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Temporal Processing and Phonological Impairment in Dyslexia: Effect of Phoneme Lengthening on Order Judgment of Two Consonants

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The evidence of supporting phonological deficit as a cause of developmental dyslexia has been accumulating rapidly over the past 2 decades, yet the exact mechanisms underlying this deficit remain controversial. Some authors assume that a temporal processing deficit is the source of the phonological disorder observed in dyslexic children. Others maintain that the phonological deficit in dyslexia is basically linguistic, not acoustic, in nature. Three experiments were conducted and tested the impact of the temporal alteration and the impact of complex syllabic structure on consonant order judgments. Thirteen phonological dyslexics (age 10–13) and 10 controls matched for chronologial age were compared on a Temporal Order Judgment (TOJ) task using the succession of two consonants (/p/ /s/) within a cluster. In order to test the possible relevance of the temporal deficit hypothesis, the task also included two additional conditions where either the two stimuli were artificially slowed or two phonological structures were opposed (CCV and CVCV). As expected, the TOJ performance was significantly poorer in dyslexics than in controls. Moreover, in the ''slowed speech'' condition dyslexics' performance improved to reach the normal controls' level, whereas manipulating the phonological structure complexity provided no significant improvement. Finally dyslexics' performances, especially on the slowed condition, were found correlated with several tests of phonological processing. These results lend support to the general temporal deficit theory of dyslexia.

Key Words: dyslexia; phonology; temporal processing; phonetics; auditory.

INTRODUCTION

It is generally assumed that 8 to 10% of the population is affected by developmental dyslexia, defined as a learning disorder that specifically causes a lag in written language acquisition of at least 2 years with respect to average performance of the general population. For most researchers in this area, the mechanism responsible for such a learning disorder is a deficit in certain aspects of language processing rooted in

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a constitutional maturational abnormality of the brain structures in charge of language processing (Galaburda et al., 1994). Linguistic research in this field has focused mainly on three areas: phonological awareness (Snowling, 1981; Bruck & Treiman, 1990; Bruck, 1992), naming speed in studies on lexical access (Felton, Naylor, & Wood, 1990; Wolf & Obregon, 1992; Korhonen, 1995), and short-term working memory (Karz, Shankweiler, & Liberman, 1981; Liberman, Mann, Shankweiler, & Werfelman, 1982; Mann & Liberman, 1984). Among the results obtained over the past few years in these different areas, the most convincing findings concern dyslexics' deficiencies in phonemic parsing, assembly, and categorization. The parsing abilities of 8-year-old dyslexics are not as good as those of same-age normal readers. Dyslexics are particularly poor at tasks such as deleting the first phoneme or the onset of a syllable (Morais, Cluytens, & Alegria, 1984; Bruck & Treiman, 1990). At the present time, thus, most authors agree that the core deficit in dyslexia is impaired phonological awareness. Accordingly, it has been repeatedly shown that young children's abilities in awareness and manipulating the phonological structure of language is a prerequisite to learning to read and so is considered an explanation for dyslexia (Bradley & Bryant, 1978; Bryant, Bradley, MacLean, & Crossland, 1989).

From a different perspective, a number of studies have found evidence of a deficit at a perceptual rather than a cognitive level. For instance, several authors have documented impaired categorical perception in dyslexics (Godfrey, Syrdal-Lasky, Millay, & Knox, 1981; Manis et al., 1997; Reed 1989). Such evidence has led some authors to argue for a phonological representation deficiency (Swan & Goswami, 1997), assuming that an impairment in precision of phonological representations should explain, partly, some of the difficulties in phonological processing and in reading displayed by dyslexic children.

Some authors consider this impairment to stem from a more general disorder. Tallal and her collaborators, for example, assume that a temporal processing deficit is the source of the phonological disorder observed in ''language-learning impaired'' (LLI) children (Tallal & Piercy, 1973, 1974, 1975; Tallal et al., 1996; Merzenich et al., 1996). Tallal's work also suggests that these children, including so-called ''disabled reading children'' (Tallal, 1980), have trouble perceiving the rapid, unstable acoustic characteristics of speech and short events such as formant transitions. This observation is at the origin of the famous and much debated theory of rapid auditory temporal processing deficit in dyslexia.

