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Norbert Maïonchi-Pino, Bruno De Cara, Annie Magnan and Jean Ecalle

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ROLES OF CONSONANT STATUS AND SONORITY IN PRINTED SYLLABLE PROCESSING:

EVIDENCE FROM ILLUSORY CONJUNCTION AND AUDIO-VISUAL RECOGNITION TASKS IN FRENCH ADULTS.

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Norbert Maïonchi-Pino

Université Lumière Lyon 2, France

Bruno De Cara

Université de Nice-Sophia Antipolis, France

Annie Magnan

Université Lumière Lyon 2, France

Jean Ecalle

Université Lumière Lyon 2, France

Correspondence shoud be send to: Norbert Maïonchi-Pino, Laboratoire d'Etude des Mécanismes Cognitifs, EMC, EA 3082 CNRS, 5 avenue Pierre Mendès-France, F-69500 Bron, France. E-mail: norbert.maionchi-pino@univ-lyon2.fr

Abstract

The paper investigates how French readers visually process consonant clusters between two syllables. First, we aimed at assessing whether skilled adults were sensitive to syllable-sized units. Second, we wondered whether syllable processing depended on linguistic characteristics of consonant clusters such as consonant status and sonority profile. Two visual recognition tasks were used: the classical illusory conjunction paradigm (Prinzmetal, Treiman & Rho, 1986) and an original audio-visual recognition tasks. The results showed that syllable-sized units were used in both tasks. However, sonority profile and consonant status modulated syllable processing whatever the task. Consonant clusters whose sonority profile was 'sonorant coda-obstruent onset' (e.g. 'LP' in 'TOLPUDE') was preferred to all other sonority profiles. These behavioural results were in line with linguistic principles according to which the best contact between two syllables lies on a peak in sonority at the end of the first syllable following by a drop in sonority at beginning of the subsequent one (e.g., Hooper, 1972 ; Clements, 1990).

Key words: sonority, consonant status, syllable, visual processing, intervocalic cluster.

Résumé

Notre étude visait à étudier le rôle du codage phonologique en lecture silencieuse chez des adultes français. Nous avons particulièrement étudié le profil de sonorité, les règles phonotactiques ainsi que la structure syllabique aux frontières syllabiques grâce à une tâche de reconnaissance audio-visuelle et au paradigme des conjonctions illusoires (Prinzmetal, Treiman & Rho, 1986). Nous avons évalué si les adultes experts avaient recours aux syllabes. Nous souhaitions également observer si le codage phonologique était sensible à des facteurs linguistiques tels que le statut de la consonne pivot et au profil de sonorité. Les résultats obtenus dans les deux expériences ont montré que les adultes s'appuyaient sur les syllabes. Cependant, le recours aux syllabes était influencé et contraint par la phonotactique. En effet, les adultes se sont montrés sensibles aux profils de sonorité pour déterminer les frontières syllabiques. Ainsi, les profils intervocaliques respectant un cycle de sonorité optimal (i.e., coda liquide-attaque plosive) ont été préférés aux autres profils de sonorité. Ces données s'accordent avec les théories linguistiques selon lesquelles le contact optimal entre deux syllabe repose sur une coda plus sonore que la consonne subséquente en position d'attaque (e.g., Clements, 1990).

Mots clés : sonorité, consonne pivot, syllabe, phonotactique, cluster intervocalique.

In this article, we proposed the convention according to which the bolded and underlined part of pseudowords represents the blue-colored and the rest the red-colored part.

INTRODUCTION

Over the past decade, many researchers have investigated which sublexical units could be involved in the visual word recognition process. Several hypotheses have been tested. The syllable has been one of the most privileged units and received an important amount of attention especially with Romance languages such as Spanish (e.g., Álvarez, Carreiras & Perea, 2004) or French (e.g., Conrad, Grainger & Jacobs, 2007). However, only little research has been conducted regarding the role of phonetic properties such as sonority profile in printed syllable processing in French. Most of experiments only evidenced the role of syllable-sized units in visual word recognition by handling syllable frequency (Álvarez, Carreiras & Taft, 2001), syllabic neighborhood (e.g., Mathey & Zagar, 2002), bigram frequency (e.g., Doignon & Zagar, 2005) or phonological priming (e.g., Colé, Magnan & Grainger, 1999). Few studies specifically addressed the role of acoustic-phonetic properties and phonotactics within the syllabic boundary in printed word processing in French (but see Bedoin & Dissard, 2002; Fabre & Bedoin, 2003). This paper proposes to assess the role of consonant status and sonority profile on the organization of syllabic boundaries and on the use of syllables as phonological reading units in two visual recognition tasks.

THE SYLLABLE'S ROLE AND THE LINGUISTIC CONSTRAINTS

What is a syllable? Currently, a syllable is not described as a linear letters or phonemes string but is rather defined with a hierarchical internal structure that can be split up into two main constituents: an onset and a rime (Fudge, 1987; Goldsmith, 1990; Treiman, 1989). A rime can be subdivided into a vocalic nucleus (vowel) and a coda (final consonant or cluster). A syllable can be also defined by a vocalic nucleus possibly surrounded by consonants (see Durand, 1995 about obligatory vs. optional consonant margins).

