tdrdt is marginally significant for /p/.
The tdrpm (index of escape) parameter showed no significant result

3.3 AERODYNAMIC ANALYSIS

Table 2 gives mean values and standard deviation for peak pressure (pm) in hPa

/b/	N	Mean	Sd
DY	71	3.13	1.97
RA	74	5.11	2.54
CA	81	3.07	1.78

/p/	N	Mean	Sd
DY	75	6.09	2.34
RA	77	9.49	3.80
CA	82	6.90	2.39

Table 2 : Average of peak pressure values for /b/ and /p/ (hPa)

Figure 6 shows the overall shape of the pm data, for each consonant /b/ and /p/ respectively using boxplot displays.
For the peak pressure analysis, we used regression analysis instead anova, because our data were unbalanced. The dependent variable was the pm variable, the predictor was the qualitative variable group, ie a three level factor: DY, CA, RA. Separate analysis were carried on for each consonant. For both analysis, the DY group was the reference level, so each model respectively test the difference between the DY and the CA group, and the difference between the DY group and the RA group.

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For /b/, results show a very significant difference between the group DY and the group RA ($p<.001$), and no significant difference between the DY and the CA groups. For /p/, we get similar results.

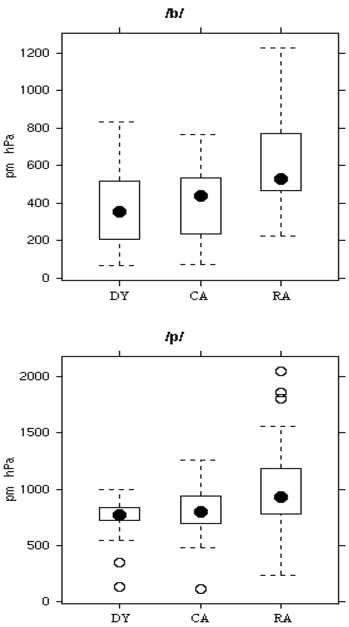

Figure 6 : Boxplots of peak pressure data

4. DISCUSSION

Our data suggest that the dyslexic group more frequently deviated from the target consonant than the control groups. As expected, production of /b/ is more difficult than /p/ for all groups but especially for dyslexics which one knows that they encounter difficulties with voicing opposition. Errors occurred at the infra phonemic level with [b̥] and (Bl) realizations.

The results of the logistic models for temporal analysis show that for the /b/ consonant, the lower the closing phase (tdrdt) is, the higher the probability to belong to the DY group. For the consonant /p/, there is no such effect to distinguish the DY from the CA group, and a slight effect to distinguish the DY from the RA group. Moreover, we noted differences in the timing between the three articulatory phases: durations tends to increase from closing phase to closure phase and for closure phase to release phase for the control groups. For the dyslexic group, the first two phases durations (closing and closure) are about equals. Further analysis should reveal relationship between error pattern and articulatory phase durations.

Our results are on the whole in keeping with previous studies in speech production [12] in suggesting that developmental dyslexia may be accompanied by motor speech deficits. This study raises theoretical implications and the relationship between articulatory and phonological deficit should be addressed in future work. Moreover, clinical implications for the diagnosis and remediation should be noted.

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