Allophonic mode of speech perception in dyslexia.

Willy Serniclaes, Sandra van Heghe, Philippe Mousty, René Carré, Liliane Sprenger-Charolles

To cite this version:

Willy Serniclaes, Sandra van Heghe, Philippe Mousty, René Carré, Liliane Sprenger-Charolles. Allophonic mode of speech perception in dyslexia.. Journal of Experimental Child Psychology, 2004, 87 (4), pp.336-61. 10.1016/j.jecp.2004.02.001 . hal-00733550

HAL Id: hal-00733550
https://hal.science/hal-00733550

Submitted on 24 Sep 2012

JECP 87 (2004) 336–361

Title: **Allophonic mode of speech perception in dyslexia**

Willy Serniclaes[a], Sandra Van Heghe[b], Philippe Mousty[b],

René Carré[c], and Liliane Sprenger-Charolles[a]

[a]LEAPLE, CNRS & Université René Descartes,

7 rue Guy Môquet, BP8, 94801 Villejuif Cedex, Paris, France

[b]LAPSE, Brussels' Free University (ULB),

CP 191, 50 av. F.D. Roosevelt, 1050 Brussels, Belgium

[c] CNRS & Ecole Nationale Supérieure des Télécommunications, Paris

46 rue Barrault, 75634, Paris Cedex, France

Address for correspondence:

Willy Serniclaes

LEAPLE, CNRS, UMR 8606

Campus Hôpital de Villejuif

7 rue Guy Môquet, BP8, 94801 Villejuif Cedex, Paris, France

FAX: (33) 1 49 58 38 36

Email : wsernic@vjf.cnrs.fr

Abstract

Perceptual discrimination between speech sounds belonging to different phoneme categories is better than between sounds falling within the same category. This property, known as ‘categorical perception’, is weaker in children affected by dyslexia. Categorical perception develops from the predispositions of the newborn for discriminating all potential phoneme categories in the world’s languages. Predispositions that are not relevant for phoneme perception in the ambient language are usually desactivated in early childhood. However, the present study shows that dyslexic children have kept a higher sensitivity to phonemic distinctions irrelevant in their linguistic environment. This suggests that dyslexic children use an ‘allophonic’ mode of speech perception which, although without straightforward consequences for oral communication, has obvious implications for the acquisition of alphabetic writing. Allophonic perception specifically affects the written language, contrary to other manifestations of dyslexia, and is therefore susceptible to be the core deficit.

Key words

Dyslexia; Categorical Perception; Speech Development; Phonetic Predispositions.

Dyslexia is characterized by severe reading impairment without other physiological or psychological problems (Shaywitz, 1998). Although the deficit is most apparent in written language, there is a growing amount of evidence that children with developmental dyslexia do not apprehend speech sounds in the same way as average readers. A striking difference lays in phonemic awareness, i.e. in the conscious access to phonemes, evidenced in tasks involving the manipulation of phoneme segments within words or pseudowords (Liberman, Shankweiler, Fisher, & Carter, 1974). The deficit in phoneme awareness is a reliable characteristic of developmental dyslexia. It has been regularly found for groups across different studies and for individuals within studies (Brady & Shankweiler, 1991; Ramus, Rosen, Dakin, Day, Castellote, White, & Frith, 2003). The deficit might directly arise from a specific trouble in the conscious access to phonemic representations but related problems in the perceptual representation of speech (Morais, Alegria, & Content, 1987), as well as in verbal short-term memory and slow automatic naming (Snowling, 2000), suggest different explanations. Dyslexics also have some deficit in speech perception. A fair proportion of dyslexic children show a weakness in phoneme discrimination, as they make a larger number of errors than do average readers when presented with pairs of syllables which only differ by a single phonemic feature (Reed, 1989; Masterson, Hazan, & Wijayatilake, 1995; Mody, Studdert-Kennedy, & Brady, 1997; Adlard, & Hazan, 1998). This might indicate a weakness in the very representations of speech sounds, a view, which is further supported by the presence of a categorical perception deficit in dyslexia.

Categorical perception deficit

'Categorical Perception' (CP) corresponds to the degree at which acoustic differences between variants of the same phoneme are less perceptible than differences of the same acoustic magnitude between two different phonemes (Liberman, Harris, Hoffman & Griffith, 1957). Different studies suggest that children with dyslexia are less categorical than average readers in the way they perceive phonetic contrasts (Godfrey, Syrdal-Lasky, Millay & Knox, 1981; Werker & Tees, 1987; Serniclaes, Sprenger-Charolles, Carré & Démonet, 2001; Bogliotti, Messaoud-Galusi, & Serniclaes, 2002). A striking common point between these studies is that they all show that dyslexics do poorly at discriminating between phonemes from different phonetic categories and that they do *better* at discriminating between acoustic variants of the same phoneme. This shows that not only the distinctions between categories are less clearcut but also that the internal structure of the categories is less coherent.

The difference in CP between dyslexics and controls is reliable provided that the data are collected in appropriate conditions, i.e. in conditions where phonemic categories are neither too weakly nor too strongly discriminable by the controls. As far as we now, the CP deficit was always present in these conditions although it was not always tested (as in Brandt & Rosen, 1981), sometimes marginally significant (as in Reed, 1989) and sometimes without concomitant differences in within-category discrimination (as in Messaoud-Galusi, Carré, Bogliotti, & Serniclaes, 2002). The CP deficit was also investigated with labeling data by comparing the slopes of the labeling curves, a shallower slope indicating less sharply defined category boundaries. The CP deficit was present and significant in these studies (Reed, 1989; Manis, McBride-Chang, Seidenberg, Keating, Doi, Munson & Petersen, 1997; Joanisse, Manis, Keating, & Seidenberg, 2000; Messaoud-Galusi, in press). However, in some of these studies the CP deficit was only found for the subgroups of dyslexics most severely affected.

Allophonic perception

The perception of phonological categories can be conceived as the end-product of three successive stages, the first consisting in the extraction of acoustic cues, the second in the analog-to-digital transform of acoustic cues into phonetic categories, and the third in the grouping of phonetic categories into phonological ones (Werker & Logan, 1985; Werker & Tees, 1984a; Serniclaes, 2000). In this framework, a representation deficit might arise at each of these three levels, i.e. "auditory", "phonetic" or "phonological" (Figure 1).

Insert Figure 1 about here

The hypothesis of an auditory deficit can gain some support from the fact that the performances of dyslexics are weaker than those of controls in non-speech auditory tasks such as judgments of temporal order between acoustic stimuli (Tallal, 1980). However, performances on these tasks do not have straightforward implications for speech perception (Studdert-Kennedy, 2002) and auditory deficiencies are less reliable across individuals than are phonological ones (Ramus, Rosen, Dakin, Day, Castellote, White, & Frith, 2003).