In French, phonological (Véronis, 1986) and phonetic properties (Altmann, 1997; Cutler, 1997) could account for the syllable's role to segment printed words. The structural system of French revealed leading information: its vocabulary is composed by a high rate of polysyllabic words (83.3%) (Content, Mousty & Radeau, 1990). This could argue for a more efficient role of syllables as segmentation units whereas in English, monosyllabic words are predominant, what could explain the greater relevance of rime units (e.g., Treiman, Mullennix, Bijelbac-Babic & Richmond-Welty, 1995). From a phonetic point of view, the first syllable is unstressed in French and the phonemes are acoustically unclear to identify because of the coarticulation (e.g., Altmann, 1997). French speakers would also use a more global syllabic code rather than a phonemic code (Sprenger-Charolles & Colé, 2003, p. 101).

French is also commonly described as a syllable-timed language with clear-cut syllable boundaries (Kaye & Lowenstamm, 1984). French is governed by the *Maximal Onset Principle* (for a review, see Spencer, 1996), correlated with the *Sonority Sequencing Principle* (Clements, 1990). The *Maximal Onset Principle* induces a syllabification that maximizes the number of consonants at the beginning of a syllable. Otherwise, whatever the number of consonants within the syllabic boundary, the optimal syllabification tends to attribute all the consonants following the nucleus to the next syllable in order to privilege an opened structure (i.e., CV) and a *maximal onset*, excepted whether this *maximal onset* is considered as illegal. For instance, in a CVCCVC word (e.g. 'tablette'), the boundary falls between CV and CCVC ('ta-blette') as long as the consonant cluster ('bl') is attested as a legal phonotactic cluster at a beginning of a syllable (Hooper, 1972; McQueen, 1998). Therefore, in the case of illegal clusters (i.e., clusters that can not appear at the beginning of a word; Dell, 1995; McQueen, 1998; e.g., 'lc' in 'balcon'), syllabification will be located between the two consonants of the intervocalic cluster ('bal-con'). Meanwhile, these statements have been evidenced essentially in speech perception. One of our aims was to demonstrate how syllabification was applied in letter string processing by adult readers.

The sonority profile of consonants is an acoustic-phonetic aspect (Price, 1980) which refers to a sonority hierarchy between phonemes, correlated with the degree of articulatory opening of the vocal tract (Selkirk, 1984). According to this scale, vowels are the most sonorant sounds, followed, in decreasing order, by liquids, nasals, fricatives and stops (fully obstruction of the vocal tract). Liquids (e.g. /R/, /l/) and nasals (/m/, /n/) are classified as sonorant consonants while fricatives (/s/, /f/) and stops (/p/, /t/) are considered as obstruent consonants. In French language, phonemes are specifically assigned to a phonological status as a function of their sonority rank. For instance, low-sonority consonants (/p/, /t/) are frequent as onsets but rare as codas (Blevins, 1995). Statistical analyses for disyllabic CVC.CVC words confirm that high-sonority consonants predominate in coda position whereas low-sonority consonants are frequent in onset position (e.g. 'balcon' ; Content et al., 1990). According to Clements' (1990) works, the preferred syllable across languages respects a sonority profile which is described with an onset growing in sonority towards the vocalic nucleus and falling minimally beyond the vowel. Thus, the coda of the first syllable must be close in sonority to the preceding vowel. Therefore, the *optimal* syllable structure is a CV structure (consonant-vowel) (Kaye & Lowenstamm, 1984; Clements, 1990). A syllable is considered as *complex* as soon as it differs from this *optimal* sonority structure. This complexity hierarchy (based on sonority profile) constraints syllabic structures (Zec, 1995). In line with this principle, the syllabic boundaries are more or less complex according to the sonority profile of the intervocalic clusters (Hooper, 1972; Pulgram, 1970; Selkirk, 1982).

EXPERIMENTAL EVIDENCE ABOUT SONORITY

Nowadays, it is well-known and well-accepted that phonology is early and automatically activated during silent reading in adults (e.g., Frost, 1998). Nevertheless, no consensus has been found on the relevant size for phonological units in silent reading. Among studies about syllable processing in French adult readers (see Colé et al., 1999; Ferrand & New, 2003), only a few of these investigated how sonority and phonotactics influence syllable-based segmentation. From works inspired by Gross, Treiman & Inman (2000) and Prinzmetal, Treiman & Rho (1986), two recent studies (Bedoin & Dissard, 2002 and Fabre & Bedoin, 2003) examined the role of sonority for syllable-based segmentation in CVCCV pseudowords. Bedoin and co-workers found that a target-letter was better detected when preceded by a sonorant rather than an obstruent consonant. For instance, the target-letter 'T' was better detected in 'VULTI' than in 'VUCTI' (Bedoin & Dissard, 2002). Similarly, Fabre & Bedoin (2003) showed that syllabic segmentation was improved (i.e., decrease of the error rate) only when the coda of the first syllable was sonorant. These results are in line with previous results released by Content, Meunier, Kearns and Frauenfelder in speech perception (2001b) and with phonotactic rules according to which the simple and the most frequent succession of two consecutive syllables corresponds to the pattern where the end of a syllable is higher in sonority than the beginning of the following one (Clements, 1990; Murray & Vennemann, 1983; Vennemann, 1988).

Unfortunately, it is worth stressing that Bedoin's works did not compare all the different possible sonority profiles within the syllable boundary and neglected the investigation of the consonant status as coda or onset. Indeed, as previously demonstrated by Content, Kearns and Frauenfelder (2001a) in speech perception, the onset would be more reliable than the offset as the onset could act as alignment point for lexical search. Furthermore, it remains also important to investigate whether sonority profile, phonotactics and consonant status are involved in syllable-based segmentation in silent reading.

