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# Categorical perception of speech sounds and dyslexia

## Perceptual basis of the phonological deficit in dyslexia

- 1 This paper deals with the perceptual basis of the phonological deficit in developmental dyslexia. Arguments in support of the phonological nature of dyslexia were summarized in Sprenger-Charolles & Serniclaes (this volume). More precisely, dyslexics were found to have severe difficulties in reading due to the phonological demands of having to map graphemes to phonemes. The fact that dyslexics suffer from an impairment in phoneme awareness is well documented (see for a review: Snowling, 2001). However, a primary requirement for establishing grapheme-phoneme correspondences is to be endowed with well-defined phonemic categories. Here we consider the evidence suggesting that phonological reading impairments in dyslexia arise from a deficit in the categorical perception of phonemes.

## The categorical perception deficit in dyslexia

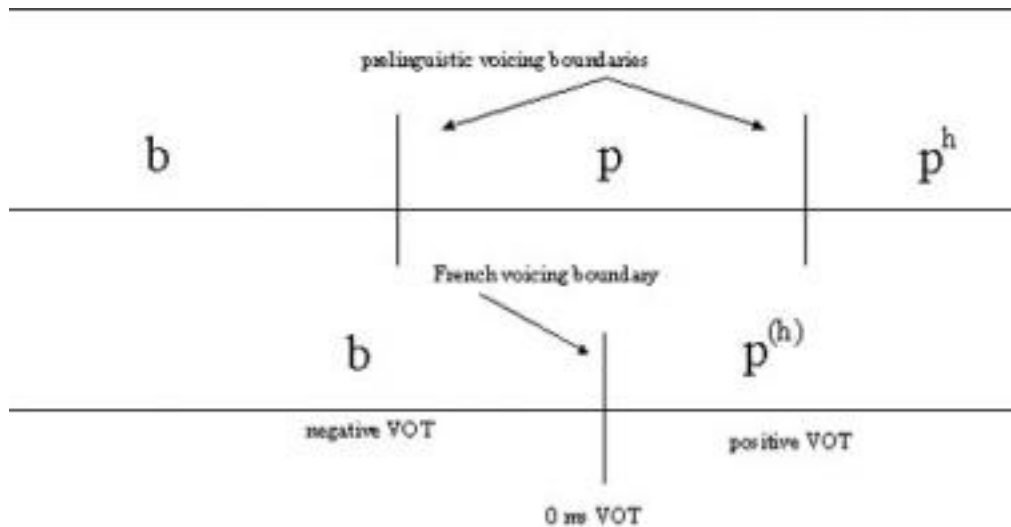
- 2 When asked to discriminate pairs of spoken syllables which only differ by a single phonemic feature, such as /ba/ and /da/, dyslexic children make a larger number of errors than do average readers (Reed, 1989; Masterson, Hazan & Wijayatilake, 1995; Mody, Studdert-Kennedy & Brady, 1997; Adlard & Hazan, 1998). This weakness in phoneme discrimination is not a matter of perceptual acuity. Rather, it arises from specific problems in the categorical perception of speech sounds. "Categorical perception" (CP) corresponds to the extent to 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). Normal listeners do better on between, rather than within, category discrimination of speech sounds. However, 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 finding in all these studies is that, compared to normals, dyslexics do poorly on between-category (i.e. phoneme) discrimination but do equally well or *better* on discriminating within-category acoustic variants of the same phoneme.

## Reliability of the categorical perception deficit

- 3 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 know, the CP deficit in dyslexics was always present in these conditions, although it was not always tested (Brandt & Rosen, 1981), sometimes marginally significant (Reed, 1989) and sometimes without concomitant differences in within-category discrimination (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; Joannis, Manis, Keating, & Seidenberg, 2000). However, in the two later studies the CP deficit was only found for the subgroups of dyslexics most severely affected.