In previous studies the focus has been on the auditory vs. speech specific nature of the deficit (Reed, 1989; Mody et al., 1997; Adlard & Hazan, 1998), without considering the exact status of the latter. Yet the distinction between a phonetic vs. phonological deficit is interesting because graphemes are related to phonological segments rather than to phonetic ones (Morais et al., 1987). An important finding in this regard is that dyslexics do *better* at discriminating acoustic differences within the same phoneme category (Serniclaes et al., 2001). This might reflect a higher sensitivity to ‘allophones’, i.e. variants of the same phoneme in the production of speech under the effect of coarticulation.

Allophones constitute separate phonetic categories in early childhood and their integration into phoneme categories is achieved through fairly complex developmental processes. Neonates can already discriminate between a range of phonetic categories, even those that are not present in their ambient language (for a review see: Vihman, 1996). These predispositions are activated or not as a function of the presence versus absence of the corresponding contrast in the linguistic environment and the decline occurs within the first year of life (Werker & Tees, 1984b). It involves a change in processing strategies rather than a sensorineural loss (Werker & Tees, 1984a). Adult listeners keep some ability for encoding non-native phonetic contrasts, but with a shorter memory decay period than for native contrasts. According to Werker and Tees (1984a), this might reveal "... a level of processing intermediate in accessibility between that which has previously been referred to as phonetic (or linguistic) processing and the level often labeled as nonlinguistic acoustic processing. Since this intermediate level appears to correspond to natural phonetic boundaries it is useful to label it a "phonetic" level, and to label the level corresponding to native language boundaries a "phonemic" level." (pp. 1875-1876).

The persistence of phonetic boundaries in speech processing is quite understandable from a functional point of view. The same phoneme is realized as different phonetic units, depending on the context (e.g. palatal and velar /k/ stops). Such 'allophonic' variations imply that the same phonemic category is a compound of different phonetic ones. As a consequence, the predispositions for perceiving these boundaries have to be "coupled" during perceptual development in order to perceive the phoneme categories (Serniclaes, 1987). Categorical perception of phonemes thus arises not only from reducing the initial sensitivity to phonetic distinctions irrelevant in the ambient language but also from couplings between the predispositions for perceiving these distinctions. As these are complex developmental processes, they might fail in some part of the population for genetic and/ or environmental reasons. In particular, a failure of the coupling process might explain the CP deficit found in dyslexic children.

Insert Figure 2 about here

Voicing perception in French offers an interesting opportunity for testing this hypothesis. There are three possible voicing categories across languages, and these categories depend on ‘Voice Onset Time’ (VOT), i.e. the temporal relationship between onset of ‘voice’ (laryngeal vibrations) and release of the mouth closure (Lisker & Abramson, 1964). The first category is characterized by the onset of voice before closure release (negative VOT; e.g. /ba/), the second by the almost coincidence of voice onset and closure release (short positive VOT; e.g. /pa/) and the third by a delay of voice onset relative to the release (long positive VOT; e.g. /p^{h}a/). In languages where the three VOT categories are phonemic, such as Thaï, listeners exhibit two boundaries for voicing perception, a negative VOT boundary and a positive VOT one (Abramson & Lisker, 1970; Figure 2). These boundaries are precluded in the infant’s predispositions (Lasky, Syrdal-Lasky, & Klein, 1975; Aslin, Pisoni, Hennessy, & Perrey, 1981), which opens the way to categorical perception of voicing in three-category languages as well as in languages with a single distinction between short vs. long positive VOT categories (e.g. English). Only the positive VOT boundary remains active in these two-category languages. However, other two-category languages among which French and Spanish use a single distinction between negative VOT and moderately long positive VOT categories (Caramazza & Yeni-Komshian, 1974; Williams, 1977). The perceptual boundary is located around 0 ms VOT in these languages (Serniclaes, 1987), a possibility which is not directly forecasted in the infant's predispositions. This suggests that the zero VOT boundary is obtained by coupling between predispositions during perceptual development. As the phonological coupling between predispositions is a fairly complex developmental process, it might be affected by failures in some part of the population due to genetic differences and /or environmental factors. The implication of the lack of coupling would be the persistence of three voicing categories in the perceptual repertoire. This would in turn give rise to non-categorical perception of voicing with intra-categorical discrimination peaks, a profile which is susceptible to be found in dyslexic children given the previous evidence of their weaker categorical perception and increased within-category discrimination.

The perception of allophonic variants of French voicing categories was investigated in the present study by collecting discrimination responses of dyslexic children, average readers of the same age and average readers adults for pairs of stimuli along the VOT continuum. Our previous work indicates that the difference in CP between dyslexics and controls is reliable provided that the data are collected in appropriate conditions, i.e. in conditions where phonemic categories are neither too weakly nor too strongly discriminable by the controls (Serniclaes et al., 2001). In order to maximize the possibility of tapping into the right level of difficulty four different VOT continua were used here.

METHOD

Participants

Three groups of subjects participated in the study, a group of 18 dyslexic children with a mean age of 9 years (m= 108.7 months; sd=8.0), a group of 23 average readers children of about the same chronological age (m= 110.6 months; sd= 9.2), and a group of 12 adults without antecedents of dyslexia. The reading level was assessed by the Lobrot L3 test (Lobrot, 1973). The reading age was at least one and a half year below their chronological age for the dyslexic children and at least equal or above the chronological age for the AR children. All these children had normal nonverbal and verbal IQs (WISC, IQ>80). All participants were native speakers of French with no history of neurological or psychological disorders.

Stimuli

Four different VOT continua were used. Two of them, a /ba-pa/ one and a /ga-ka/, were created with a sinewave analog speech synthesizer (/ba-pa/SW & /ga-ka/SW). In sinewave synthesis (Remez, Rubin, Pisoni, and Carrell, 1981), the formants are replaced by pure tones. Most naïve subjects hear sinewave analogues of speech sounds as whistles but the same stimuli are perceived as speech sounds when the subject’s attention is drawn towards their phonetic properties. A second /ba-pa/ continuum was obtained by adding low frequency modulation to the sinewave sounds (/ba-pa/MOD). A second /ga-ka/ continuum was derived from natural speech syllables, a /ga/ and a /ka/ pronounced by a French speaker (the first author), by progressively editing the VOT of the /ga/ and replacing the edited segments by corresponding segments extracted from /ka/ (/ga-ka/NAT). The stimuli on each continuum ranged from –60 ms VOT to +60 ms VOT in six steps of 20 ms. For the three synthetic continua, VOT differences were simulated by modifying the energy onset in the frequency region of the first formant (F1) relative to the energy onset in the region of the upper formants (F2 & F3), a procedure known as ‘F1 cutback’ (Liberman, Delattre, & Cooper, 1958). The phonemic boundaries along these continua, assessed by collecting identification data in a set of 5 adult French-speakers, were located at 18 ms VOT for /ga-ka/NAT and at a significantly shorter value ($p<.001$), around 8 ms VOT, for the 3 other continua. The mean VOT boundary for the 4 continua was located at 10 ms VOT.