In line with the experiments carried out by Bedoin and al., the role of syllabic units has been recently tested in visual word processing in French children (Colé & Sprenger-Charolles, 1999; Colé et al., 1999; Duncan, Seymour, Colé & Magnan, 2006), and especially through a set of experiments using the illusory conjunction paradigm (e.g., Doignon & Zagar, 2006). Experimental data showed that syllable-based segmentation early emerge in beginning readers, as soon as the end of the first year of reading instruction. However, other previous research argued that children's use of syllabic units would be dependent on syllable structure complexity (e.g., CCV, CVC; Sprenger-Charolles, Siegel & Bonnet, 1998).

Some studies lead to consider that sonority profile can notably account for cluster reduction or consonant deletion in reading acquisition. For example, Sprenger-Charolles and Siegel (1997) found that beginning readers more frequently deleted sonorant consonants like 'r' than obstruent consonants like 't' in aloud pseudoword reading. This effect occurred whatever the position of the high-sonority consonant in consonant cluster (e.g., 'r' in 'tr̲ibul' or in 'tir̲bul'). The complex syllable structures (e.g. CCV, CVC) were also preferentially simplified into open structure (i.e. CV) which corresponds to the optimal syllable in terms of sonority. Sprenger-Charolles and Siegel (1997) conclude that children tended to omit sonorant consonants because of their phonetic properties (i.e., sonority profile) and not because of their location within the consonant cluster. This set of data suggests that syllables are early used in beginning readers but syllable-based segmentation seems to be influenced and modulated by sonority and phonotactic rules. So, we could predict that French adults could be sensitive to sonority profile within syllable.

THE PRESENT STUDY

The aim of this study was threefold. First, we aimed at further assessing whether French adults used syllables to silently process printed pseudowords through the illusory conjunction paradigm and an audio-visual recognition task. Secondly, we investigated the role of sonority profile within consonant cluster on syllable-based segmentation. We predict that coda (ie. last consonant of the first syllable) and onset (ie. first consonant of the second syllable) sonority would influence visual syllable processing, as already demonstrated in speech perception by Content et al. (2001a; 2001b). Third, we extended Fabre and Bedoin's (2003) methodology to all sonority profiles by crossing coda and onset sonority, still using the illusory conjunction paradigm (Prinzmetal et al., 1986). We also compared four different sonority profiles within the syllabic boundary. As suggested by Content et al. (2001a), consonants within the syllabic boundary would have a different status in speech perception. We also tested this assumption in the first experiment; we assessed the status of the intervocalic consonants by presenting a target-letter which was either the coda or the onset. In the second experiment, the status of these consonants was studied by deleting either the coda or the onset. In both experiments, the use of pseudowords did constraint the resort to a phonological coding. The illusory conjunction paradigm (used in first experiment) specifically allowed us to investigate whether syllable was a perceptive unit involved at an early processing level, before full pseudowords identification. The audio-visual recognition task (used in experiment 2) allowed us to study the involvement of a phonological processing and whether syllable was the relevant phonological reading unit. Finally, both experiments investigated how sonority profile could influence the use of phonological syllable-sized units.

EXPERIMENT 1

Experiment 1 was designed to replicate Fabre & Bedoin's (2003) previous results showing adult readers' sensitivity to sonority in syllable-based segmentation. Keeping the same methodology as Fabre and Bedoin (2003), we created disyllabic pseudowords with consonant clusters distributed into four conditions of sonority profile (i.e., Sonorant-Sonorant; Sonorant-Obstruent; Obstruent-Sonorant; Obstruent-Obstruent). Moreover, we alternated the location of the target-letter between the first consonant of the cluster (coda) and the second consonant of the cluster (onset). We expected that adults would faster respond (i.e., faster assignation of the target-letter color) when color and syllable segmentation were compatible than when there were not. Furthermore, we predicted that the color syllable compatibility effect would be maximum when the consonant cluster corresponded to the optimal sonority profile (i.e., Sonorant-Obstruent).

PARTICIPANTS

Twenty-five students (mean age = 21;0 ; σ: 15.2 months) from the University of Lyon participated in this experiment. There were 5 men and 20 women. They were all French native speakers and right-handed. They had normal or corrected-to-normal vision.

METHOD

MATERIAL AND DESIGN

Twenty-four disyllabic pseudowords (matched on orthographic length) were created (see Appendix). The pseudowords were composed of letters with regular spelling-to-sound correspondences. All pseudowords had an initial CVC syllable structure and an intervocalic consonant cluster CC. Syllable boundary was located within the consonant cluster (i.e., between the third and the fourth letters; e.g., TOL.PUDE). Consonant sonority (sonorant vs. obstruent) was manipulated within the intervocalic consonant cluster leading to 4 types of sonority profile: Sonorant-Sonorant (e.g., TORLADE); Sonorant-Obstruent (e.g., TOLPUDE); Obstruent-Sonorant (e.g., DOTLIRE); Obstruent-Obstruent (e.g., BICTADE).

Each pseudoword was repeated four times through two conditions (color-syllable compatible and incompatible). First and second syllables never had the same color. For both compatible and incompatible conditions, the target-letter to be detected was always at the border of the colored segments. In the compatible condition, color segmentation was in line with syllable-base segmentation. Thus, different colors (i.e., 'red' or 'blue') were assigned to the first and the second syllables. On the other hand, in the incompatible condition, stimuli were split up, either before the consonant cluster (e.g., TO.LPUDE) or after this one (e.g., TOLP.UDE; see Figure 1). For instance, in TOLP.UDE, the first segment embodied the cluster whereas, in TO.LPUDE, the cluster was embedded in the second segment. Both segmentations (i.e. cluster included in the first or in the second segment) were presented in the incompatible condition. In both compatible and incompatible conditions, each pseudoword was presented twice since the letter to be detected was either the first or the second consonant of the intervocalic cluster. Target-letters (coda, onset) referring to the same pseudoword were not consecutively presented. Two experimental lists were created for counterbalancing the order of colors within the pseudoword. For instance, in list 1, the pseudoword ‘BICTADE’ had the segment ‘BIC’ colored in red and the segment ‘TADE’ in blue while color assignation was inverted in list 2.

