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How do consonant feature values affect the processing of a CVCV structure? Evidence from a reading task¹

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Abstract

This paper discusses one experiment on French which shows that distinctive phonological feature similarity between consonants influences the processing of a C₁VC₂V pseudo-word during a high demanding reading task. Participants made more errors in recalling the voicing of C₂ (but not C₁) when C₁ and C₂ disagreed in voicing than when they agreed, a pattern reminiscent of progressive harmony. A similar trend was found for manner similarity. This study confirms that sub-phonemic information about voicing is extracted rapidly in reading and can cause early phonetic priming. The elaboration of lateral inhibitory relations between phoneme detectors during reading acquisition can serve to counter errors from this early phonetic priming .

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1. Introduction

A great deal of research has provided evidence for the involvement of phonological knowledge in printed word identification (for reviews, see Berent & Perfetti 1995; Frost 1998) and several models assume that it participates in this process (Bosman & Van Orden 1997; Coltheart, Rastle, Perry, Langdon & Ziegler 2001; Van Orden 1987; Van Orden, Jansen op de Haar & Bosman 1997). Many experimental results emphasize the role of sub-lexical phonological units in written word recognition, even in adult good readers. For instance, orthographic-phonological regularity effects occur in lexical decision tasks, although the task lists include many pseudo-homophones to discourage the involvement of phonology (Gibbs & Van Orden 1998). In addition, recent evidence for a phonological repair effect in print processing (*e.g.*, false detection of the letter “a” before the pseudo-word “*stuto*” in native speakers of Spanish) argues for the mandatory status of phonological processes (Hallé, Dominguez, Cuetos & Segui 2008). Furthermore, homophony has been shown to increase error rates in semantic relatedness decisions (Luo, Johnson & Gallo 1998), in semantic categorisation (Van Orden 1987; Peter & Turvey 1994), in semantic relatedness judgements (Lesch & Pollatsek 1998), and in proofreading (Bosman & de Groot 1996; Sparrow & Mielliet 2002). In French, performance improves if the printed target is preceded by a homophone of a semantically related word in a lexical decision task, provided that a brief SOA (100 ms) is used (Bedoin 1995), as is the case in naming in English (Lesch & Pollatsek 1993; Lukatela, Lukatela & Turvey 1993; Lukatela & Turvey 1991). Moreover, improved performance has been recorded in the case of prime-target phonological similarity in Serbo-Croatian, Chinese, Dutch, English, and French (Berent 1997; Brysbaert 2001; Ferrand & Grainger 1992; Grainger & Ferrand 1996; Lukatela & Turvey 1994; Perfetti & Bell 1991; Perfetti & Zhang 1991; Rayner, Sereno, Lesch & Pollatsek 1995). However, phonological effects have rarely been studied at the sub-phonemic level in reading.

Yet, in speech perception, phonetic features have been shown to influence lexical access. For instance, while the lexical advantage classically observed for phoneme monitoring decreases if the target is embodied within a pseudo-word differing from a word by one phonetic feature, it completely disappears if the pseudo-word differs by additional features (Connine, Titone, Delman & Blasko 1997). Similarly, a spoken prime, which only differs by one phoneme from a word semantically related to the target, produces a facilitatory semantic priming effect only if this difference does not exceed two phonetic features (Milberg, Blumstein & Dworetzky 1988; Connine, Blasko & Titone 1993; Marslen-Wilson, Moss & van Halen 1996). Ernestus and Mak (2004) found a similar effect in Dutch for spoken and written word recognition. When directly assessed with primes and targets which share phonetic features but no entire phoneme, a high phonetic similarity impairs the processing of the target (Goldinger, Luce & Pisoni 1989; Goldinger, Luce, Pisoni & Marcario 1992). Inhibitory effects of phonetic similarity have also been recorded in speech production, with increased latencies if the onset of the visual prime and target shared phonetic features (Rogers & Storkel 1998).

As far as reading is concerned, a range of results, which cannot be accounted for by phonemic decoding only, suggests that the phonological code involved in lexical access is fine enough to entail feature-based representations (Connine, Blasko & Titone 1993; Marslen-Wilson, Moss & van Halen 1996). However, in priming experiments, the phonetic feature overlap between the printed prime and target provides a pattern of effects which is rather complex.

On the one hand, an important phonetic overlap between prime and target sometimes results in a facilitatory effect. For example, in English, Lukatela, Eaton, Lee, and Turvey (2001) displayed two kinds of printed pseudo-word primes before a riming target and used a brief SOA (57 ms). In the high phonetic-similarity condition, the prime and the target differed

only by voicing (*e.g.*, ZEA - sea), while in the low phonetic-similarity condition they differed by two or more phonetic features (*e.g.*, VEA – sea). Response times in the lexical decision task were shorter when prime and target differed only by one phonetic feature. A pattern of facilitatory priming effect has also been observed in two priming experiments in French, using a very brief presentation time (33 ms) for the prime, which was immediately replaced with the target (Bedoin & Krifi, to appear). In one experiment, shorter lexical decision latencies have been recorded when prime and target shared both place and manner, rather than place only, a facilitatory priming effect which argues for the readers' sensitivity to manner similarity. In the other experiment, shorter response times were recorded when prime and target shared voicing and place or voicing and manner, rather than only voicing, a pattern of facilitatory priming which may reflect the subjects' sensitivity to manner and to place similarity in reading. Taken together, with a very short SOA, sub-phonemic prime-target similarity appears to increase performance in lexical decision tasks, at least when manner or place similarity are manipulated.