Procedure

The stimuli were presented in pairs in a pairwise (AX) discrimination task. Subjects were told they were going to hear speech-like sounds and were required to deliver their response (same or different) by pressing the appropriate key on a computer keyboard. For each continuum, all possible stimulus pairings were presented (Table 1). Each stimulus was paired with itself ('same' pair e.g. S1-S1) and each was paired with another in each order ('different' pair e.g. S1-S2, S2-S1). This resulted in 49 pairings for each continuum. The pairs were presented in random order within 4 blocks, one for each continuum, in the following order: /ba-pa/SW, /ba-pa/MOD, /ga-ka/SW, /ga-ka/NAT. The interstimulus interval within pairs (ISI) was100 ms and the intertrial interval (ITI) was 500 ms.

Insert Table 1 about here

Statistical analyses

Correct discrimination scores were calculated for both "same" and "different" pairs. For "same" pairs, the scores were the proportions of "same" responses. For each pairing of different stimuli, correct response scores were obtained by computing the mean proportion of “different” responses to pairs of acoustically different stimuli (e.g. S1-S2 and S2-S1). The data were analyzed by Logistic regression, which is the most appropriate method for the multivariate processing when the dependent variable is a proportion (McCullagh & Nelder, 1983). The data collected for the different steps were analyzed separately with group (3 levels: adults, AR children, DYS children), continuum (4 levels: ba-pa SW, ba-pa MOD, ga-ka SW and ga-ka NAT) and pair (from 6 levels for 1-step pairings to 4 levels for 3-step pairings) as categorical independent variables. Effects were tested by Wald Chi-square. A hierarchical backward strategy (Kleinbaum & Klein, 2002) was used for variable selection with the following stages: (1) test of the 3-way continuum-pair-group interaction; (2) test of two-way interactions between variables after exclusion of the 3-way interaction if the latter was non-significant; (3) test the main effects after the exclusion of non-significant 2-way interactions, if any.

Categorical perception was assessed by measuring the 'Phoneme Boundary Effect' (PBE), i.e. the difference in discriminations scores between stimulus pairs straddling the phoneme boundary vs. those belonging to the same phoneme category. The following contrasts were used in this purpose (see Table 1 for the relationship between VOT and pairs): for 1-step pairings, the S4S5 score minus the mean of all the other scores; for 2-step pairings, the mean of the S3S5, S4S6 scores minus the mean of the S1S3, S2S4, S5S7 ones; for 3-step pairings, the mean of the S2S5, S3S6, S4S7 scores minus the S1S4 score. Categorical perception was tested on responses collected for 1-step, 2-step and 3-step pairings. Larger steps were not used for testing categorical perception, as they do not allow distinguishing between within- and between-category discrimination.

Differences between the two discrimination peaks present in the data, at –30 and 10 ms VOT, were tested with the following contrasts (see Table 1): for 1-step pairings, the S2S3 score minus the S4S5 one; for 2-step pairings, the mean of S1S3 and S2S4 scores minus the mean of the S3S5 and S4S6 ones; for 3-step pairings, the S1S4 score minus the mean of the S3S6 and S4S7 ones.

Phonemic discrimination was tested on the scores collected both for the pairs including the same stimuli and for those including different endpoint stimuli (S1-S7 and S7-S1). These data were analyzed with group (3 levels), continuum (4 levels) and pair (2 levels: same or different) as categorical independent variables.

RESULTS

For 1-step pairings, there was an effect of group (χ^2 [2] = 11.9, $p<.01$), continuum (χ^2 [3] = 12.0, $p<.01$), and pair (χ^2 [5] = 52.7, $p<.001$). The group-continuum interaction was not significant (χ^2 [6] = 8.58, $p=.20$), and so were the continuum-pair and continuum-pair-group interactions (χ^2 [15] = 14.2, $p=.51$; χ^2[30] = 21.6, $p=.87$; respectively). The group-pair interaction was significant (χ^2[10] = 22.7, $p<.05$) and the PBE was significantly larger for adults vs. both dyslexic and AR children (χ^2 [1] = 12.5, 4.13; $p<.001$; $p<.05$; respectively). There was also a nearly significant increase of PBE for AR vs. dyslexic children (χ^2 [1] = 3.82; $p=.051$). The mean scores for the four voicing continua are shown in Figure 3 for each one-step pair and each group. Two different discrimination peaks are apparent for each group, one at 10 ms VOT and the other at –30 ms VOT. However, the relative magnitudes of the peaks depend on the group. The 10 ms peak is much larger than the –30 ms for the average readers both adults and children, whereas the two peaks have about the same size for the dyslexic children. The difference in magnitude between the 10 ms VOT and –30 ms VOT peaks was significantly smaller for dyslexic children vs. both AR children and adults (contrast χ^2 [1] = 5.40, $p<.05$; 8.29, $p<.01$, respectively). The 10 ms VOT peak was significantly larger for adults vs. dyslexic children (χ^2 [1] = 5.08, $p<.05$). All the other differences between peaks were non significant across groups ($p>.11$).

Insert Figure 3 about here

For 2-step pairings, the effects of continuum and pair were significant (χ^2 [3] = 10.2, $p<.05$; χ^2 [4] = 153, $p<.001$; respectively). The effect of group was non significant (χ^2 [2] = 1.55, $p=.46$) and so were those of the group-continuum, pair-continuum and group-pair-continuum interactions (χ^2 [6] = 2.96, $p=.81$; χ^2 [11] = 18.4, $p=.072$; χ^2 [22] = 16.0, $p=.82$; respectively). The group-pair interaction was significant (χ^2 [8] = 25.8, $p=.001$) and the PBE was significantly larger for adults vs. both dyslexic and AR children (χ^2 [1] = 8.72, 10.2; $p<.01$; $p=.001$; respectively). The difference in PBE between AR vs. dyslexic children was non significant (χ^2 <1). The difference in magnitude between the pairs straddling 10 ms VOT and those straddling –30 ms VOT was significantly larger for adults vs. both dyslexic and AR children (χ^2 [1] = 6.52; 4.87;

respectively; both $p<.05$). The same difference was non significant between dyslexic and AR children ($\chi^2 <1$).

For 3- step pairings, the main effect of pair was significant (χ^2 [3] = 89.6, $p<.001$) and so were the continuum-group, continuum-pair and group-pair interactions (χ^2 [6] = 22.2, $p=.001$;χ^2 [9] = 29.0, $p=.001$;χ^2 [6] = 29.6, $p<.001$; respectively). The main effects of group, continuum and the continuum-pair-group interaction were non-significant (χ^2 [2] = 5.47, $p=.065$; χ^2 [3] <1; χ^2[18] = 10.3, $p=.92$; respectively). The PBE was smaller for dyslexic children vs. both AR children and adults (χ^2[1] =12.4, 18.8; respectively, both p<.001). The difference in PBE between AR children and adults was not significant (χ^2[1] = 3.09; p=.079). The difference in magnitude between the pairs straddling 10 ms VOT and those straddling –30 ms VOT was significantly smaller for dyslexic children vs. both AR children and adults (χ^2 [1] = 10.9, $p=.001$; 18.8, $p<.001$, respectively). The same difference was just non significant when adults were compared to AR children (χ^2 [1] = 3.66, $p=.056$).