TOL.**PUDE** TO.**LPUDE** TOLP.**UDE**[1]

Figure 1. Examples of the three possible color segmentation

PROCEDURE

The participants were tested individually in a 12-to-15 minute single session. The experiment proceeded on a PowerBook G4 computer monitor running under Macintosh 9.2 operating system. The script of the experiment was built with PsyScope 1.2.5 (Cohen, MacWhinney, Flatt & Provost, 1993). Participants were placed at a distance of 57 cm from the screen. The material was presented in police “Arial” and size “48” font. Target-letters and test pseudowords were always displayed in upper-case letters. Each trial began with a green square presented for 1500 ms in the centre of the screen and replaced by a fixation point (i.e., ‘+’) for 300 ms. After the fixation point, a black-colored target-letter corresponding to either the first or the second consonant of the intervocalic cluster appeared in the centre of the screen for 1500 ms. Then, the test-pseudoword flashed during 230 ms in one of the four angles of the screen. After that, a 200 ms-white screen preceded the appearance of a printed question mark (i.e., ‘?’) which remained on the screen until the participant’s response (see Figure 2). Participants were instructed to decide as quickly and as accurately as possible what was the color of the target-letter in the subsequently flashed test-pseudoword. As response mode, participants had to press on the “blue” or “red” button (respectively the “a” or “p” keys on the computer). These operating buttons also reflected the right-handed preference. The number of “blue” and “red” responses was balanced in each experimental list and for each experimental condition. Before beginning the experimental lists, participants were trained to the experimental protocol with a practice list containing four different trials.

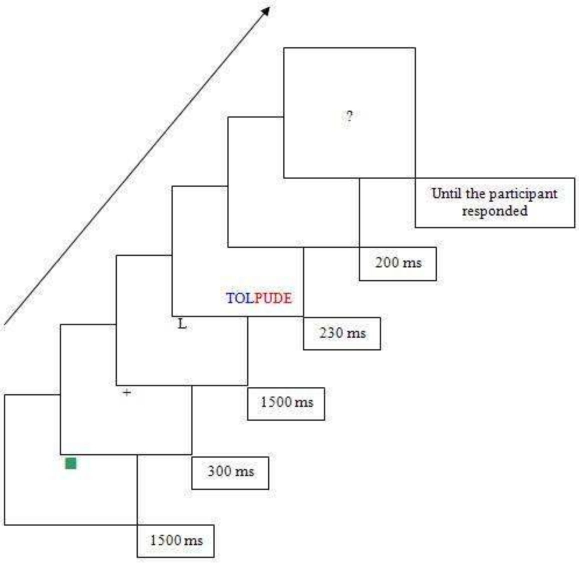

Figure 2. Illustration of the setup of experiment 1.

RESULTS

An analysis of variance (ANOVA) was performed on the data using subjects (*F*1) and items (*F*2) as random variables. Only correct detection times were included in the analyses. The correct response times were standardized (i.e., for each subject, the response times away from more or less two standard deviations were considered as errors, which excluded ≈ 2.2% of the data). No analysis on the errors was conducted because of the low number of errors (≈ 6.5% of the global data; i.e., 2.2% from RT standardization and 4.3% of errors).

A four within-subject factors (Color-Syllable Congruency: compatible vs. incompatible; Type of Detection: coda vs. onset; Coda Sonority: sonorant vs. obstruent; and Onset Sonority: sonorant vs. obstruent) repeated measures ANOVA was conducted on mean response times. We presented only the main effect of 'Color-Syllable Congruency' released by the ANOVA, *F*1(1, 24) = 36.38, $p < .01$, $\eta^2 = 0.60$, *F*2(1, 40) = 13.46, $p < .01$, $\eta^2 = 0.25$, before analyzing separately color-syllable compatibility and incompatibility. The color of the letter was globally faster detected when the color-syllable overlap was compatible (561 ms) rather than when the color-syllable overlap was incompatible (605 ms).

When considering the color-syllable compatible condition, the three within-factors repeated measures ANOVA highlighted a significant main effect of 'Onset Sonority', *F*1(1, 24) = 14.60, $p < .01$, $\eta^2 = 0.48$, *F*2(1, 40) = 13.52, $p < .01$, $\eta^2 = 0.25$; that is, the color of the target-letter was faster decided for an obstruent onset (535 ms) than for a sonorant onset (587 ms). A main 'Coda Sonority' effect was also released, exclusively from the analyses by subjects, *F*1(1, 24) = 5.71, $p < .03$, $\eta^2 = 0.15$, *F*2 < 1. Indeed, sonorant codas (545 ms) led globally to faster detection times than obstruent codas (577 ms). At last, a significant main 'Type of Detection' was observed, *F*1(1, 24) = 7.48, $p < .01$, $\eta^2 = 0.31$, *F*2(1, 40) = 6.50, $p < .02$, $\eta^2 = 0.14$. Onsets were more quickly detected (540 ms) than codas (582 ms). The 'Onset Sonority*Type of Detection' interaction was also significant, *F*1(1, 24) = 12.43, $p < .01$, $\eta^2 = 0.34$, *F*2(1, 40) = 5. 47, $p < .02$, $\eta^2 = 0.13$. This interaction reached significance because onset detection was quicker than coda detection only in the case of an obstruent onset. Finally, a significant 'Coda Sonority*Onset Sonority' interaction emerged from the analyses by subjects, *F*1(1, 24) = 5.55, $p < .03$, $\eta^2 = 0.24$, *F*2 < 1. This effect is exclusively due to the significant decrease of the detection times only if the coda of the first syllable was sonorant and the onset of the second syllable was obstruent (see Figure 3).