The observation of a phonetic similarity effect at such an early stage of print processing is intriguing, because prime-target experiments usually fail to produce any phonological priming effect at prime exposures shorter than 45 ms (Perfetti & Bell 1991), or 43 ms (Grainger & Ferrand 1996). However, some studies have shown phonological priming effects using presentation times as brief as 29-30 ms (Booth, McWhinney & Perfetti 1999; Lukatela, Frost & Turvey 1998). Additionally, it cannot be excluded that sub-phonemic similarity effects could occur before the usually assessed phonemic effects.

To account for the facilitatory phonetic priming observed by using a very short SOA, a between-level mechanism can be described in the context of an interactive-activation model (McClelland & Rumelhart 1981), assuming separate levels of representation for features, phonemes, and words. In reading, activation may spread from one letter to phoneme

candidates, and then to their constituent phonetic features. These phonetic features may in turn reinforce the activation of the set of phonemes with which they are compatible. Therefore, in the case of the successive processing of two letters (and phonemes) which share many phonetic features, the identification of the second letter may be improved. This mechanism may be reflected by the facilitatory phonetic priming effect observed in reading experiments using short SOAs.

On the other hand, a negative impact of phonetic feature overlap has been recorded in priming experiments using a 66 ms SOA in French (Bedoin & Krifi, to appear). Contrary to results obtained with a shorter SOA, response latencies (and error rates) increased in the case of voicing and manner similarity, as compared to the voicing similarity condition. The error rate also increased in the case of voicing and place similarity, as compared to the voicing similarity condition. In addition, longer response times were recorded in the case of both place and manner similarity than in the case of only manner similarity. The latter effect was confirmed with a 100 ms SOA. Such inhibitory phonetic priming effects have also been observed when prime and target, which basically differed by one phonetic feature (either place or manner), shared the same value for the voicing feature. For instance, lower performance was observed for the prime-target pair *don-BON* ([dɔ̃]-[bɔ̃]), than for *ton-BON* ([tɔ̃]-[bɔ̃]) (Bedoin 1998; Bedoin & Chavand 2000). This effect may reflect the negative impact of voicing similarity in print processing. Surprisingly, it occurred not only with a 66 ms SOA and a 100 ms SOAs, but also with a 33 ms SOA (at least, in adult skilled readers).

Furthermore, this inhibitory effect of voicing similarity has been replicated in an experiment assessing the impact of phonetic feature similarity between the consonants of a single C₁VC₂V pseudo-word. The subjects had to silently read the pseudo-word, which was displayed for 50 ms, and immediately replaced with a visual mask (17 ms). Then, a letter appeared below and the reader decided if it was present or not in the pseudo-word. In adult

skilled readers, performance in C₂ identification decreased when C₁ and C₂ shared the same voicing value (Bedoin 2003; Krifi, Bedoin & Mérigot 2003), or the same manner value (Bedoin & Krifi 2008), which mimicked the inhibitory phonetic priming effect previously obtained between stimuli. Finally, we replicated this negative effect of voicing similarity in children (third and fifth graders) who had a normal reading level. Surprisingly, second graders and dyslexic children exhibited a facilitatory voicing similarity effect for the identification of C₂. This suggested that the facilitatory phonetic priming effect is provided by a long-standing mechanism, whereas the inhibitory phonetic priming effect observed in skilled readers is determined by a secondary mechanism, associated with good reading skills. Additionally, the mechanism allowing inhibitory phonetic priming to occur in reading seemed to have a slower time course than the mechanism allowing facilitatory phonetic priming, at least in the case of manner or place similarity.

The negative impact of shared phonetic features observed in these previous experiments, mainly with a 66 ms or a 100 ms SOA, is in line with inhibitory phonetic priming effects reported in speech processing (Goldinger, Luce & Pisoni 1989; Goldinger, Luce, Pisoni & Marcario 1992). The authors interpreted such effects in the context of the neighbourhood activation model of word recognition (Luce, Pisoni & Goldinger 1990), and explained inhibition as competition among phonetically similar words in memory. However, the inhibitory phonetic similarity effect that we observed when phonetic similarity was manipulated between the consonants of a CVCV pseudo-word cannot be easily accommodated within this framework. Therefore, we favour the interactive activation model (McClelland & Rumelhart 1981) as a potential framework to account for our results, a possibility suggested but not further detailed by Goldinger, Luce, Pisoni, and Marcario (1992). In such a model, excitatory activation is passed between separate levels of representation for features, phonemes and words, which could account for the facilitatory

phonetic priming effects observed in the case of very brief presentation times. But this model also posits inhibitory within-level lateral connections. Consequently, the recognition of the first consonant in a printed CVCV pseudo-word could lead to the suppression of phoneme competitors. Our assumption is that, in skilled readers, the weight of lateral inhibitory connections among phonemes is modulated by the phonetic overlap: the higher the number of shared phonetic features, the stronger the lateral inhibitory connection between phonemes (Bedoin 2003). This mechanism could account for the pattern of inhibitory effects in the case of high phonetic similarity. We also suppose that it is completed later than the mechanism based on excitatory connections between levels.

In the present research, we firstly aim at providing new evidence for the early mechanism based on between-level connections, which is assumed to provide a pattern of facilitatory priming. Until now, evidence for this mechanism has been obtained regarding voicing similarity effects only in very young readers and in dyslexic children (Bedoin & Krifi 2008), but not in adult skilled readers. We propose an experimental design that potentially highlights this early mechanism, by disturbing the course of the secondary mechanism based on inhibitory connections. We expect to preclude the involvement of the second mechanism (based on lateral inhibitory connections) by using not only a very brief SOA, but also a high demanding task. Therefore, we manipulate the voicing and manner similarity of the consonants in a C₁VC₂V target displayed for 33 ms (*i.e.*, near the perception threshold). This target is masked and the reader has to pronounce either C₁V or C₂V. We expect better performance for C₂V recall in the case of voicing similarity or manner similarity.