For steps larger than three, i.e. from four to six steps, all the pairs straddle both the –30 ms peak and the 10 ms VOT one, which makes that differences in discrimination scores between these peaks could not be further tested. However, 6-step pairings give indications on the discriminability between endpoint stimuli (S1-S7 & S7-S1). The endpoint discrimination scores were examined together with those collected for pairs including the same stimuli (e.g. S1-S1), in order to control for biases towards "different" responding. All the interactions were non significant (group-pair: (χ^2 [2] = 3.62, $p=.16$; group-continuum: χ^2 [6] = 9.87, $p=.13$; pair-continuum: χ^2 [3] = 4.18, $p=.24$; group-pair-continuum: χ^2 [6] = 1.40; $p=.97$). The effects of continuum, pair and group were significant (χ^2 [3] = 13.0, $p<.01$; χ^2 [1] = 7.08, $p<.01$; χ^2 [2] = 30.4, $p<.001$, respectively). Correct discrimination was higher for adults (89 %) than for AR children (75 %) and dyslexic children (72 %) but only differences between adults and children were significant (χ^2 [1] 20.6; 30.2; both $p<.001$; for adults vs. AR and dyslexics respectively; χ^2 [1] = 2.01, $p=.16$; for AR vs. dyslexic children). Correct discrimination was slightly larger for "different" pairs (79%) vs. "same" pairs (75%). It was largest for the /ga-ka/NAT continuum (81 %), followed by /ga-ka/SW (76%), /ba-pa/MOD (74%) and /ba-pa/SW (71%).

DISCUSSION

Phonemic Discrimination

Discrimination of continua endpoints was not perfect even for adults but it was lesser for children than for adults. This can be related to the acoustic properties of the stimulus continua used for collecting the responses. These continua were constructed by modifying the sole VOT, which is only one among the many acoustic cues contributing to the voicing distinction in natural speech (Delattre, 1968). Whereas adult speakers can to some extend modify the perceptual weighting of the cues in order to adapt their percepts to reduced-cue stimuli, children are less flexible (Simon & Fourcin, 1978; Ohde & Haley, 1997; Nittrouer, Miller, Crowther & Manhart, 2000; Hazan & Barrett, 2000). Although previous studies also suggest that discrimination between phoneme categories depends on the reading level, discrimination between continua endpoints was not significantly better for AR vs. dyslexic children in the present study. This might be due to the fairly long interstimulus interval (100 ms) used here. In the study by Mody et al. (1997), below-average readers made substantially more errors in phoneme discrimination than did above-average readers at a very short ISI (10 ms) whereas differences were weaker for longer ISIs (50 or 100 ms). In the study by Adlard and Hazan (1998), where a single ISI of 1 second was used, the phoneme discrimination performance of average readers was not significantly better than that of dyslexics as a group. Reed (1989), who also used an ISI of 1 second, did not obtain a significant difference between reading disabled children and normal readers in the discrimination of stimuli straddling the phoneme boundary. Finally, we did not find a difference between dyslexic and AR children on endpoint discrimination in a former study with 100 ms ISI (Serniclaes et al., 2001).

Categorical Perception

While phonemic discrimination refers to the perception of between-category differences, categorical perception indicates the relative perceptibility of between vs. within-category discrimination. It is perfectly possible to reach fairly high levels of phoneme discrimination in spite of weak categorical perception, as evidenced by the perception of stable vowels (Pisoni, 1971). However, even if it is not necessarily related to phonemic discrimination, non-categorical perception of phonemic distinctions probably has various other consequences on spoken language processing. As only differences between phonemes are necessary for word recognition, categorical perception of phonemes allows filtering out irrelevant information for phoneme recognition. The implication of reduced CP is to overload upstream processes and memory buffers, which necessary has consequences in terms of rate and capacity. Although the functional importance of the CP deficit for oral communication remains unknown, it probably has deleterious effects on written language performances, as will be further commented below.

The amount of Categorical Perception was assessed by measuring the Phoneme Boundary Effect (PBE), i.e. the increased discrimination of stimulus pairs straddling the phoneme boundary vs. those belonging to the same phoneme category. Differences in PBE between groups were significant whenever testable (for 1- to 3-step pairings). In each case, the PBE was significantly larger for adults vs. children. This provides further evidence in support the effect both age and dyslexia on categorical perception. Previous studies on the phonemic labeling of stimuli along reduced-cue continua show that the slopes of identification functions are children are shallower for children vs. adults (Hazan & Adlard, 2002; Messaoud-Galusi, in press).

For 1- and 3-step pairings, the PBE was significantly larger for AR vs. dyslexic children. The lack of significant effect for 2-step pairing is related to a reduction of the within-category peak. The latter is probably less salient for this pairing, as it does not include a pair centered on –30 ms VOT (Table 1). The smaller PBE for children affected by dyslexia is in agreement with the results of a fairly large number of previous studies which show that these children have a deficit in categorical perception (see Introduction). Further, the present results might help understanding why the deficit is not systematically significant in the results reported in the literature. We have just seen that the difference in CP between dyslexics and controls depends on what might be in first instance considered as details of the procedure, such as the size of the pairings used for collecting the discrimination data. However, the effects of such tiny procedural differences becomes meaningful insofar they affect the perceptibility of intra-phonemic boundaries and that the latter are at the origin of the CP deficit.

For average readers, either children or adults, perception was fairly categorical with a dominant discrimination peak at the phonemic boundary (10 ms VOT with the present stimuli) although a secondary peak was also visible at –30 ms VOT. This latter peak is located in the same region as one of the two voicing boundaries found in languages with three voicing categories (Abramson & Lisker, 1970). Remember that prelinguistic children are sensitive to this boundary (Lasky et al., 1975; Aslin et al., 1981). The fact that average readers keep some sensitivity to a boundary which is non phonemic in their language is in agreement with the results of other studies which suggest that desactivation of predispositions not relevant in the linguistic environment is only functional, without neural extinction (Werker & Tees, 1984a). The residual sensitivity might arise from an enrooting of phonetic boundaries in psychoacoustic properties (Rosen & Howell, 1987), as the latter remain necessary for the perception of nonspeech stimuli, irrespective of their linguistic relevance. Evidence in support to the psychoacoustic explanation arises from the fact that categorical perception was evidenced for differences in tone onset time in nonspeech stimuli, similar to differences in voice onset time in speech stimuli (Jusczyk, Pisoni, Walley, & Murray, 1980; Pisoni, 1977). However, psychoacoustic boundaries are less flexible than those found in speech (Repp & Liberman, 1987). An alternative possibility is that the similitude between phonetic and psychoacoustic boundaries is due to the progressive emergence of a speech specific system in the human during phylogenetic development (Liberman, 1998). In this view, predispositions for perceiving phonetic features are specific to speech. Their persistence in the perceptual repertoire might then arise from their potential usefulness for learning foreign languages.