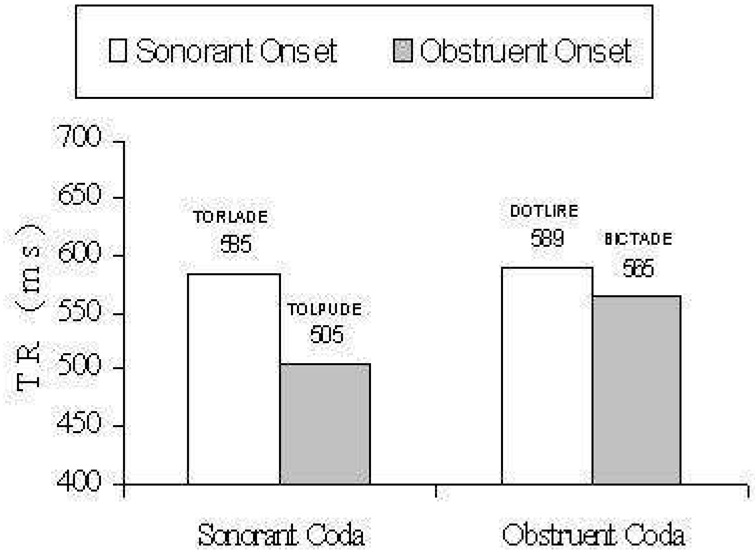

Figure 3. Mean response times (in milliseconds) in the color-syllable compatibility condition as a function of coda sonority and onset sonority.

When considering the color-syllable incompatible condition, the three within-factors repeated measures statistical analyses revealed that the same significant effects as in the compatible condition. Therefore, 'Coda Sonority' was significant, $F1(1, 24) = 15.23$, $p < .01$, $\eta^2 = 0.39$, $F2(1, 40) = 11.70$, $p < .01$, $\eta^2 = 0.23$; that is, the color of an sonorant coda (579 ms) was faster decided than with an obstruent coda (631 ms). A significant 'Type of Detection' effect was observed in the analyses by subjects, $F1(1, 24) = 6.55$, $p < .02$, $\eta^2 = 0.27$, $F2 < 1$. Onsets were more quickly detected (581 ms) than codas (623 ms). The 'Onset Sonority*Type of Detection' interaction was significant only in the analyses by subjects, $F1(1, 24) = 7.87$, $p < .01$, $\eta^2 = 0.25$, $F2 < 1$. This interaction showed that onsets were more rapidly detected than codas only with obstruent onsets. To conclude, a 'Coda Sonority*Onset Sonority' interaction reached significance in the analyses by subjects only, $F1(1, 24) = 8.34$, $p < .01$, $\eta^2 = 0.26$, $F2 < 1$. This interaction emerged because response times were shorter only when the coda of the first syllable was sonorant and the onset of the second syllable obstruent (see Figure 4).

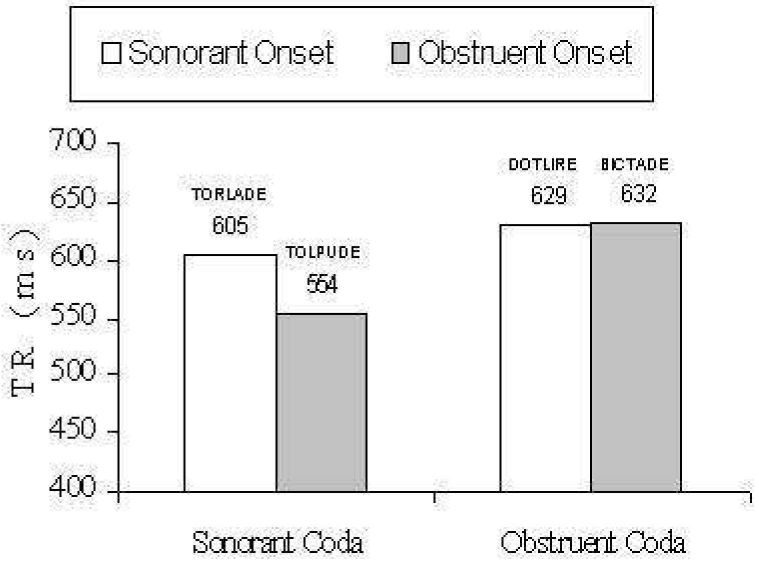

Figure 4. Mean response times (in milliseconds) in the color-syllable incompatibility condition as a function of coda sonority and onset sonority.

EXPERIMENT 2

The aim of Experiment 2 was to extend results found in Experiment 1 to an audio-visual recognition task. Each pseudoword to be recognized was simultaneously presented from both visual and auditory modalities. Thus, we ensured subjects would access to pseudoword pronunciation as the same time as they saw the pseudoword displayed on the screen. We still manipulated sonority as regards consonant clusters, leading to 4 types of sonority profiles as in Experiment 1. When the pseudoword to be recognized was identical to the pseudoword subsequently displayed as test, we hypothesized that adults would show fastest response times when sonority profile corresponded to the optimal syllable contact (i.e., Sonorant coda - Obstruent onset).