Secondly, we address the function of the assumed system of lateral inhibitory connections modulated by phonetic overlap between phonemes. According to previous results, this sophisticated aspect of phonological representations emerges from reading acquisition (Krifi, Bedoin & Mériqot 2003; Bedoin & Krifi 2008). We assume that it builds

up in order to counter reading errors that are due to the facilitatory priming mechanism. Paradoxically, by favouring the successive activation of phonetically similar phonemes, the facilitatory priming mechanism may indeed introduce a bias, which can result in reading errors. For instance, in a C_1VC_2V target containing two phonetically similar consonants, there could be a tendency to erroneously extend the phonetic features of C_1 to C_2 , as observed in progressive harmony. In linguistics, harmony phenomena have been described as quite frequent for vowels. Consonant harmony is not uncommon, although less frequent (Hansson 2001). In language acquisition, consonant harmony is a well-established phenomenon (Rose 2001; dos Santos 2007; Pater & Werle 2003; Fikkert & Levelt, in press). If an analogy can be made between harmony phenomena and the facilitatory priming effect occurring in reading, the elaboration of strong lateral inhibitory connections between similar consonants can be viewed as an efficient device to prevent reading errors.

In the context of this interpretation, the present research aims at providing evidence for a paradoxical negative impact of facilitatory phonetic priming, as a source of errors in phoneme identification in reading. By using a task which requires subjects to read one syllable of a printed C_1VC_2V pseudo-word aloud, a qualitative analysis of errors is possible. Among errors in C_2 recall, we expect a higher proportion of responses that do not preserve the voicing value of C_2 , when C_1 and C_2 have different voicing values, because of an extension of the C_1 voicing value to C_2 (*i.e.*, consonant harmony). Similarly, we expect more errors in which the manner value of C_2 is inaccurate, when C_1 and C_2 have different manner values. As a first attempt to assess these effects with a new task, our experiment does not provide an exhaustive investigation of sub-phonemic similarity effects for every phonetic feature type. We choose to test only the effects of voicing and manner similarity, because both types of features can be assessed through two feature values (*i.e.*, voiceless consonants can be pitted against voiced ones, and stop consonants against fricative ones), whereas three values of place

are represented in our list of consonants. Therefore, place similarity effects are not directly investigated here, but the similarity of consonants regarding this feature has been controlled between experimental conditions.

2. Experiment

Participants

We tested 24 Lyon University students, 15 female and 9 male (mean age = 30.4 years; SD = 5.4 years). All subjects were skilled readers and native French speakers; they had normal or corrected-to-normal vision and were right-handed according to the Edinburgh test (Oldfield 1971).

1.1. Material

The experimental list contained 296 stimuli (see Appendix A), which were either a printed C₁VC₂V pseudo-word or one single printed syllable. Twelve consonants² were used to create the items, and they were distributed into 3 categories for place: category 1 contained /p, b, f, v/, category 2 contained /t, d, s, z/, category 3 contained /k, g, ʃ, ʒ/. The only vowel that we used was /y/ (printed *u* in French). The list was divided into 4 blocks punctuated with rests: in 2 blocks, the participant had to recall the first syllable, in the two other blocks he had to recall the second one.

In the two blocks where C₁V was the target (*Rank 1*), we proposed 4 experimental conditions. In the *Rank 1 – isolation* condition, the syllable *pu*, [py] was presented as a single syllable *pu--*. In the *Rank 1 – voicing and manner similarity* condition, the C₁V target syllable shared voicing and manner with the following C₂V syllable (e.g., *putu* [pyty]). In the *Rank 1 – manner similarity* condition, the C₁V target shared only the manner value with C₂V (e.g.,

² These twelve consonants represent the whole set of obstruents available in the French consonant system.

pudu [pydy]). In the *Rank 1 – voicing similarity* condition, the C₁V target only shared the voicing value with C₂V (e.g., *pussu* [pysy]).

In the two blocks where the target was the second syllable (*Rank 2*), we also proposed the same 4 experimental conditions: *Rank 2 – isolation* condition (e.g., *--pu* [py]); *Rank 2 – voicing and manner similarity* condition (e.g., *tupu* [tupy]); *Rank 2 – manner similarity* condition (e.g., *dupu* [dypy]); *Rank 2 – voicing similarity* condition (e.g., *supu* [sypy]).

2.3. Procedure

Each participant was tested individually and sat in front of a Macintosh iBook, at a distance of 57 cm from the screen. Each trial began with a 1500 ms fixation dot, then the lower-cased printed stimulus covering 2° of visual angle was displayed for 33 ms. It was replaced immediately with a 17 ms visual mask (XXXXXX), and the participant had to pronounce C₁V in two blocks or C₂V in the two other blocks. Oral responses were recorded. Because the task is very difficult, participants performed it at first on a practice block, until they reached at least 50% accuracy before beginning the experiment. If a participant did not reach 50% accuracy after three practice blocks, the participant was not retained for the experiment (11.11% of the subjects). The order of the blocks varied systematically between the participants.

2.4. Results

A general repeated measures analysis of variance was conducted on error rates, with two intra-individual factors: Target Position (C₁V, C₂V), and Sub-phonemic Similarity (*isolation; voicing and manner similarity; manner similarity; voicing similarity*). Responses were more accurate for the recall of the first syllable, $F(1, 23) = 26.39$, $p = .0001$, which suggests that syllables have been processed sequentially, as has already been shown for pseudo-word reading in French (Juphard, Carbonnel, Ans & Valdois 2006). We also observed a Target

Position \times Sub-phonemic Similarity interaction, $F(3, 69) = 7.48, p = .0002$. As shown in Figure 1, no significant effect of sub-phonemic similarity occurred for C_1V recall. On the contrary, regarding C_2V target identification, the presence of a preceding syllable had a negative impact. Fewer errors were made when C_2V was presented in isolation than when it was located to the right side of another CV syllable. This effect was significant when the two consonants C_1 and C_2 shared both manner and voicing, $F(1,69) = 15.72, p = .0002$, or only manner, $F(1,69) = 29.61, p = .0001$, or only voicing, $F(1,69) = 21.29, p = .0001$. However, in line with our hypothesis, response accuracy was better on C_2V , if C_2 shared both manner and voicing with C_1 , rather than only manner. Unfortunately, this comparison did not reach significance, $F(1,69) = 2.18, p = .14$.