In their initial experiment of 1973 on LLI children, Tallal and Piercy first demonstrated a processing deficit for rapidly presented nonverbal stimuli. Two tones (105 and 305 Hz) of 75 ms duration were heard in pairs varying in interstimulus interval (ISI). When the ISI was long, difficulty processing the phonemes disappeared. Thus the problem appears to be due to event brevity and not to an impaired ability to judge temporal order. Subsequently, Tallal (1980) began to focus more specifically on dyslexic children using a task similar to the one in her initial study. Dyslexics were found to have trouble not only with the discrimination and TOJ of pure tones, but also with the distinction between syllables such as /ba/ and /da/. Moreover, these authors (Tallal & Piercy, 1975) further showed that expanding the transitional element of synthetic syllables (by bringing the formant transition duration from 40 to 100 ms) significantly improved TOJ performance. Based on these results, the authors developed a therapeutic technique involving training in temporal processing. In two often-cited twin articles (Tallal et al., 1996; Merzenich et al., 1996), they convincingly demonstrate that manipulating the temporal characteristics of acoustic stimuli may considerably improve language performances in various developmental speech and/or reading problems.

Tallal et al.'s work triggered a heated debate. The hypothesized temporal processing deficit received mixed reactions. Farmer and Klein (1995), while recognizing the existence of a deficit, claim that methodological differences in the TOJ tests make it difficult to ascribe the poor scores to a temporal processing deficit. Others were more frankly hostile to such a view. McAnally et al. (1997), for example, failed to find an effect of manipulation in time or frequency on phonemic discrimination performance in dyslexics. Studdert-Kennedy and Mody (1995) criticized the results of Tallal's analyses, contending that TOJ errors on two consecutive syllables or tones reflect an impaired ability to identify two similar short stimuli rather than a difficulty judging their order of occurrence. In their opinion, the Tallal experiments assess speech discrimination ability, not a general temporal deficit. Moreover, they view Tallal's TOJ task as a diagnostic tool for detecting discrimination difficulties but, as these authors stated, ''we have no experimental evidence at all for deficits either in auditory temporal perception or in general rate of auditory perception among the reading-impaired'' (Studdert-Kennedy & Mody, 1995, p. 509).

Referring to Tallal and Piercy's results (1974) on LLI subjects, which were partially replicated by Reed (1989) for dyslexic children on the [ba]–[da] TOJ task, Mody et al. (1997) contested the acoustic nature of the problem, thereby rejecting the rapid auditory temporal processing hypothesis. They conducted three experiments which showed that children selected precisely on the basis of their failure on the [ba]–[da] TOJ task did not differ from the controls when (1) the TOJ task was facilitated by the use of easier-to-discriminate syllables, (2) only the acoustic characteristics of the stimuli were retained (by generating their nonspeech equivalents), and (3) the ability to detect short events within syllables was analyzed. The authors used these three arguments to refute the idea that the disorder observed in these children is a general (nonspecific), acoustic (nonphonetic), and more precisely temporal deficit.

In the present article, we were interested in one relatively unexplored aspect of the temporal processing deficit in dyslexics, namely their difficulties dealing with consonant clusters, taken as a special case of deficit in processing the sequential order of short auditory stimuli. Accordingly, educators and therapists in French-speaking countries have long been aware of this behavior of children learning to read and spell, consisting in a tendency to randomly modify the consonant cluster. For example, ''spectacle'' (''show'') becomes ''pestacle,'' ''bras'' (''arm'') becomes ''bar,'' and ''plombage'' (tooth filling) becomes ''pelombage.'' Errors like these are found in the speech of nondyslexic children between the ages of 3 and 5, after which they spontaneously disappear. In dyslexics, however, such errors persist in oral language and are often still present in both reading and writing until the age of 11 to 13.

As a possible explanation of such behavior, some authors assume that dyslexic children are not able to correctly transcribe the order of infrasyllabic constituents. As a result, syllabic complexity (the consonant cluster onset) would account for this type of difficulty. Accordingly, data have been provided showing that the order of the constituents in a syllable with a simple structure (like CVCV) is decoded better than the order of those same constituents in a complex syllabic structure (like CCVCV) (Bruck & Treiman, 1990; Bruck 1992).

The present study was thus designed (a) to determine whether the deficit in dyslexic children lies in an impaired ability to judge the order of events in two different syllabic structures (CCV and CVCV), (b) to explore a possible link between order judgment and event duration in such sequences proposed to dyslexic children and controls, and (c) to investigate the issue of whether evidence of temporal deficit is related with (and may be considered possibly causal to) these children's phonological impairment.