Whereas the discrimination peak located at the phoneme boundary (10 ms VOT) was much larger than the allophonic peak (-30 ms VOT) for both adults and AR children, both peaks had about the same magnitude for dyslexic children. The difference in relative peak magnitude between dyslexic children and AR controls was significant for 1-step and 3-step pairings. This difference was however not significant for 2-step pairings, probably because none of the 2-step pairs was centered on the peak values (-30 and 10 ms VOT), contrary to what prevailed for 1-step and 3-step pairings (see Table 1). The increased sensitivity to the –30 ms VOT boundary in dyslexic children indicates that their discrimination profile is closer to the one of the prelinguistic children as they both discriminate three voicing categories. However, some linguistic influence is present in the dyslexics' responses as evidenced by the location of their positive VOT peak which coincides with the French voicing boundary and is closer to 0 ms by comparison with the universal positive VOT boundary (Figure 2).

Much the same results were obtained in another study with two groups of 10-year old children, one with at least 6 months reading delay and the other with a reading advance of at least 6 months (Bogliotti et al., 2002). Discrimination data collected on a /do-to/ VOT continuum revealed that a single discrimination peak, located at the phonemic boundary, was present for good readers. The phonemic peak was smaller for the bad readers and a second peak was present in the negative VOT region (around –20 ms), although the latter was much smaller than the phonemic one.

Finally, the perceptibility of extraneous phonetic boundaries is not a particularity of the voicing feature. Similar results have been recently obtained for the perception of stop place of articulation by French-speaking adults, without history of dyslexia (Serniclaes & Carré, in press). Dyslexics should be more sensitive to these phonetic boundaries for place, as they are for the voicing ones, a possibility that is currently under investigation.

Allophonic perception

Although the exact nature of the predispositions for perceiving phonetic distinctions is still unclear, the present results show that the residual sensitivity to those among the predispositions that are not linguistically relevant is much larger for children affected by dyslexia. The enhanced sensitivity of dyslexic children, by comparison with average readers of the same age, to variants of the same phoneme category might result from a delay in perceptual development as we do not know yet whether the dyslexic categorical perception deficit diminishes with ageing and/or with exposure to written language. However, even if it disappears later, the perception of allophonic variants during early reading acquisition probably has severe implications because it reveals the weakness, if not the total absence, of phoneme representations. The lack of invariant phoneme representations constitutes a considerable obstacle for the set-up of phoneme-grapheme correspondences, which are normally involved in early stages of reading acquisition (Sprenger-Charolles, Siegel, & Bonnet, 1998). However, allophonic representations of speech sounds should not raise problems for speech perception, as the latter is conceivable with other units than the phoneme (McQueen & Cutler, 2001). The damages of an allophonic mode of speech perception would then be almost entirely restricted to written language, with oral communication remaining largely unaffected. As a severe reading deficit without other linguistic or cognitive problems is the basic characteristic of dyslexia, allophonic perception might constitute its true determinant rather than a correlated symptom. It has therefore a major theoretical interest for establishing a link between speech perception and reading deficits.

As a trouble of phonological development, allophonic perception offers a new explanation of dyslexia in terms of deviant phonological processes. While the hypothesis of a phonological deficit has often been considered in the literature, it has never been directly attributed to phonological processing. Rather, it has been ascribed to defects in either auditory or phonetic processing which would in turn affect phonological processes (Figure 1), or to conscious access to phonemes. But none of these hypotheses directly deals with phonological mechanisms and they do therefore not allow specifying the precise nature of the deficit (Ramus, 2001). The allophonic perception hypothesis assigns the deficit to the weakness or absence of phonological recoding of phonetic predispositions in the course of perceptual development, which constitutes an important step towards the specification of the underlying processes. Further research should allow to better understand the mechanisms involved in phonological recoding in average readers as well as the exact reasons of their failure in subjects affected by developmental dyslexia. One interesting possibility is that the failure arises from a weaker development of phonological couplings between predispositions. Couplings can explain how a new categorical boundary is derived from the universal boundaries found in the prelinguistic infant and perceptual data collected on adults indeed suggest that the French voicing boundary results from a coupling between predispositions (Serniclaes, 2000). Further, connectionist simulations suggest that reduced phonological couplings, or "attractions" in the connectionist terminology, might account both for the reading deficit in developmental dyslexia (Harm & Seidenberg, 1999). Finally, couplings are intrinsically more complicated than desactivations and hence more exposed to failures in the course of perceptual development. They might therefore account for the fairly large prevalence of dyslexia.

A further specificity of allophonic perception is that, unlike other phenomena associated with dyslexia, it is functionally independent of other biologically related symptoms. Dyslexia is a hereditary neurological disorder (Cardon, Smith, Fulker, Kimberling, Pennington, & De Fries, 1994; Pennington, & Gilger, 1996) with correlated deficiencies in different parts of the brain but only those directly affecting phonological processing are the true determinants of dyslexia. All the other deficits will only affect reading acquisition indirectly and have extraneous consequences on other functions such as those involved in oral language, in conscious access to perceptual units in other domains than speech, or in visual perception. This is not to say that these deficits might not have consequences for reading, but the latter will not be specific enough to comply with the definition of dyslexia. Finally, the fact that dyslexics are *more* acute in the perception of non-phonological properties clearly allows excluding interpretations in terms of general cognitive abilities. Rather, dyslexia seems to arise from a particular mode of speech perception, which, although quite satisfactory for the purpose of oral communication, renders the child unable to respond to the demands of alphabetic writing.

REFERENCES

Abramson, A.S., & Lisker, L. (1970). Discriminability along the voice onset time continuum: cross-language tests. In B. Hala, M. Romportl,. & P. Janota, P. (Eds.), *Proceedings of the 6th International Congress of Phonetic Sciences.* (pp.569-573). Prague: Academia.

Adlard, A., & Hazan,V. (1998). Speech perception in children with specific reading difficulties (Dyslexia). *Quarterly Journal of Experimental Psychology, 51A,* 153-177.

Aslin, R.N., Pisoni, D.B., Hennessy, B.L., & Perrey, A.V. (1981). Discrimination of voice onset time by human infants: New findings and implications for the effect of early experience. *Child Development, 52,* 1135-1145.