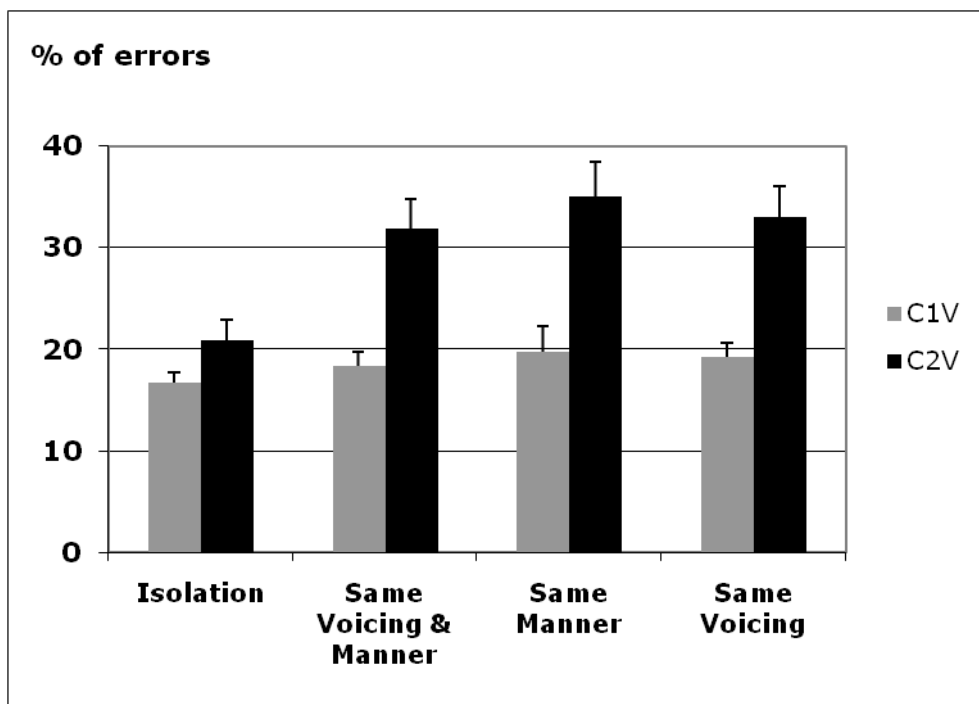


Figure 1: Mean percentages of errors in the production of the target syllable (C_1V or C_2V), depending on the relation between those consonants. Error bars represent standard errors.

Two other analyses tested whether there was a consonant-harmony-like trend towards extending voicing and/or manner values from C_1 to C_2 . A first analysis assessed the percentage of inaccurate responses that preserved the voicing value of the target. The Target Position \times

Sub-phonemic Similarity interaction was significant, $F(2, 46) = 3.02, p = .05$. Among errors made for CV₂ recall, the percentage of responses which preserved the voicing value of C₂ was higher in the case of voicing similarity with C₁ than in the case of voicing difference with C₁, $F(1, 46) = 4.33, p = .0432$ ($\eta^2=.086$), which is a medium effect (*i.e.*, $\eta^2 > .06$) according to Cohen (1988). This effect is consistent with our hypothesis about facilitatory phonetic priming occurring rapidly in reading. It is also in accordance with our assumption about consonant harmony in early stages of print processing. In these results, only progressive harmony can be inferred, since there was no significant difference of voicing preservation among errors for C₁ recall, depending on voicing similarity between the two consonants, $F(1, 46) = 1.95, p = .1697$ ($\eta^2=.041$). It is important to note that the effect on C₂V cannot be explained by a mere markedness tendency based on phonetic naturalness³. This markedness effect is indeed only present in the isolation condition, $F(1, 46) = 4.03, p = .05$.

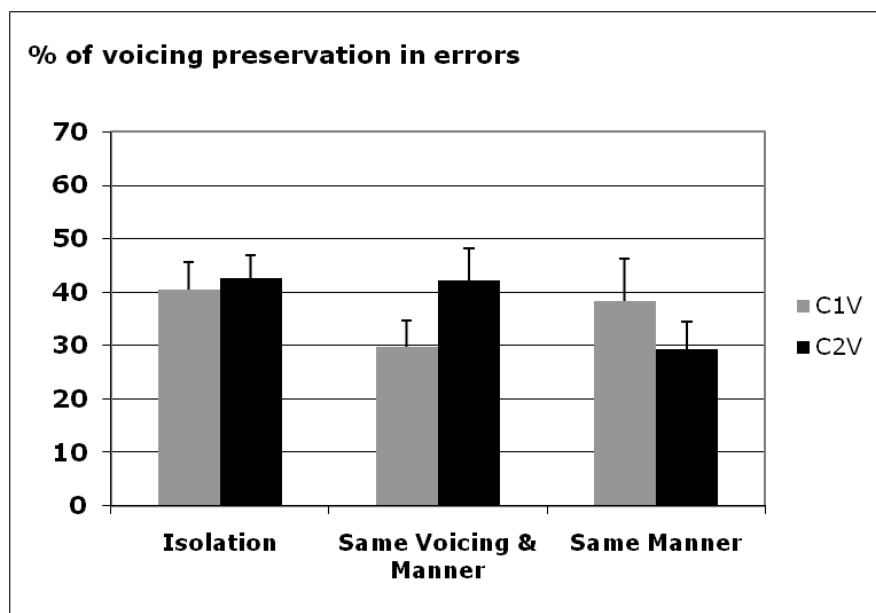


Figure 2: Mean percentages of responses that preserved the voicing value of the target (the first syllable, C₁V, or the second one, C₂V) among inaccurate responses. Error bars represent standard errors.