Three experiments were therefore conducted. The first looked at whether judgments of consonant order in a CCV syllable are problematic for dyslexic children. To make sure the difficulty is not related to the complex syllabic structure (consonant cluster onset), the second experiment compared consonant-order decoding in two situations: (1) in a CVC sequence, which is a simple syllable structure with a given total duration, and (2) in a CCV sequence in which the duration of the consonant cluster was lengthened to equal that same duration. Processing is more difficult in the latter case because the syllable is complex, but acoustic processing (segment lengthening) should compensate for this. If event duration is not a critical factor, then dyslexic children should obtain good scores with the simple syllabic structure and have considerable difficulty with the complex, temporally altered syllable. If on the other hand, event duration turns out to be crucial, then we can conclude that syllabic structure is not the only explanation for the order judgment deficit. The third experiment tested the impact of the temporal alteration on consonant order judgments. Improved scores would prove that consonant brevity is indeed a problem for these children and would argue in favor of the general temporal processing deficit theory. Finally, disclosing a correlation between temporal order judgment and performance to classical phonological tasks would add further evidence for such a view.

METHOD

Subjects

The subjects were 13 phonologically dyslexic children (11 boys and 2 girls) ranging in age from 9.8 to 13.7 years and 10 normal readers (boys) ranging in age from 11.5 to 13 years. The dyslexic subjects were attending school in a center specializing in the treatment of dyslexia. They were selected on the basis of the criteria generally used to diagnose phonological dyslexia, namely a normal IQ; no neurological, auditory, or visual disorders of any kind; no attention deficit, and a 2-year lag in reading ability (''Test de l'Alouette,'' P. Lefavrais). The normal reading subjects were attending junior high school and were recruited by means of a questionnaire that made sure the children had no family or personal history of a speech acquisition disorder.

Materials and Procedure

As a preliminary step, the subjects took four phonological awareness tests: rhyme judgments, deletion of first phoneme, dictation of simple syllable nonsense words, and dictation of complex syllable nonsense words.

Then the three event-order judgment experiments were conducted. Given that one of the criticisms of Tallal's studies is her claim that tone processing and syllable transition processing are analogous, only short consecutive events without transitions were used here. The consonant clusters ps and sp were chosen because, unlike the cluster dr, for example, they have the advantage of being noises without formant information and thus without formant transitions. Furthermore, ps and sp are both legal clusters in French, which made it possible to present the stimuli in either order. The clusters were inserted in the vocalic context a-a so as to avoid acoustic artifacts (truncation of the burst in the ps cluster and poor audibility of the [s]). None of the resulting stimuli (apsa, aspa, apəsa, asəpa) were words, so they necessarily activated the phonological channel and avoided lexical access. The stimuli were recorded in an anechoic chamber with a natural male voice and then digitized on a SUN computer.

Experimental Settings

In all three experiments, the stimuli were presented in random order. The subjects heard the stimuli through headphones and had to answer by pressing two designated keys on the computer keyboard in the order they thought they heard the two consonants. To lighten the memory load for the subject, the keyboard was covered in such a way that only the letters P and S were visible.

In the first experiment, consonant order was judged in a CCV syllable. A block of 60 temporally unaltered stimuli was generated (30 aspa and 30 apsa). In the second experiment, the two consonants were altered in two ways. In Block A, both sounds retained their intrinsic duration but they were separated by the neutral French vowel (schwa) so that both stimuli had a simple syllable onset; the total duration of the pəs or səp was 210 ms. In Block B, the two sounds were lengthened to 210 ms but they still formed a single unit; the syllable onset was thus a consonant cluster. The total duration was the same in Blocks A and B. Then the two blocks were combined to form one 120-stimulus block containing 30 aspa, 30 apsa, 30 apəpa, and 30 asəpa. For the third experiment, we generated a block of 60 temporally unaltered stimuli (30 aspa and 30 apsa) and a block of 60 temporally altered stimuli containing 30 aspa and 30 apsa in which the ps (or the sp) was lengthened from its normal duration of 140 ms to twice that length (280 ms).

All three experiments were run on a Macintosh 7200 computer using Psyscope software.

RESULTS

Experimental Tasks

Experiment 1: Event Order Judgment in a CCV structure. The difference between the two groups was highly significant (one-way ANOVA: $F = 22.082$, $p = .0001$) confirming previous evidence that dyslexic children exhibit a specific deficit in judging of the order of two stimuli. Moreover, it appears that this deficit is also present for consonant order judgment, even for those consonants which are phonetically very different ([p] and [s] differing by more than one phonetic feature).