## The locus of the CP deficit in the framework of the three-stage model of speech perception

- 4 Phonological categories can be conceived as the end-products of three successive processing stages, the first consisting of the extraction of acoustic cues, the second of the analog-to-digital transform of acoustic cues into phonetic categories, and the third of the grouping of phonetic categories into phonological ones (Werker & Logan, 1985; Werker & Tees, 1987; Samuel & Kat, 1996; Serniclaes, 2000). In this framework, a representation deficit might arise at each of these three levels, i.e. "auditory", "phonetic" or "phonological". The difference between a phonetic vs. phonological deficit has already been considered in the literature (Morais, Alegria, & Content, 1987). However, the focus has been on the auditory vs. speech specific nature of the deficit, without considering the exact status of the later. 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 a variety of nonspeech auditory tasks including judgments of temporal order between nonspeech 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, in press). Attempts to reduplicate the speech deficits with similar nonspeech stimuli did not provide straightforward support for the auditory hypothesis. The reduced performance of dyslexics for the discrimination of minimal pairs of synthetic speech sounds, differing by the value of a single phonetic feature, was not found for similar nonspeech contrasts (Mody, Studdert-Kennedy, & Brady, 1997). In a study where exactly the same stimuli were used to compare speech and nonspeech performances, a categorical perception deficit was found in both conditions (Serniclaes et al., 2001). However, the categorical boundary was not located at the phonetically relevant position in the nonspeech condition where it corresponded to the qualitative change between rising and falling transitions. This suggests a double deficit, one for speech perception and the other for nonspeech auditory perception. Whether categorical perception processes in the speech and nonspeech modes are totally independent remains unknown after decades of research. What is already clear from studies on normal adults is that categorization processes for speech are not entirely reducible to those for general auditory perception because, among other reasons, phonetic boundaries are more flexible than are the nonspeech ones (Repp & Liberman, 1987). Nonspeech boundaries are gripped to natural boundaries, such as rising vs. falling frequency transitions, whereas phonetic boundaries are contextually variable and only correspond to a natural boundary in the neutral vowel context (Serniclaes & Carré, 2002).
- 5 The presence of a speech specific component in the categorical perception deficit of dyslexic children raises the question of its precise nature, phonetic or phonological. Let us briefly consider the development of speech perception in order to answer this question. One prevalent theory about the origin of phonetic perception states that human infants are born with a predisposition for perceiving all the possible phonetic contrasts, and whether these predispositions are activated or not depends on the presence versus absence of the corresponding contrast in the linguistic environment (Werker & Tees, 1984a). Neonates can already discriminate between a range of phonetic categories, even those which are not present in their ambient language (for a review see : Hallé, 2000; Vihman, 1996). Categorical perception of phonemes arises from deactivating (or rather reducing: Werker & Tees, 1984b) the initial sensitivity to phonetic distinctions irrelevant in the ambient language. However, deactivation of allophonic distinctions is not sufficient for adapting the initial predispositions to phonetic contrasts, to the phonological structures of the different languages. In many instances the phonological boundaries do not coincide with those precluded in the predispositions. Further adaptative mechanisms are needed which operate through *couplings* between predispositions (Serniclaes, 1987) in order to generate language-specific boundaries.



6 **Figure 1. Voicing categories and perceptual boundaries along the voice onset time (VOT) continuum. Top: Possible voicing categories in the world's languages (voiced, /b/: long negative VOT; voiceless, /p/: near 0 ms VOT; voiceless aspirated, /p<sup>h</sup>/: long positive VOT) and corresponding boundaries. Prelinguistic infants are sensitive to these boundaries. Bottom: French voicing categories (voiced, (/b/; slightly aspirated, (/p<sup>(h)</sup>/) and perceptual boundary (around 0 ms VOT). The later is not precluded in the infant's predispositions.**

7 These boundaries are generated through fairly complex developmental processes and they might therefore 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 allophonic categories. Such categorical perception of allophonic distinctions could give rise to a non-categorical perception of phonemes with intra-categorical discrimination peaks, similar to those found in dyslexic children, given the previous evidence of their weaker categorical perception and increased within-category discrimination. If speech perception is allophonic for dyslexic children their perceptual deficit would be specifically phonological. This hypothesis is attractive because it would provide a straightforward explanation for their weakness in phoneme awareness and, as explained below, to their impairments in phonological reading skills.