³ In French voiceless obstruents, phonation begins just after the oral release (short voicing lag) but in voiced obstruents, it starts well before the oral release (long voicing lead; Lisker & Abramsom 1964). Because short voicing lag is easier to produce than long voicing lead (Ohala 1983; Kent 1983), French voiceless obstruents are considered unmarked. If there is an effect of markedness in our experiment, we expect to find more errors where voiced obstruents become voiceless rather than vice versa, regardless of the voicing value of C₁.

Secondly, the percentage of errors preserving manner was analyzed. Unlike the results regarding the effect of voicing similarity, the Target Position \times Sub-phonemic Similarity interaction was not significant as far as manner similarity is concerned, $F(2, 46) = 2.40, p = .10$. However, like the results for voicing similarity, the observed trend only concerned C₂V: as illustrated in Figure 3, the preservation of manner in C₂V recall tended to be less important when C₁ and C₂ had different values for manner, $F(1, 46) = 3.15, p = .0825 (\eta^2=.064)$. This trend is consistent with our assumption about progressive consonant harmony, but its size is less important than the size of the voicing similarity effect on C₂. This trend of manner similarity effect on C₂V production is nevertheless higher than the impact of manner similarity on C₁, $F(1,46) = 1.25, p = .27 (\eta^2=.0265)$.

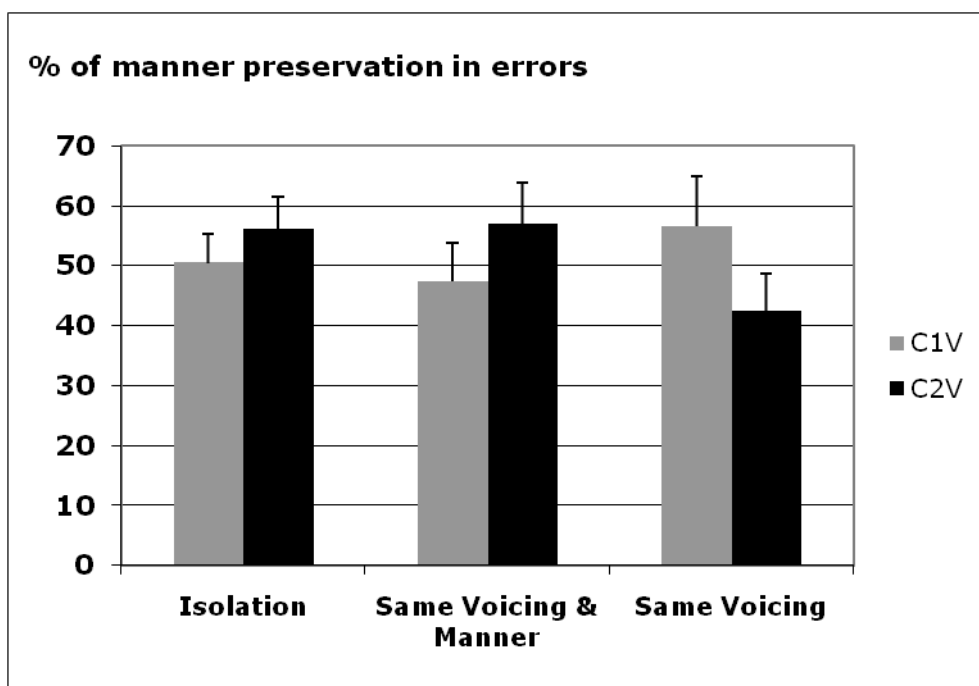


Figure 3: Mean percentages of responses that preserved the manner value of the target (the first syllable, C₁V, or the second one, C₂V) among inaccurate responses. Error bars represent standard errors.

By comparing Figures 2 and 3, a general difference appeared in phonetic feature preservation, to the advantage of manner preservation. To test the existence of an overall advantage for manner preservation in printed stimuli processing, we assessed which phonetic feature type (manner, voicing or place) was better preserved among errors made for syllables presented in isolation. This analysis revealed an effect of feature type, $F(2,46) = 10.70$, $p = .0002$. The preservation of the manner value was higher than the preservation of the voicing value, $F(1,46) = 3.98$, $p = .05$ ($\eta^2 = .08$), and the percentage of voicing preservation was higher than the percentage of place preservation, $F(1,46) = 6.84$, $p = .01$ ($\eta^2 = .13$). The hierarchy in phonetic feature preservation observed in this experiment suggests a high efficiency of manner extraction in reading, an effect which will be discussed regarding the literature about differences in status for phonetic feature types. Additionally, the prominence of manner preservation in the recall of printed syllables could provide an explanation for why C_1 's manner value had a lower impact than C_1 's voicing value over C_2V recall in this experiment. If the manner value of C_2 is particularly efficiently extracted, it could be less affected by the context of the other syllables. Finally, we assessed whether the percentage of manner preservation among erroneous responses differed between stop and fricative consonants. This analysis revealed a general advantage for the recall of the fricative value, $F(1,23) = 4.96$, $p = .04$, which could be related to the saliency of the acoustic correlates of fricatives, but this effect did not interact with the target position, $F(1,23) < 1$, nor with the similarity condition, $F(2,46) = 2.14$, $p = .13$.