Bogliotti, C., Messaoud-Galusi, S., & Serniclaes, W. (2002). Relations entre la perception catégorielle de la parole et l'apprentissage de la lecture. *XXIVèmes Journées d'Etudes sur la Parole (JEP). (pp. 197-200).* Le Chesnay, France: INRIA.

Brady, S.A., & Shankweiler, D. (1991). *Phonological processes in literacy.* Hillsdale, NJ: Erlbaum.

Brandt, J., & Rosen, J.J. (1980). Auditory Phonemic Perception in Dyslexia : Categorical Identification and discrimination of stop consonants. *Brain and Language, 9,* 324-337.

Caramazza, A., & Yeni-Komshian, G.H. (1974). Voice onset time in two French dialects. *Journal of Phonetics, 2,* 239-245.

Cardon, L.R., Smith, S.D., Fulker, D.W., Kimberling, W.J., Pennington, B.F., & De Fries, J.C. (1994). Quantitative trait locus for reading disability on chromosome 6. *Science, 266,* 276-279.

Delattre P. (1968). From acoustic cues to distinctive features. *Phonetica,18,* 198-230.

Godfrey, J.J., Syrdal-Lasky, A.K., Millay K.K., & Knox, C.M. (1981). Performance of dyslexic children on speech perception tests. *Journal of Experimental Child Psychology, 32,* 401-424.

Harm, M.W., & Seidenberg, M.S. (1999). Phonology, Reading Acquisition, and Dyslexia : Insights from connectionist models. *Psychological Review, 196,* 491-528.

Hazan, V., & Barrett, S. (2000). The development of phonemic categorization in children aged 6-12. *Journal of Phonetics, 28,* 377-396.

Joanisse, M. F., Manis, F. R., Keating, P., & Seidenberg, M. S. (2000). Language deficits in dyslexic children: Speech perception, phonology, and morphology. *Journal of Experimental Child Psychology, 77,* 30-60.

Jusczyk, P.W., Pisoni, D.B., Walley, A., & Murray, J. (1980). Discrimination of relative voice onset time of two-component tones by infants. *Journal of the Acoustical Society of America, 67,* 262-270.

Kleinbaum, D.G., & Klein, M. (2002). *Logistic regression.* New York: Springer.

Lasky, R.E., Syrdal-Lasky, A., & Klein, R.E. (1975). VOT discrimination by four to six and a half months old infants from Spanish environments. *Journal of Experimental Child Psychology, 20,* 215-225.

Liberman, A. M. (1998). Three questions for a theory of speech. *Journal of the Acoustical Society of America, 103,* 3024.

Liberman, A.M., Delattre, P.C., & Cooper, F.S. (1958). Some cues for the distinction between voiced and voiceless stops in initial position. *Language and Speech, 1,* 153-166.

Liberman, A.M., Harris, K.S. Hoffman, H.S., & Griffith, B.C. (1957). The discrimination of speech sounds within and across phoneme boundaries. *Journal of Experimental Psychology, 54,* 358-368.

Liberman, I.Y., Shankweiler, D., Fisher, W.F., & Carter, B. (1974). Explicit syllable and phoneme segmentation in the young child. *Journal of Experimental Psychology, 18,* 201-212.

Lisker, L., & Abramson, A.S. (1964). A cross-language study of voicing in initial stops: acoustical measurements. *Word, 20,* 384-422.

Lobrot, M. (1973). *Lire.* Paris: ESF.

Manis, F.R., McBride-Chang, C., Seidenberg, M.S., Keating, P., Doi, L.M., Munson, B., & Petersen, A. (1997). Are speech perception deficits associated with developmental dyslexia ? *Journal of Experimental Child Psychology, 66,* 211-235.

Masterson, J., Hazan,V., & Wijayatilake, L. (1995). Phonemic processing problems in developmental dyslexia. *Cognitive Neuropsychology, 12,* 233-259.

McCullagh, P., & Nelder, J.A. (1983) *Generalized Linear Models*. London: Chapman & Hall.

Messaoud-Galusi, S., Carré, R., Bogliotti, C., & Serniclaes, W. (2002). Origine du déficit de perception catégorielle des dyslexiques. *XXIVèmes Journées d'Etudes sur la Parole (JEP).* (pp. 193-197). Le Chesnay, France: INRIA.

Messaoud-Galusi, S. (in press). The effect of age and reading level on perceptual weighting strategy. *Proceedings of the 15th Iinternational Congress of Phonetic Sciences, Barcelona, August 3-9, 2003.*

McQueen, J., & Cutler, A. (2001). Spoken word access processes: An introduction. *Language and Cognitive Processes, 16,* 469-490.

Mody, M., Studdert-Kennedy, M., & Brady, S. (1997). Speech perception deficits in poor readers: Auditory processing or phonological coding? *Journal of Experimental Child Psychology, 64*, 199-231.

Morais,J., Alegria, J., & Content, A. (1987). The relationships between segmental analysis and alphabetic literacy: An interactive view. *Cahiers de Psychologie Cognitive. European Bulletin of Cognitive Psychology, 7,* 415-438.

Nittrouer, S., Miller, M.E., Crowther, C.S., & Manhart, M.J. (2000). The effect of segmental order on fricative labeling by children and adults. *Perception and Psychophysics, 62,* 266-284.

Pennington, B.F., & Gilger, J.W. (1996). How is dyslexia transmitted ? In C.H. Chase, G.D. Rosen, G.F. Sherman (Eds.), *Developmental dyslexia: neural, cognitive and genetic mechanisms.* (pp. 41-61). Baltimore: York Press.

Pisoni, D.B. (1971). On the nature of categorical perception of speech sounds. *Supplement to Haskins Labs. Status Report on Speech Research, SR-27*, 1-101.

Pisoni, D.B. (1977). Identification and discrimination of the relative onset time of two components tones: implications for voicing perception in stops. *Journal of the Acoustical Society of America, 61,* 1352-1361.

Ramus, F. (2001) Talk of two theories. *Nature, 412,* 393-395.

Ramus, F., Rosen, S., Dakin, S.C., Day, B.L., Castellote, J.M., White, S., & Frith, U. (2003). Theories of developmental dyslexia: Insights from a multiple case study of dyslexic adults. *Brain, 126,* 841-865.

Reed, M.A. (1989). Speech perception and the discrimination of brief auditory cues in dyslexic children . *Journal of Experimental Child Psychology, 48*, 270-292.

Remez, R.E., Rubin, Ph.E., Pisoni, D.B., & Carrell, T.D. (1981). Speech perception without traditional speech cues. *Science, 212*, 947-950.

Repp, B.H., & Liberman, A.M. (1987). Phonetic category boundaries are flexible. In S. Harnad (Ed.), *Categorical Perception.* (pp.89-112). Cambridge: University Press.

Rosen, S., & Howell, P. (1987). Auditory, articulatory, and learning explanations of categorical perception in speech. In S. Harnad (Ed.), *Categorical Perception.* (pp.113-160). Cambridge: University Press.