Experiment 2: Comparison of Event Order Judgments in a simplified syllabic structure and duration-equated complex syllabic structure. In this experiment, we explored the effect of increasing the interstimulus interval by the interposition of the neutral vowel, as opposed to the original CCV structure extended to the overall same duration. For both controls and dyslexics, a two-factor ANOVA (subject group and alteration mode) yielded a nonsignificant difference between the two tasks (alteration: $F = .929$, $p = .3404$; alteration $\times$ group interaction: $F = 1.129$, $p = .2939$).

Thus, discriminating two consecutive consonants in a simple (VCVCV) syllabic structure appears to be just as difficult for dyslexics as in a complex (VCCV) syllabic structure. Since the two conditions were otherwise equal in stimuli duration, the possible facilitatory or inhibitory effect of a longer processing time can be ruled out (see Figs. 1–3).

Experiment 3: Effect of Lengthening on Event Order Judgments. Here, we tried to compare the effect of lengthening the consonant duration on event order judgment.

The subject group $\times$ lengthening interaction was significant (two-factor ANOVA: interaction: $F = 5.46$, $p = .0243$). Thus, lengthening appears to improve consonant

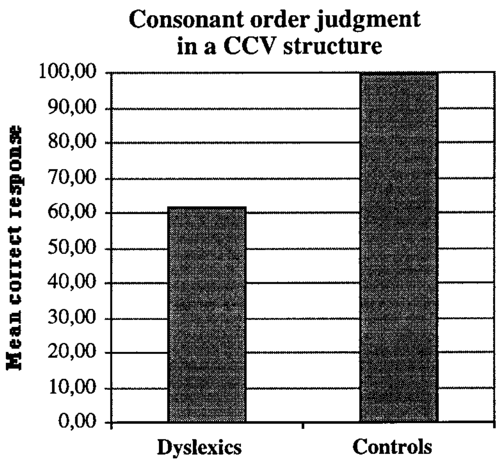


FIG. 1. Comparison of performance on a temporal order judgment (TOJ) task using consonant clusters /sp/ and /ps/ between dyslexics and controls showing significant impairment in the former group.

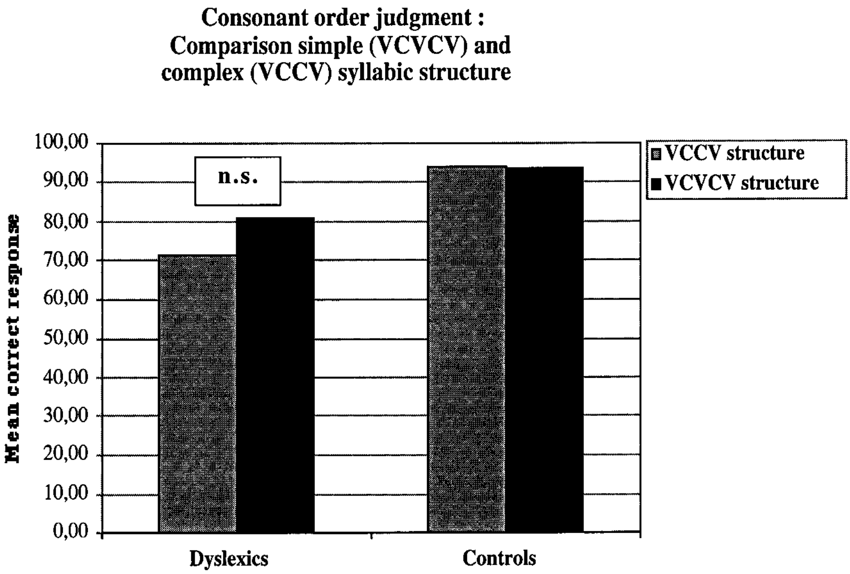


FIG. 2. Comparison of two conditions of increasing syllabic complexity of the same task as in Fig. 1. Dyslexics' performance is not significantly improved by reducing syllabic complexity.

order judgments in phonologically dyslexic children. Consequently, consonant brevity does indeed account for their poor order judgment scores.

Phonological Awareness Tests

The results for dyslexics and controls were significantly different on the four phonological awareness tests (ANOVA: $27.7 \leq F \leq 108.965$, $p < .01$, for the four tests).