3. Discussion

The main issue of this paper was the assessment of sub-phonemic similarity effects between the consonants of a written stimulus in the early stages of print processing. Psycholinguistic studies have suggested that the phonological code generated by print is detailed down to the level of phonetic features (Abramson & Goldinger 1997; Bedoin 2003; Lukatela et al. 2001; Hallé et al. 2008), but further empirical evidence is required. In previous priming experiments, we have shown that similarity of voicing, place or manner of articulation between sequentially processed consonants impaired the identification of the target presented in second place, provided that a 66 ms or 100 ms SOA was used. This negative priming effect, which echoed the negative phonetic priming effect observed in speech processing (Goldinger, Luce & Pisoni 1989; Goldinger, Luce, Pisoni & Marcario 1992), has been interpreted as resulting from the involvement of lateral inhibitory relations between phonemes (Bedoin 2003). In contrast, a briefer presentation of the prime (33 ms SOA) led to a facilitatory priming effect in the case of place or manner similarity, but not for voicing similarity in adult skilled readers (Bedoin & Krifi, to appear). However, a facilitatory voicing priming effect occurred in young readers (second graders) and in dyslexic children (Krifi, Bedoin & Mérigot 2003). This suggests that manner, place or voicing similarity produces facilitatory priming, which relies on a fast low-level mechanism, as assumed in models describing the rapid interactive activation of excitatory connections between the level of phonemes and the level of phonetic features (McClelland & Rumelhart 1981). In adult skilled readers, this low-level mechanism may be rapidly (particularly in the case of voicing similarity) replaced by another one, which is of higher level and probably based on lateral inhibitory connections at the phonemic level. The experiment presented in this paper was designed to preclude the involvement of the latter mechanism, by interrupting print processing when low-level mechanisms were still activated. To this purpose, a brief SOA (33

ms) and high demanding task were used. Unlike previous experiments, the participants had to do something more difficult than just recognize a target word (lexical decision), or decide if a letter shown on the screen was present or not in the previously presented CVCV target. Instead, they had to identify one consonant in a specific part of the briefly presented CVCV pseudo-word in order to pronounce it. The task was so difficult that practice was necessary before the participants reached 50% accuracy.

Consistent with our hypothesis, in such experimental conditions, voicing similarity between the two consonants did not provide any negative priming effect, although participants were adult skilled readers. On the contrary, fewer errors were made for the second consonant identification when it shared the same voicing value as the consonant presented in the first syllable of the CVCV pseudo-word. Although this effect did not reach significance, the observed trend is in accordance with the assumed rapid facilitatory phonetic priming in print processing.

A more precise investigation of the nature of errors made in C₂V recall reveals that the phonetic feature value of the first consonant tends to be extended to the second one. More precisely, the proportion of erroneous responses preserving the voicing value of the C₂ target was significantly lower when this value differed between C₁ and C₂. Conversely, in the case of voicing difference between consonants, the voicing value in erroneous responses for C₂ was the same as the voicing value of C₁ in more than 70% of responses. The same phenomenon occurred for manner, but to a lesser (and non significant) extent. This difference between voicing and manner similarity effects will be discussed later. Therefore, in French adult skilled readers, before any inhibitory phonetic effect, it seems that phonetic priming occurs based on sub-phonemic similarity, and this can be interpreted as an analogue of progressive consonant harmony.

The assumed progressive consonant harmony phenomenon can be viewed as a source of reading mistakes in polysyllabic printed stimuli. This low-level mechanism, which may extend the voicing value from the first consonant to the second one, could indeed account for a certain proportion of the errors made in C₂V recall, in particular when the two consonants within the CVCV differ by voicing. Therefore, the elaboration of lateral inhibitory relations based on sub-phonemic similarity between phonemes could be viewed as an efficient solution to counter reading mistakes. Indeed, after the processing of the first consonant, the lateral inhibitory relations within the reader's phonological representations may put at disadvantage phonemes which would have been erroneously favoured by the previous harmony mechanism. However, we observed no sign of any involvement of lateral inhibitory relations between phonetically similar phonemes in either very young readers (second graders) or dyslexic children (Krifi, Bedoin & Mériqot 2003). Therefore, we could hypothesize that lateral inhibitory relations are associated with successful reading acquisition. This aspect of phonological organisation may be seen as a sophisticated and late outcome of reading experience. It could participate in reducing reading errors that are due to lower-level mechanisms.

In a previous study, we attempted to favour the refinement of between-phoneme inhibitory connections in dyslexic children by submitting them to an audio-visual training centred on the voicing contrast. According to the pattern of voicing similarity effects in CVCV pseudo-words reading before and after the training program, and in comparison with the results of a control group which was not provided with this program, we observed no sign of any involvement of lateral inhibitory relations before training. However, after training, dyslexic children exhibited performances that could be explained by lateral inhibitory relations (Bedoin 2003; Krifi, Bedoin & Mériqot 2003). The results presented in this present paper suggest that the elaboration of between-phoneme lateral inhibitory connections could

counter some reading errors. This work encourages us to develop programs which enhance lateral inhibitory relations in an attempt to improve the organisation of phonological knowledge and reading performance.