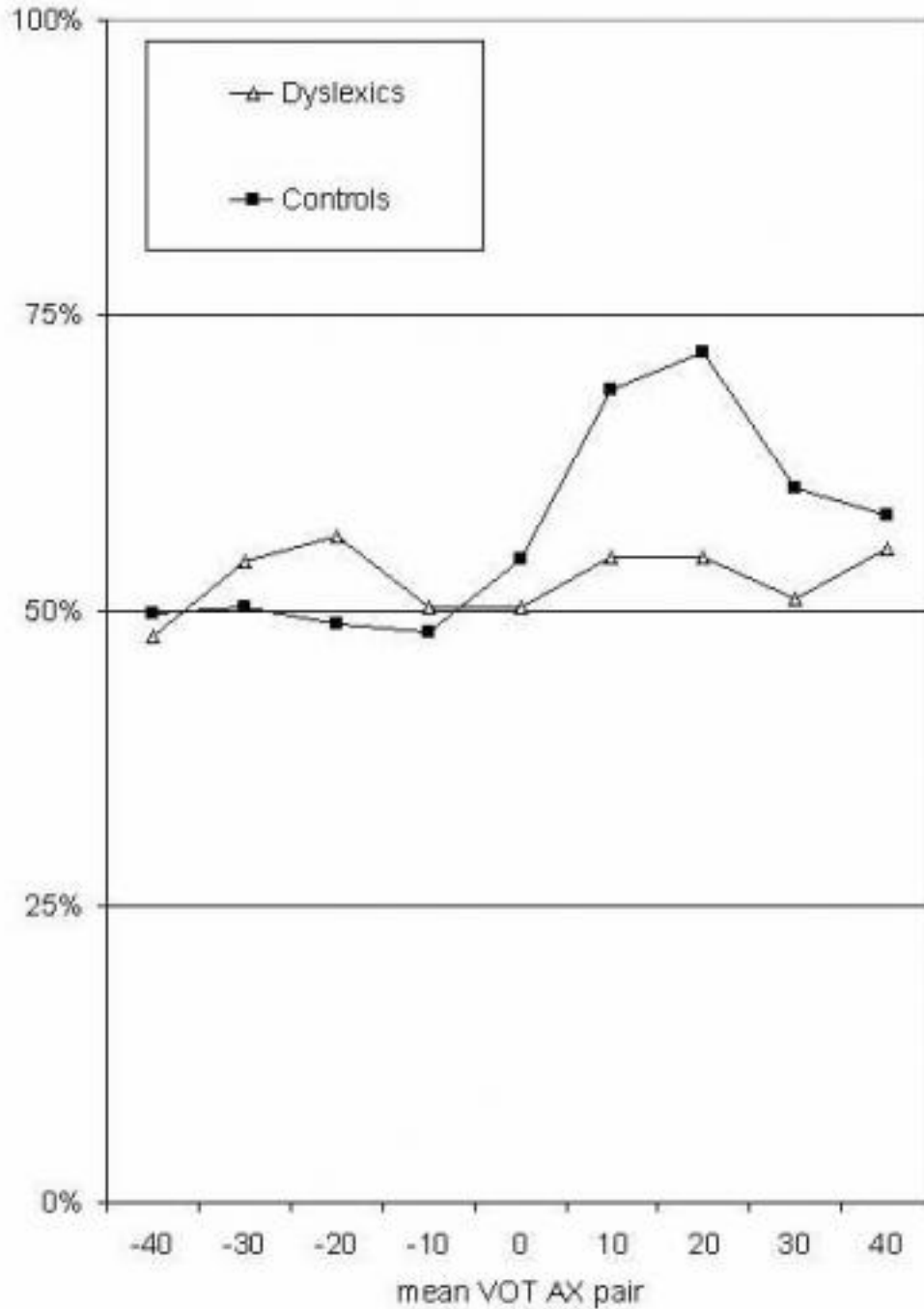
## Data in support of an allophonic mode of speech perception in dyslexia