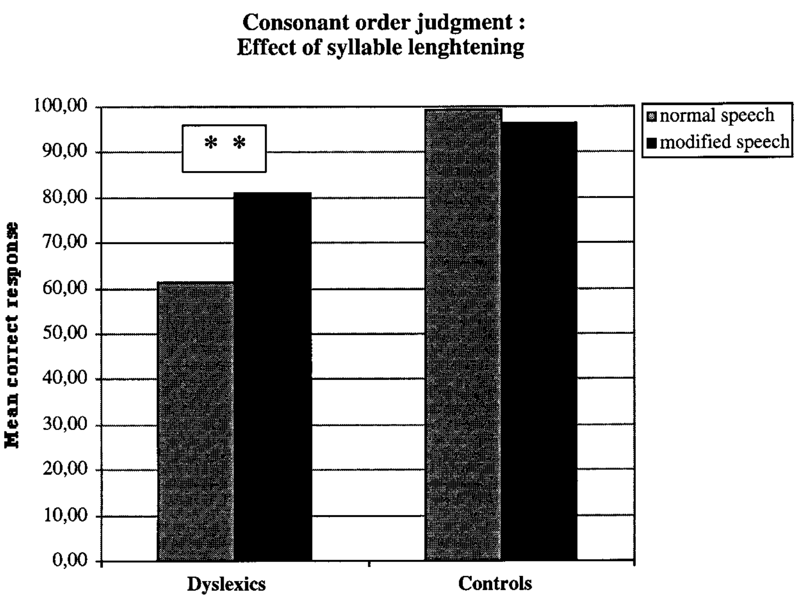


FIG. 3. Comparison of two conditions of temporal processing difficulty of the same task as in Fig. 1. Dyslexics' performance is significantly improved by lengthening of stimulus duration.

TABLE 1
Results of Phonological Awareness Tests in Phonological Dyslexics

Dyslexics	Rhyme judgment	First phoneme deletion	Simple nonword dictation	Complex nonword dictation
Mean correct (%)	81.08	52.15	42.00	26.62
Standard deviation	10.57	22.85	26.33	22.74

Furthermore, in the dyslexics, the complex nonsense words (CCVCV syllable) were much more difficult to write than the simple ones (CVCV syllable). The large standard deviations obtained here further demonstrate the high degree of heterogeneity among phonologically dyslexic children (see Tables 1 and 2).

Correlation with Phonological Processes

Rank correlations were performed between the rate of correct responses on each condition explored in the TOJ experiment and each of the four above-reported tasks. Of those, only phoneme deletion and nonword spelling to dictation were found correlated to TOJ performance (first pheneme deletion/normal CCV order judgment: r = .644: p = .0175; simple and complex nonword spelling/temporally modified CCV structure: r = .564: p = .0448).

DISCUSSION

The present article takes place within the current debate on the nature of the phonological deficit observed in the large majority of dyslexic children. Results are globally consistent with the general ''temporal processing deficit'' hypothesis first proposed by Tallal and coworkers (Tallal & Piercy, 1973; Tallal, 1980; Tallal, Miller, & Fitch, 1995; Tallal et al., 1997). Moreover, and as a cosequence, they also lend support to the use of lengthened acoustic stimuli for training children with such phonological deficits (Tallal et al., 1996; Merzenich et al., 1996; Habib et al., 1999).

Several authors, however, based on results obtained from different lines of research, have overtly criticized such a view and consequently questioned the usefulness of temporally based remediation methods.

As stated above, the most radical objections to the temporal processing deficit theory have come from the Studdert-Kennedy group (Studdert-Kennedy & Mody, 1995; Mody, Studdert-Kennedy, & Brady, 1997; see also Nittrouer, 1999).

Results from our first experiment do not confirm Mody et al.'s (1997) claim that it is because of the phonetic similarity of the stimuli that dyslexics fail in temporal

TABLE 2
Results of Phonological Awareness Tests in Control

Controls	Rhyme judgment	First phoneme deletion	Simple nonword dictation	Complex nonword dictation
Mean correct (%)	98.18	96.46	99.55	98.18
Standard deviation	2.09	2.81	1.61	1.62

order judgment tasks. As an argument for this assumption, these authors showed that a group of poor readers perform as well as controls on a TOJ task with two more discriminable pairs (/ba/ /sa/) (/da/ /ʃa/) which differ, within each pair, from more than one acoustic trait, whereas the same children performed significantly below normals in a similar task where the two elements of the pair were acoustically more similar (/ba–da/). In addition to the fact that such negative inference may require stronger statistical power (see Denenberg, 1999, for a thorough methodological discussion of this article), our data also stand at variance from such conclusions (see also Appendix 1).

Actually, if this were true, then the TOJ task performance of our dyslexics would have been normal here, since, although the stimuli we have used are as phonetically different as those used in Mody et al. (1997), the dyslexics performed significantly below normal controls. How to explain then such discrepant results? Perceiving the immediate succession of two consonants is certainly more difficult than perceiving two consecutive syllables. Thus, Mody et al.'s task may have been too easy for the TOJ deficit to show up.