Finally, in the experiment presented in this paper, we have seen that the manner value of C_1 tended to extend to C_2 . However this effect did not reach significance, contrary to the effect observed regarding voicing similarity. Thus, the manner value of C_1 had less impact than its voicing value upon C_2 . This could be interpreted as an argument for differences in the efficiency of phonetic feature identification in reading based on feature class. Since the manner value of C_2 was affected to a lesser extent than its voicing value, manner appears to be extracted from the printed letters in priority or more easily than voicing in our reading task. Moreover, regarding the percentage of preservation of each phonetic feature in single syllables, the manner value was better preserved than voicing and place in the erroneous responses, which provides additional evidence for the prominence of manner extraction in the early stages of print processing. This is in line with phonological theories characterised by an internal structure of feature types (Clements 1985). The restriction of phoneme substitution errors of some aphasic patients to voicing, manner, or place (Blumstein 1990), and the selective disturbance of discrimination for voicing or place (Caplan & Aydelott Utman 1994; Miceli, Caltagirone, Gainotti & Payer-Rigo 1978; Oscar-Berman, Zurif & Blumstein 1975) suggest that phonetic features pattern in natural classes. However, their potential hierarchical organisation is still debated. Manner has been proposed to be most prominent as it defines the representation of a segment within a syllable (Van der Hulst 2005). Additionally, according to Stevens (2002), the identification of articulator-free features (manner and sonority) provides the basis for identifying articulator-bound features (place and voicing), since the former establish regions in the signal where acoustic evidence for the articulator-bound features can be found (Stevens 2002). This observation is consistent with the improved discrimination of

articulator-free over articulator-bound features observed in aphasic patients (Gow & Caplan 1996), with the improved preservation of manner features under noisy listening conditions (Wang & Bilger 1973, but see Miller & Nicely 1955 for improved preservation of voicing and nasality), and with the stronger sensitivity of nine-month-old children to manner similarity than to place similarity in sequentially presented syllables (Jusczyk, Goodman & Baumann 1999). Moreover, estimates of psychological distance between consonants derived from similarity rating performed by listeners of spoken consonants showed that manner of articulation is the most important auditory dimension, followed by voicing, and subsequently place of articulation (Peters 1963). In a series of 6 metalinguistic experiments requiring French subjects to match a printed syllable target with one of two proposed other syllables according to their intuitive estimation of acoustic similarity, a bias in favour of manner similarity was reported over voicing and place in guiding similarity judgements (Bedoin & Krifi, to appear). Therefore, the greater preservation of the manner value than the voicing value of C_2 , and the lesser vulnerability of C_2 's manner value than C_2 's voicing value to the phonetic characteristics of C_1 observed in our experiment are consistent with the prominent status of manner reported in the literature. These results also provide new empirical evidence for the involvement of a phonological code in reading and suggest that, the code can be detailed down to the level of hierarchically organised phonetic features.

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Appendix

Items for C₁V identification (*Rank 1*) in the four experimental conditions

(In French, in general, the letter sequence *ch* represents the sound [ʃ], and the letter *j* represents the sound [ʒ].)

Isolation	difference in place	difference in place and voicing	difference in place and manner
pu--	putu	pudu	pussu
tu--	puku	pugu	puchu
ku--	tupu	tubu	tufu
fu--	tuku	tugu	tuchu
ssu--	kupu	kubu	kufu
chu--	kutu	kudu	kussu
bu--	fussu	fuzu	futu
du--	fuchu	fuju	fuku
gu--	sufu	suvu	supu
vu--	suchu	suju	suku
zu--	chufu	chuvu	chupu
ju--	chussu	chuzu	chutu
	budu	butu	buzu
	bugu	buku	buju
	dubu	dupu	duvu
	dugu	duku	duju
	gubu	gupu	guvu
	gudu	gutu	guzu
	vuzu	vussu	vudu
	vuju	vuchu	vugu
	zuvu	zufu	zubu
	zuju	zuchu	zugu
	juvu	jufu	jubu
	juzu	jussu	judu

Items for C₂V identification (*Rank 2*) in the four experimental conditions

Isolation	difference in place	difference in place and voicing	difference in place and manner
--pu	tupu	dupu	supu
--tu	kupu	gupu	chupu
--ku	putu	butu	futu
--fu	kutu	gutu	chutu
--ssu	puku	buku	fuku
--chu	tuku	duku	suku
--bu	sufu	zufu	chuku
--du	chufu	jufu	tufu
--gu	fussu	vussu	kufu
--vu	chussu	jussu	pussu
--zu	fuchu	vuchu	kussu
--ju	suchu	zuchu	puchu
	dubu	tubu	tuchu
	gubu	kubu	kuchu
	budu	pudu	zubu
	gudu	kudu	jubu
	bugu	pugu	vudu
	dugu	tugu	judu
	zuvu	suvu	vugu
	juvu	chuvu	zugu
	vuzu	fuzu	jugu
	juzu	chuzu	duvu
	vuju	fuju	guvu
	zuju	suju	buzu
			guzu
			buju
			duju
			guju