Furthermore, we created reduced pseudowords that subjects had to identify as different from pseudowords to be recognized. The reduced pseudowords directly derived from the pseudowords to be recognized by deleting one of the consonant within the consonant cluster. Consonant deletion lead to cluster reduction which was phonological different as regards the type of deleted consonant. On one hand, for onset deletion, cluster reduction involved resyllabification (consonant in coda position moved to onset position, e.g. BIC.TADE reduced to BI.CADE). On the other hand, for coda deletion, cluster reduction did not modify syllabification (consonant in onset position remained in onset position, e.g. BIC.TADE reduced to BI.TADE). As we assumed that syllabification change would be phonologically more salient than syllabification identity, we hypothesized that onset deletion (which lead to new syllabication, e.g. BIC.TADE reduced to BI.CADE) would be faster detected than coda deletion (which did not change syllabication, e.g. BIC.TADE reduced to BI.TADE).

PARTICIPANTS

A total of 20 French students (mean age = 22;4 ; σ: 37.6 months), different from experiment 1, from the University of Lyon participated in the experiment. There were 2 men and 18 women. They were all native speakers of French and were right-handed. They had normal or corrected-to-normal vision and reported no hearing disorder.

METHOD

MATERIAL AND DESIGN

The twenty-four pseudowords to be recognized were the same as those used in experiment 1. In the identical condition (response ‘yes’), each pseudoword to be recognized was identical to the pseudoword subsequently displayed as test. On the other hand, in the deletion condition (response ‘no’), each pseudoword to be recognized should be identified as different from the reduced pseudoword subsequently displayed as test. Each pseudoword was repeated four times, twice in each condition (identical and deletion). In the deletion condition, cluster reduction was alternatively created by the deletion of the first consonant (coda e.g., TOLPUDE reduced to TOPUDE) or by the deletion of the second consonant (onset e.g., TOLPUDE reduced to TOLUDE). Deletion never simultaneously affected both consonants of the cluster.

PROCEDURE

The participants were run individually in a 13-to-15 minute single session. The experiment proceeded on a PowerBook G4 computer monitor running under Macintosh 9.2 operating system. The script of the experiment was built with PsyScope 1.2.5 (Cohen et al., 1993). The stimuli were presented in printed characters and were simultaneously administrated through Altec Lansing AHS 502i headphones. Participants sat at a distance of 57 cm from the screen. Printed material was presented in police “Arial” and size font “48”. Target and test pseudowords were always presented in upper-case letters. Sounds were recorded from a French native professional language and speech therapist and converted in Sound Designer II format at a 44100Hz rate in 16 bits stereo and checked through SoundForge 7.0 software. A green square was presented during 1000 ms in the centre of the screen, followed by a white screen during 1000 ms. Then, a fixation point (i.e., ‘+’) was displayed vertically centered on the left hemi-field of the screen during 500 ms. Immediately after disappearance of the fixation point, a mask (i.e., ‘XXXXXXX’) appeared on the screen for 75 ms at the same position. Then, the printed target replaced the mask and remained displayed on the screen for 2500 ms. The sound started simultaneously with the appearance of the printed target and was played once (i.e., each sound lasted roughly 500 ms). After the end of the 2500 ms display, a white screen preceded during 250 ms a second mask. The second mask appeared for 75 ms vertically centered on the right hemi-field before and was replaced by a fixation point for 500ms. When the fixation point disappeared, another mask appeared for 75 ms and the test pseudoword was displayed and remained on the screen until the participant responded. As soon as the participant responded, the test pseudoword disappeared and was replaced by a mask during 75 ms. The next sequence followed after 100 ms delay (Figure 5).

The participants were instructed to decide as quickly and as accurately as possible whether the test pseudoword was identical or not to the target pseudoword they had both heard and seen previously. Participants had to press on the keys “p” or “a”, respectively to answer “yes” or “no”. These operating buttons also reflected the right-handed preference. The number of “yes” and “no” responses were balanced in each experimental list. Before beginning the experimental lists, participants were trained with a practice list containing 4 different trials with feedback as regards response accuracy. No feedback was given for the experimental trials.