Rosen, S., & Manganari, E. (2001). Is there a relationship between speech and nonspeech auditory processing in children with dyslexia? *Journal of Speech Language and Hearing Research, 44,* 720-736.

Serniclaes, W. (1987). *Etude expérimentale de la perception du trait de voisement des occlusives du français.* Unpublished doctoral thesis. Université Libre de Bruxelles.

Serniclaes, W. (2000). La perception de la parole. In P. Escudier, G. Feng, P. Perrier & J.-L. Schwartz (Eds.), *La parole, des modèles cognitifs aux machines communicantes.* (pp.159-190). Paris: Hermès.

Serniclaes, W., & Carré, R. (in press). Perception of consonant place of articulation: phonological categories meet natural boundaries. *Proceedings of the 15th Iinternational Congress of Phonetic Sciences, Barcelona, August 3-9, 2003.*

Serniclaes, W., Sprenger-Charolles, L., Carré, R., & Démonet, J.-F. (2001). Perceptual discrimination of speech sounds in dyslexics. *Journal of Speech Language and Hearing Research, 44,* 384- 399.

Shaywitz, S. E. (1998). Dyslexia. *New England Journal of Medicine, 338,* 307-31.

Simon, C., & Fourcin, A.J. (1978). Cross-language study of speech-pattern learning. *Journal of the Acoustical Society of America, 63,* 925-935.

Snowling, M.J. (2000). *Dyslexia.* Oxford: Blackwell.

Sprenger-Charolles, L., Siegel, L.S., & Bonnet, P. (1998). Phonological mediation and orthographic factors in reading and spelling. *Journal of Experimental Child Psychology, 68*, 134-155.

Studdert-Kennedy, M. (2002). Deficits in phoneme awareness do not arise from failures in rapid auditory processing. *Reading & Writing: An Interdisciplinary Journal, 15,* 5-14

Tallal, P. (1980). Auditory temporal perception, phonics and reading disabilities in children. *Brain and Language, 9,* 182-198.

Vihman, M.V. (1996). *Phonological development: The origins of language in the child.* Cambridge (MA): Blackwell.

Werker, J.F., & Logan, J.S. (1985). Cross-language evidence for three factors in speech perception. *Perception & Psychophysics, 37,* 35-44.

Werker, J.F., & Tees, R.C. (1984a). Phonemic and phonetic factors in adult cross-language speech perception*. Journal of the Acoustical Society of America, 75,* 1866-1878.

Werker, J.F., & Tees, R.C. (1984b). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development, 7,* 49-63.

Werker, J.F., & Tees, R.C. (1987). Speech perception in severely disabled and average reading children. *Canadian Journal of Experimental Psychology, 41,* 48-61.

Williams, L. (1977). The voicing contrast in Spanish. *Journal of Phonetics**,** 5,* 169 84.

Acknowledgments

This work was supported by a ACI grant from the French “Ministère de l'Education Nationale, de la Recherche et de la Technologie". We thank Cécile Houard for her help in the preparation of the English version of this manuscript.

Table1.
VOT values. The mean VOTs of the different pairs (columns) are given as a function of pair sizes (in rows).

ms VOT	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60
0-step pairs	S1-S1		S2-S2		S3-S3		S4-S4		S5-S5		S6-S6		S7-S7
1-step pairs		S1-S2		S2-S3		S3-S4		S4-S5		S5-S6		S6-S7	
2-step pairs			S1-S3		S2-S4		S3-S5		S4-S6		S5-S7		
3-step pairs				S1-S4		S2-S5		S3-S6		S4-S7			
4-step pairs					S1-S5		S2-S6		S3-S7				
5-step pairs						S1-S6		S2-S7					
6-step pairs							S1-S7						

Figure legends

Figure 1. Information processing in reading (plain lines) and speech perception (dotted lines). Auditory, phonetic and phonological processes are involved in speech perception. Two different routes are used in reading. The phonological route proceeds by grapheme-phoneme correspondences. The orthographic route is derived from the phonological one during reading acquisition. Allophonic mode of speech perception arises from a deficit in phonological processing. It affects reading acquisition by hampering grapheme-phoneme correspondences.

Figure 2. Perceptual boundaries between voicing categories in prelinguistic children and in French. Prelinguistic boundaries are pre-planned for the perception of all potential categories (voiced as for /b/, voiceless as for /p/ and voiceless aspirated as for /p^h/) in the world's languages. In French, only two categories are present (voiced and voiceless slightly aspirated).

Figure 3. Discrimination of speech stimuli by dyslexics. Discrimination responses of dyslexics children, average readers controls and adults to pairs of stimuli differing in Voice Onset Time (VOT). Dyslexics exhibit two main discrimination peaks, instead of only one for average readers. The latter corresponds to the voicing boundary in French. The other peak corresponds to a further boundary in languages with three voicing categories.

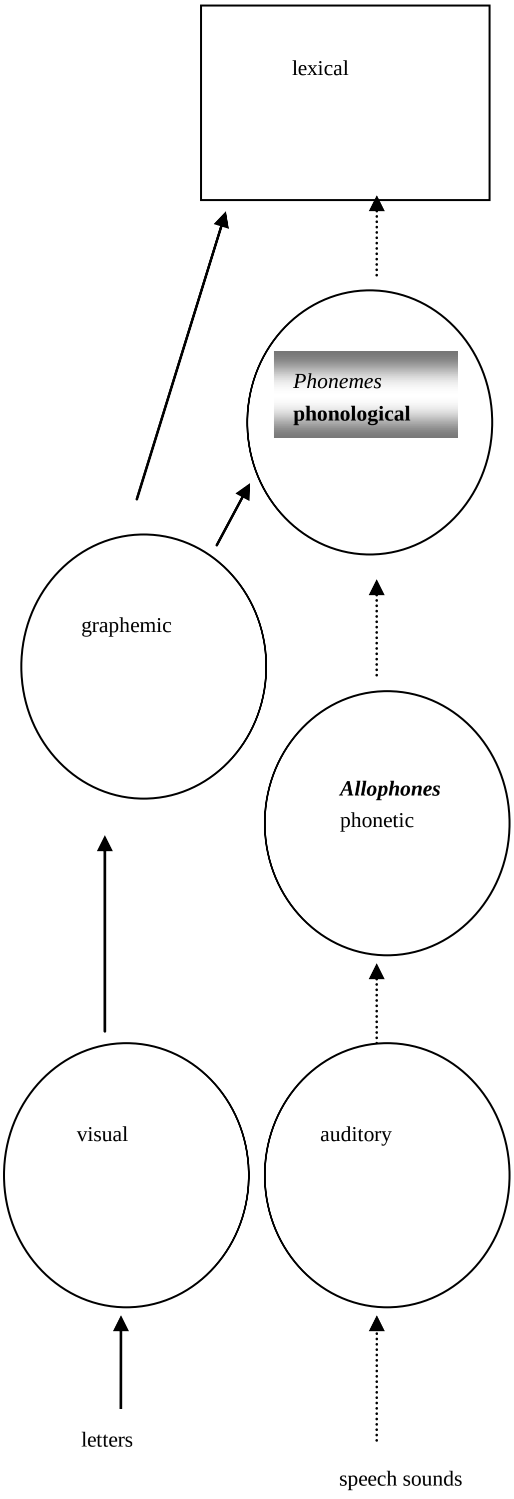
lexical
Phonemes
phonological
graphemic
Allophones
phonetic
visual
auditory
letters
speech sounds