Figure 1

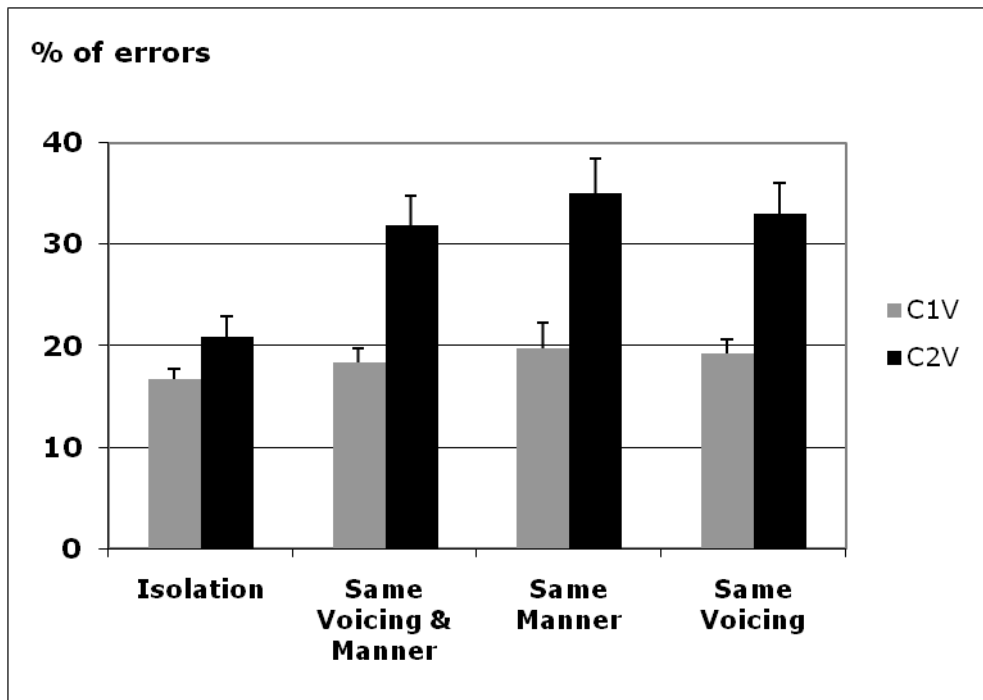


Figure 1: Mean percentages of errors in the production of the target syllable (C₁V or C₂V), depending on the relation between those consonants. Error bars represent standard errors.

Figure 2

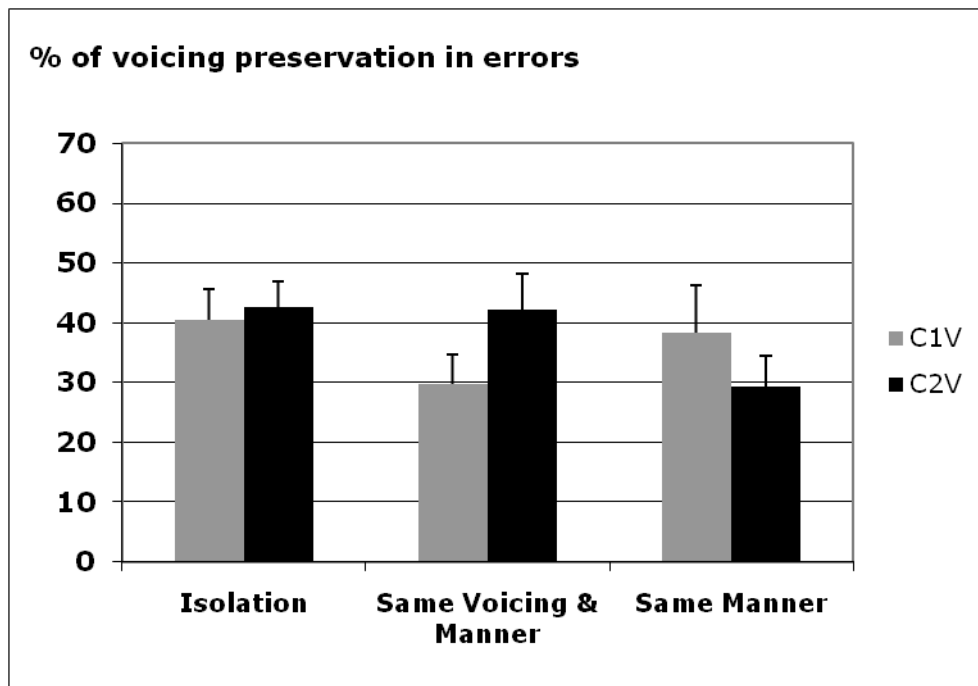


Figure 2: Mean percentages of responses that preserved the voicing value of the target (the first syllable, C₁V, or the second one, C₂V) among inaccurate responses. Error bars represent standard errors.

Figure 3

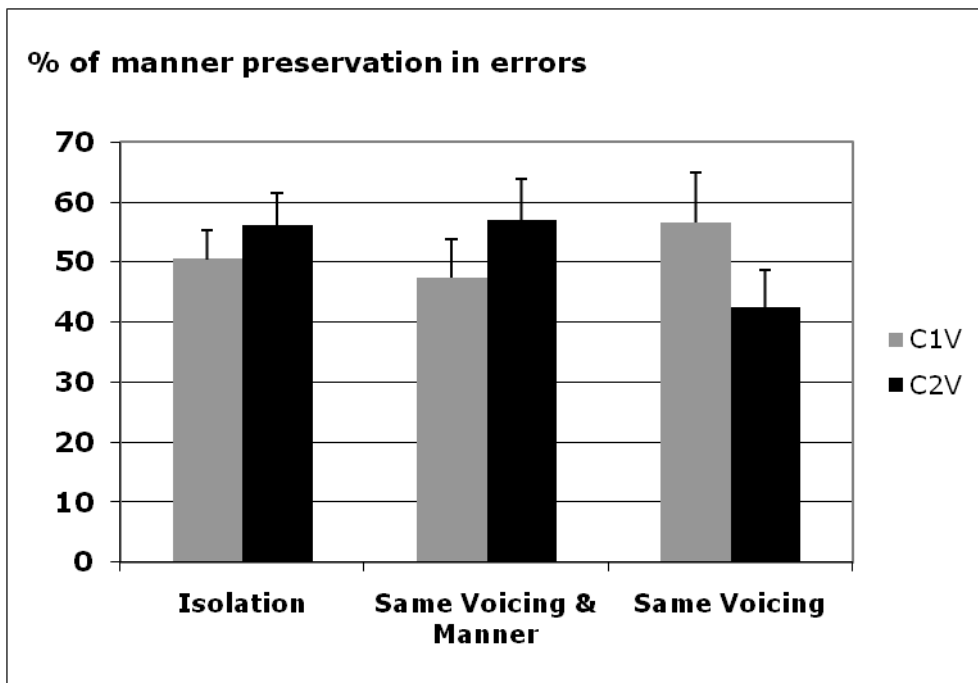


Figure 3: Mean percentages of responses that preserved the manner value of the target (the first syllable, C₁V, or the second one, C₂V) among inaccurate responses. Error bars represent standard errors.