This initial finding already suggests that there is a link between TOJ and event duration. However, a causal relation cannot be drawn from this preliminary result because syllabic complexity, not event brevity, may have resulted in poor TOJ performance.

The second experiment provided evidence of deficit consonant order judgments in dyslexics, regardless of syllabic structure, since their scores were lower than those of the controls both when the two consonants occurred consecutively in the syllabic onset and when they were separated by a vowel. The difference cannot be ascribed to total stimulus duration, since the overall duration was the same in both conditions. Syllabic complexity therefore does not account for the order judgment deficit in these dyslexic children. As is discussed below, it is conceivable that the usual difficulties experienced by dyslexic children when faced with successions of consonants are due to the fact that they are basically inapt to process sequential stimuli, especially when these stimuli are short, such as consonants. In this context it would not be a surprise to find the more salient errors in such difficult tasks as nonword phoneme–grapheme transcription, where consonantic clusters are sometimes systematically faulty. Accordingly, preliminary results our group have obtained with a temporally based training method in phonological dyslexics (Habib et al., 1999) have been especially significant on children's performance on nonword dictation tasks.

It is worthy of note, in this second experiment, that inserting a neutral vowel between the two consonant stimuli has been of no benefit to dyslexic children as to their TOJ performance. This can be seen as contradictory from previous claims that the difficulty dyslexics experience in ordering two successive events depends both on their brevity and their rapid succession (Tallal, 1980; Farmer & Klein, 1995; Tallal, Miller, & Fitch, 1995; Tallal et al., 1997). On the contrary, one must admit here that rapid succession is not the main factor explaining dyslexics' failure in apprehending the succession of two consonants.

Results from the third experiment are obviously central to the notion of temporal processing disorder since, in order to explore the link between the duration of events and the judgment of their order, the consonants were systematically lengthened by a constant factor or 200%. The results support the contention that short consonants indeed pose a significant and specific problem to dyslexics, since such temporal stretching was the only condition able to revert the dyslexics' deficit.

In their study of 15 dyslexic boys compared to 15 nondyslexic controls taken from the same school (mean age: 15;2), McAnally et al. (1997) tested the influence of artificially stretching synthetized CVC stimuli on the performance of these children at discriminating between 11 different CVC syllables. Contrary to the present work, there was no complex syllabic structure and words only included stop consonants. Moreover, in addition to time-stretched stimuli, these authors also used a compressed form of the stimuli. Although dyslexics tended to perform poorly compared to controls, this deficit was found independent of the time characteristics of the stimuli. These authors conclude that ''limited exposure of children with dyslexic to time-stretched synthetic CVC syllables did not improve their ability to identify the stimuli correctly.'' Moreover, observing that the above-cited temporally based remediation methods had involved both slowing the acoustic signal and enhancing some specific frequencies, they stated that ''if long-term exposure to acoustically modified speech had been responsible for improving speech perception, it is unclear whether this is related to time expansion or amplitude modulation.''

Our results bring further elements to this discussion. First, they suggest that if the measured variable is a judgment of order rather than a simple discrimination task, the temporal modification may become significantly efficient, since temporal modification of our acousic material was pure and devoid of any other kind of acoustic alteration. Second, our data are also consistent with the notion that two apparently distinct temporal dimensions of speech perception, stimulus duration and temporal order of these stimuli, are cognitively and probably neurobiologically linked, since manipulating one of them (the stimulus duration) influences the other (order judgment). In our opinion, therefore, it is the additive effect of dyslexics' difficulties perceiving short temporal events together with the cognitive demand of a judgment of order task that allows the deficit to emerge. Consistent with this view is recent electrophysiological work by Bradlow et al. (1999) showing that the mismatch negativity (MMN) response to a discrimination task (along a /da–ga/ continuum), which is more poorly evidenced by dyslexic than normal children, is restored if the stimuli are lengthened in such a way that the transition duration is increased from 40 to 80 ms. Indeed, despite such electrophysiological evidence, no similar effect was observed when comparing the behavioral performance of dyslexic children on a discrimination task using unmodified or lengthened material.