Figure 1

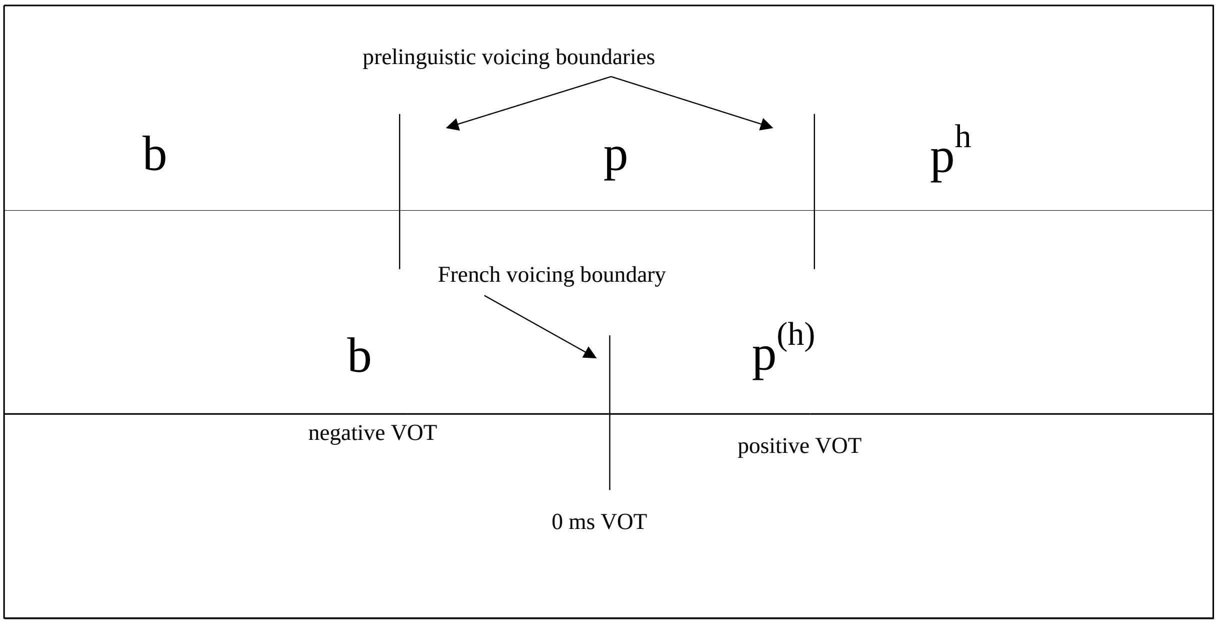
prelinguistic voicing boundaries
b
p
pʰ
French voicing boundary
b
p⁽ʰ⁾
negative VOT
positive VOT
0 ms VOT

Figure 2

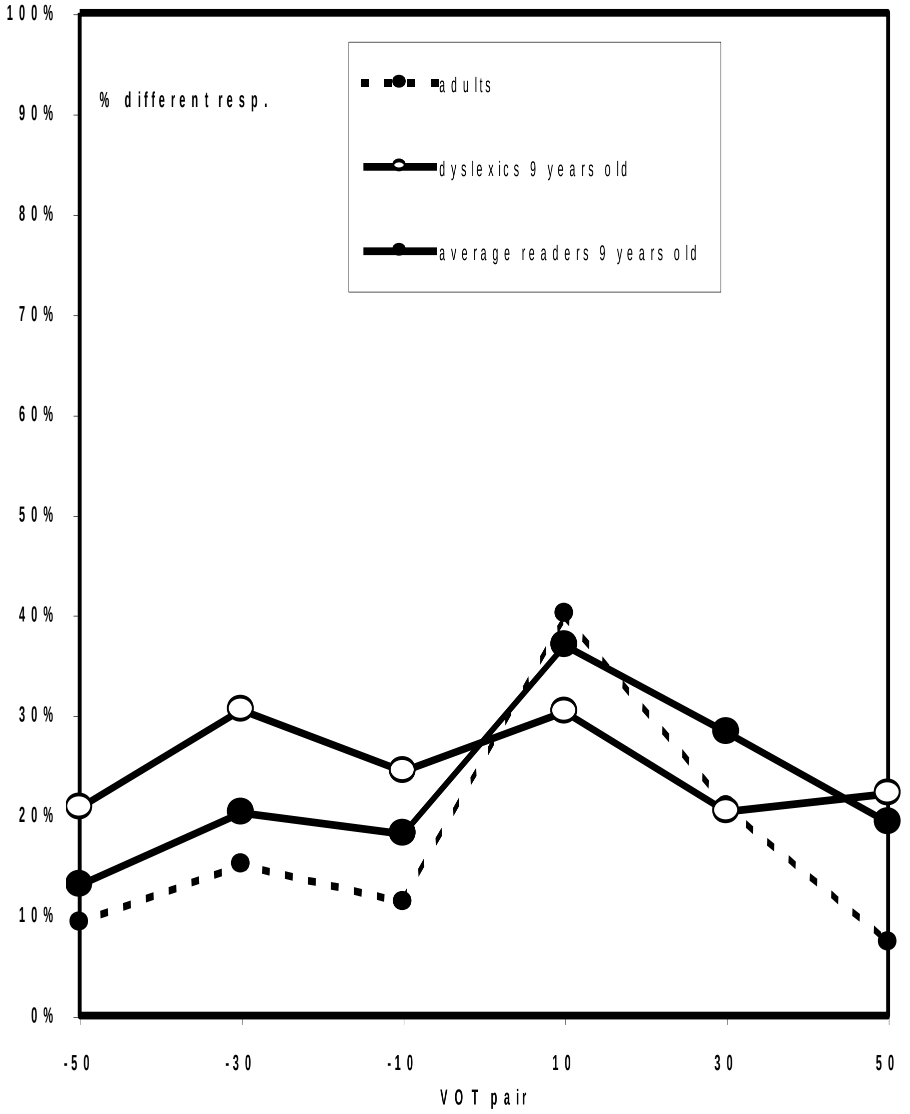
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% different resp.
adults
dyslexics 9 years old
average readers 9 years old
-50
-30
-10
10
30
50
VOT pair

Figure 3