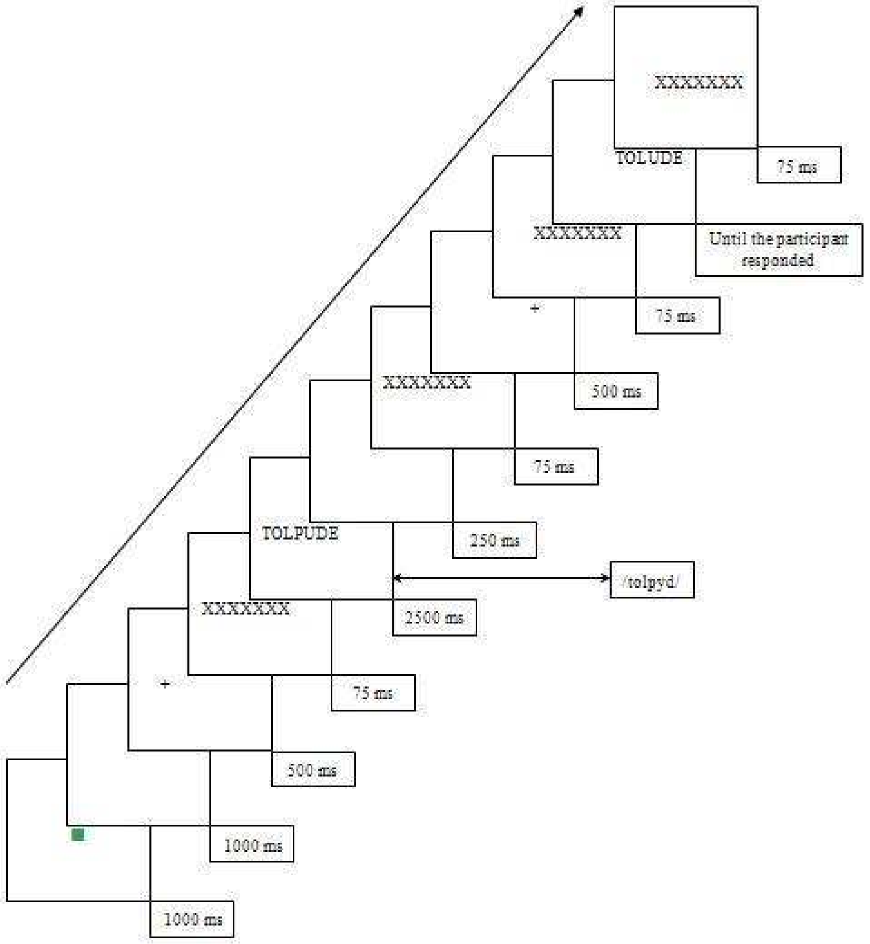

Figure 5. Illustration of the setup of experiment 2.

RESULTS

An analysis of variance (ANOVA) was performed on the data using subjects (*F*1) and items (*F*2) as random variables on the "identical" and "deletion" conditions. Only correct response times were included in the analyses. The correct response times were standardized (i.e., for each subject, the response times away from more or less two standard deviations were considered as errors, which excluded ≈ 2.4% of the data). No analysis on the errors was conducted because of the low number of errors (roughly 3.4% of the data).

As regards the identical condition, a two within-subject factors (Coda sonority: sonorant, obstruent; Onset sonority: sonorant, obstruent) repeated measures ANOVA was carried out on mean response times. The ANOVA highlighted a main effect of 'Coda Sonority', F1(1, 19) = 42.36, p < .0001, , η2 = 0.69, F2(1, 44) = 11.43, p < .01, η2 = 0.21, and a main effect of 'Onset Sonority', F1(1, 19) = 28.49, p < .0001, η2 = 0.60, F2(1, 44) = 16.60, p < .001, η2 = 0.27. Independently, these effects emerged because pseudowords with sonorant codas were more rapidly processed (625 ms) than pseudowords with obstruent codas (650 ms) while pseudowords with obstruent onsets led to faster response times (621 ms) than pseudowords with sonorant onsets (664 ms). Furthermore, the interaction between Coda Sonority and Onset Sonority was significant, F1(1, 19) = 4.94, p < .04, η2 = 0.21, F2(1, 44) = 3.14, p < .08, η2 = 0.07. This interaction emerged because of response times were shortest for a sonorant coda and an obstruent onset compared with the all other conditions, F(1, 19) = 40.44, p < .0001 (see Figure 6).

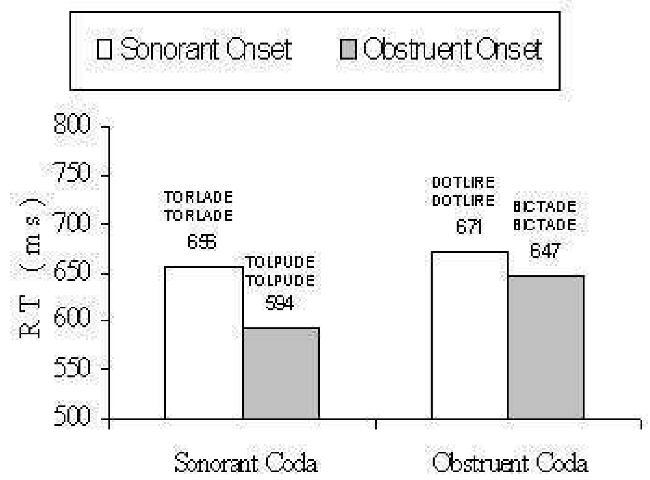

Figure 6. Mean response times (in milliseconds) in the "identical" condition as a function of coda sonority and onset sonority.

As regards the deletion condition, a three within-subject factors (Coda sonority: sonorant, obstruent; Onset sonority: sonorant, obstruent; Type of deletion: coda, onset) repeated measures ANOVA was performed on mean response times. The ANOVA revealed two main effects; namely a main effect of 'Coda Sonority', *F*1(1, 19) = 8.57, p < .009, η2 = 0.31, *F*2(1, 40) = 10.30, *p* < .003, η^2 = 0.21, and a main effect of 'Type of Deletion', *F*1(1, 19) = 22.62, p < .0001, η2 = 0.54, *F*2(1, 40) = 26.05, *p* < .0001, η^2 = 0.39. Thus, pseudowords with sonorant codas were more rapidly responded (656 ms) than pseudowords with obstruent codas (677 ms). In addition, the deletion of the coda was more rapidly detected (650 ms) than the deletion of the onset deletion (683 ms). Finally, we found a triple interaction between Coda Sonority x Onset Sonority x Type of Deletion, *F*1(1, 19) = 5.26, p < .03, η2 = 0.22, *F*2(1, 40) = 7.13, *p* < .01, η^2 = 0.15. This triple interaction emerged because the Coda Sonority x Onset Sonority interaction was only significant for 'Coda Deletion', *F*1(1, 19) = 7.71, p < .01, η2 = 0.29, *F*2(1, 20) = 8.73, *p* < .008, η^2 = 0.30. In that case, shortest responses times were found for the optimal Sonorant-Obstruent sonority profile (see Figure 7).