Finally an important consideration concerns the possible link between temporal processing deficit and phonological deficit in dyslexics. In her initial study of temporal order judgment in dyslexics, Tallal (1980) claimed that these children temporal deficit was correlated to their performance on a phonological task (more temporal processing deficit in the more phonologically impaired children). Others, however, have failed to disclose similar proportionality between the two kinds of measurements. For instance, Schultze-Körne et al. (1998) failed to disclose any relationship between spelling abilities and a gap detection task taken as an index of auditory temporal processing. Watson and Miller (1993) reported that nonverbal temporal processing was not correlated to any of the phonological variables they had investigated. More recently, however, Helenius et al. (1999) have found a clear deficit in dyslexics on a ''stream segregation task'' involving the auditory perceptual discrimination in a succession of two alternating tones. Moreover, this deficit was strongly correlated to a naming speed task, supposed to rely on phonological processes. Finally, Heath et al. (1999) make a case for oral language deficits as the crucial factor in the postulated link between temporal processing and phonological deficit in dyslexia. Specifically, they found that only those dyslexics with significant oral language deficit history may show a deficit in a nonverbal sequencing task and that performance to this task is not correlated to nonword reading performance taken as an index of phonological abilities. In our experience, however, an overwhelming majority of children with severe phonological deficit may be found to have more or less clear history of oral language deficit and/or delay, so that selecting phonological dyslexics without significant oral language deficit may be quite artificial and misleading.

More deleterious to the temporal processing hypothesis are results from a study by Nittrouer (1999). Among several tasks this author has carried out for testing the validity of a link between temporal processing and phonological deficit, a nonverbal sequencing task adapted from Tallal et al.'s (1980) and a ''stop closure detection'' task using a discrimination between words /say/ and /stay/ are relevant to the present study. None of these tasks was found significantly impaired in otherwise severely phonologically affected children. From such results, the author concludes that ''. . . no evidence was found that the children with poor phonological processing abilities had temporal processing deficits. Consequently, we must answer the question posed in the title of this article (Do temporal processing deficits cause phonological processing problems?) with a clear *no*.'' (p. 937).

The present results obviously militate in the opposite direction (see also Appendix 1). In our study, both dyslexics and normal controls received a systematic assessment of phonological abilities. As expected, the dyslexics' performance was significantly inferior to that of controls, despite a wider range of performance reflected in much larger standard deviations in the dyslexic group. Of special interest is the observation that nonword spelling on dictation is particularly impaired compared to controls. Indeed, this task requires the integrity of several cognitive domains known to be affected in dyslexics, syllabic and phonemic parsing, phoneme to grapheme conversion, phoneme discrimination and representation, as well as short term auditory memory for verbal material. It is worthy of note that dyslexics' individual performance to these phonological tasks was positively correlated to their performance on the temporal order judgment, but only for the CCV conditions (normal or slowed), not with the simpler syllabic structure. This suggests that the phonological awareness impairment usually emphasized as a crucial symptom in dyslexics may itself result, at least in part, from a more elementary deficit in order judgment of short events and depend on the brevity of these events more than on their sucession. That only the lengthened condition correlated with nonword spelling tasks further suggests that among the multiple phonetics, linguistic, and cognitive determinants of spelling performance, at least some of them are sensitive to the temporal features of human speech.

Taken together, our results support the current endeavor toward the use of temporally modified speech in training programs proposed to dyslexic children. For all that, this does not mean that the exact mechanisms of the improvement obtained with these methods have yet been elucidated. For example, beyond the mere link, demonstrated here, between consonant order judgments and consonant brevity; it would be of great value to assess the extent of the dyslexic impairment in the perception of duration itself. From another point of view, neuroimaging and neurophysiological methods could usefully complement behavioral data presented here by demonstrating the temporal and spatial characteristics of the underlying brain mechanisms. Finally, future research on phonological deficit in dyslexia will hopefully combine perceptual investigations in several modalities, including visual stimuli, whose impairments may parallel those demonstrated here (Talcott et al., 2000), along with studies exploring motor aspects of the temporal deficit (Nicolson et al., 1999).

APPENDIX 1

Methodological consideration: most authors whose work on the subject of temporal processing has yielded negative results have obtained their dyslexic and control subjects from the same global initial population, a posteriori distinguishing between the two groups according to criteria of good or poor performance in reading. To our opinion, this mode of selection actually represents the worst way to do since it maximizes the representation of nonbiological (cultural and environmental) factors, thus artificially selecting a subgroup of dyslexics more prone to be etiologically heterogeneous. On the contrary, selecting dyslexics in clinical populations, at best from centers accustomed to neuropsychological diagnosis, guarantees that the research only deals with pure dyslexics; most often with a familial history of learning disorders; more or less obvious delay in oral language acquisition; and more optionally problems in laterality, motor coordination, and/or temporal organization disturbance (Habib, in press).