8 Voicing perception in French offers an interesting opportunity to assess the effect of language on phonemic predispositions. 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 & Abranson, 1964; see Figure 1) In languages where the three VOT categories are phonemic, such as Thai, listeners exhibit two boundaries for voicing perception, a negative VOT boundary and a positive VOT one (Abramson & Lisker, 1970). These boundaries are precluded in the infant's predispositions (Lasky, Syrdal-Lasky, & Klein, 1975; Aslin, Pisoni, Hennessy, & Perrey, 1981). However, some languages among which French and Spanish, use a single distinction between negative VOT and moderately long positive VOT categories. 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. The zero VOT boundary is seemingly obtained by language-specific coupling between phonetic predispositions during perceptual development (Serniclaes, 2000).

9 The relationship between reading impairment and discrimination of synthetic syllables varying along the VOT continuum was investigated in two different studies on French-speaking children (10 year-old dyslexic children, in Bogliotti et al., 2002, or 9 year-old dyslexic children, in Van Heghe, 2001, vs. chronological age controls). Both studies reveal the presence of two different discrimination peaks, one corresponding to the phoneme boundary and the other to an allophonic one. This latter peak is less salient (in Van Heghe, 2001; not shown here) or even completely absent (in Bogliotti et al., 2002; see Figure 2) for AR vs. dyslexic children. These results suggest that the coupling between predispositions is not completed around 9 years old, given the presence of an allophonic peak for AR children at this age, and that the coupling deficit is stronger for children with reading problems, because the allophonic peak is stronger for the latter.

## % correct discrimination



10 Figure 2. Discrimination functions of 10 year-old dyslexic children (at least 18 months reading delay) and AR chronological age controls on a /do-to/ voicing continuum (from Bogliotti et al., 2002). AR exhibit a single discrimination peak at the phoneme boundary (between 10 and 20 ms VOT for these stimuli). Dyslexics exhibit another discrimination peak at a value appropriate for the perception of an allophonic distinction (between -30 and -20 ms VOT). Similar results were obtained in another study (Van Heghe, 2001).

## Possible implications of the allophonic mode of speech perception for reading

- 11 Understanding speech with allophonic rather than phonemic categories probably does not raise major problems. The access to the mental lexicon is conceivable with allophonic representations although it is more demanding in terms of information processing. The situation is quite different for understanding written language which, at least in alphabetic systems, requires phoneme representations. Arguments in support to the implications of a failure in coupling between predispositions for learning to read are provided by computer simulations. It has been shown that the suppression of "phonological attractions" between phonetic features, conceptually similar to the "phonological couplings" defined above, has important negative effects on the reading performance of a connectionist network (Harm & Seidenberg, 1999). Together with the above reported findings on allophonic perception in dyslexics this suggests that reduced phonological couplings or attractions might correspond to the central problem in dyslexia.

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## Abstract

Several studies indicate that dyslexics have a deficit in the categorical perception (CP) of phonemes when listening to speech. After reviewing data supporting the reliability of the CP deficit, we examine its possible site in the framework of a three-stage model of speech perception (auditory, phonetic and phonological). Different sources of evidence suggest that the deficit has a speech specific component. Further, the speech perception deficit appears to be phonological in nature insofar as dyslexics appear to be *better* than control subjects in discriminating allophonic distinctions, i.e. phonetic distinctions irrelevant for lexical processing in their language. Such sensitivity to allophonic variations in dyslexics might arise from a weakness in phonological couplings between phonetic features during perceptual development, which, in turn, can have specific implications for the build up of grapheme-phoneme correspondences. It may explain why dyslexics encounter significant problems in phonologically-demanding tasks like reading without experiencing similar difficulties in speech perception.

**Keywords :** phonological couplings, phonological dyslexia, speech development, categorical perception, phonetic predispositions