APPENDIX 2

Content of Phonological Assessment

Auditory Rhyme Judgment

Instruction: Do the two words sound the same?

Plante–Gomme
Rouleau–Ballot
Terre–Guerre
Voiture–Barrette
Vis–Gris
Grand–Lent
Fusil–Chenil
Chapeau–Cadeau

Nez–Baie
Fruit–Balle
Arbre–Mer
Murette–Boulette
Croc–Choc
Chaud–Pot
Sas–Bas
Ballon–Coton

Pompier–Soulier
Troc–Phoque
Mille–Bille
Gâteau–Auto
Clou–Frein
Main–Pain
Cadeau–Matin
Tabac–Hamac

APPENDIX 2 (*continued*)

Syllabic Segmentation

Instruction: Omit the second syllable and speak out the resulting nonword

Ex: per**ro**quet (/ peʀɔkɛ / ⇒ / pe-kɛ /)

Target word	Syllable 2	Resulting nonword
télévision	lé	té-vision
automobile	to	au-mobile
samaritain	ma	sa-ritain
allocation	lo	a-cation
mathématique	thé	ma-matique
alimentaire	li	a-mentaire
majorité	jo	ma-rité
photocopie	to	pho-copie
scandaliser	da	scan-liser
affectation	fec	a-tation
problématique	blé	pro-matique
exposition	po	ex-sition
perturbation	tur	per-bation
aventurier	ven	a-turier
neurologie	ro	neu-logie
résolution	so	ré-lution
catégorie	té	ca-gorie
cultivateur	ti	cul-vateur

Phonemic Segmentation

Instruction: Omit the first sound and speak out the remaining part

Ex: **ai**mant ⇒ -mant; **p**rise ⇒ -rise; **s**top ⇒ -top; **c**ol ⇒ -ol

Target word	First phoneme	Remaining part
amande	a	-mande
maison	m	-aison
cravate	c	-ravate
statue	s	-tatue
oreille	o	-reille
lampe	l	-ampe
poule	p	-oule
flèche	f	-lèche
slip	s	-lip
aigle	ai	-gle
jambe	j	-ambe
table	t	-able
dresser	d	-resser
ampoule	am	-poule
skieur	s	-kieur
outil	ou	-til
spécial	s	-pécial
éponge	é	-ponge
cloche	c	-loche
slogan	s	-logan
plat	p	-lat
image	i	-mage
fromage	f	-romage
snob	s	-nob
indien	in	-dien
dimanche	d	-imanche

APPENDIX 2 (*continued*)

Ex: **ai**mant ⇒ -mant; **p**rise ⇒ -rise; **s**top ⇒ -top; **c**ol ⇒ -ol

Target word	First phoneme	Remaining part
scorpion	s	-corpion
brise	b	-rise
coccinelle	c	-occinelle
unité	u	-nité
enfant	en	-fant
glace	g	-lace
stylo	s	-tylo
score	s	-core
caisse	c	-aisse
soupe	s	-oupe
travail	t	-ravail
prune	p	-rune
sport	s	-port

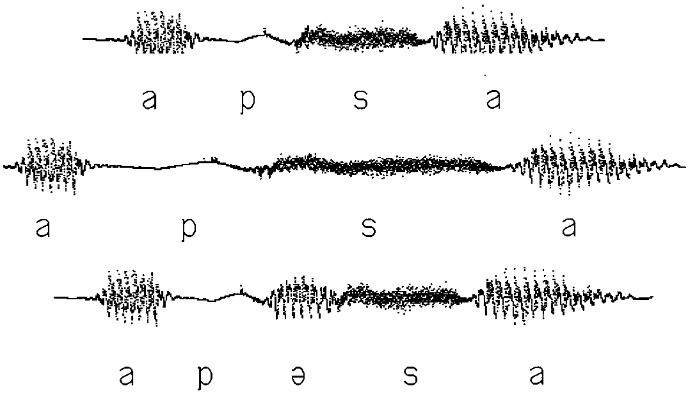
Nonwork Spelling to Dictation

claptine
strupode
flurpel
drosibe
cromitre
framible
spongar
bascure
groubac
glutral
captile
brocrin
scotule
vrindon
clutron
victeur
carpute
factime
charple
repture
mercule
forsule
bordage
forbone
disface
surgeur
larmule
trolure
cordure
docture

APPENDIX 3

Oscillograms Corresponding to the Three Different Forms of the Stimulus / apsa /

Top: normal speech
Middle: extended by 166%
Bottom: normal with neutral vowel /ə/ interposition



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