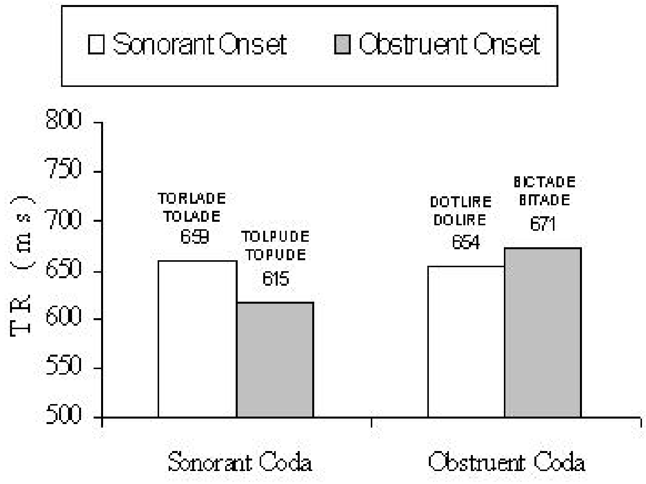

Figure 7. Mean response times (in milliseconds) in the specific 'Coda Deletion' condition as a function of coda sonority and onset sonority

DISCUSSION

In French adult readers, data provided by these experiments brought new evidence for phonological coding in printed syllable processing. Indeed, syllable-based segmentation was found in both illusory conjunction paradigm and bimodal recognition task. Other similarities across tasks can be noticed. First, we showed that sonorant codas (e.g., 'l') were basically better processed than obstruent codas (e.g., 't') whereas obstruent onsets were systematically faster detected than sonorant onsets.

These behavioral data are in line with linguistic and statistical analyses that show a higher probability for sonorants than obstruents as codas and a higher probability for obstruents than sonorants as onsets (e.g., Blevins, 1995; Content et al., 1990). Consistent with this, coda sonority and onset sonority always interacted in both experiments. This interaction revealed that adults faster responded to an optimal sonority profile, namely sonorant coda-obstruent onset, rather than any other sonority profiles. These findings reinforce the linguistic principle for the optimal syllable contact according to which the end of a syllable has to be higher in sonority than the beginning of the following one (Clements, 1990; Murray & Vennemann, 1983). This clear-cut profile could be envisaged as a relevant acoustic-phonetic cue to segment the letter string.

In addition, posterior measures revealed that this optimal pattern was not exclusively due to bigram frequency within syllabic boundary (Lexique database, New, Pallier, Ferrand & Matos, 2001). Indeed, segmentation seems to be independent from low-frequency sonority profiles (e.g., 'TL' (38) and 'DL' (12), 'LR' (0)) as well as from high-frequency sonority-profiles (e.g., 'CT' (2723) and 'PT' (1027)) which represent atypical – or preferentially less typical - sonority profiles. On the other hand, medium-frequency profiles (e.g., 'LP' (254) and 'LD' (118)) can be optimal sonority profiles. This, if bigram frequency played a role in syllable-based segmentation, it would not be as a critical factor.

In experiment 2, the main findings revealed that coda deletion entailed faster response times only when the coda was a sonorant consonant. According to Clements (1990), probability for consonant omission depends on the phonetic properties of the consonant. Indeed, a consonant should be more frequently deleted as it would rank close in sonority from the preceding vowel. Similarly, French syllabic structure analyses revealed a majority of open CV syllables (76% vs. 24% of closed CVC syllables). CV syllable is the simplest and the most frequent syllable type across in all languages (Clements & Keyser, 1983). This would explain why adults tended to reduce a complex syllable structure (e.g., CVC) into a simpler open syllable structure (e.g., CV). The open CV syllable structure is also described as the best sonority profile (Clements, 1990). This principle would account for the easier phonological processing of a sonorant coda compared with an obstruent coda.

In addition, according to Encrevé (1988), coda deletion preserves syllabification (e.g., TOL.PUDE moved to TO.PUDE) whereas onset deletion leads to resyllabification (e.g., TOL.PUDE moved to TO.LUDE). Meanwhile, results according to which syllabification preservation (i.e, coda deletion, e.g., TOL.PUDE moved to TO.PUDE) was better detected than resyllabification (i.e, onset deletion, e.g., TOL.PUDE moved to TO.LUDE) could be explained by a purely visual left-to-right sequential processing. Indeed, onset deletion preserves the three first letters of the letter string (e.g., TOL.PUDE moved to TO.LUDE) whereas onset deletion preserves the two first letters of the letter string only (e.g., TOL.PUDE moved to TO.PUDE). Thus, it is possible to consider that the initial trigram was coded as a whole large unit (such as a syllable). In that case, onset deletion –identical initial trigram like in TO.LUDE- should more difficult to detect than coda deletion –identical initial bigram like in TO.PUDE-.

On the other hand, when there was no deletion in the audio-visual recognition task (responses 'yes'), adults were sensitive to the optimal sonority profile between syllables. When the optimal profile was respected (i.e., the coda of the first syllable was higher in sonority than the onset of the second syllable), adults were able to determine faster whether target and test pseudoword were similar or not. Adults also seemed to be sensitive to the cohesion between vowel and coda as a function of the sonority rank of the coda. When coda ranked high in sonority, a clear offset for the first syllable was probably perceived by the subjects. Thus, adults were sensitive to an accurate clear-cut syllabic boundary in French (see Kaye & Lowenstamm, 1984) as claimed by Content and co-workers in speech perception and recently demonstrated by Bedoin and Dissard (2002) or Fabre and Bedoin (2003) in reading. Coda sonority effect was also observed in the first experiment when skilled readers had to detect a target-letter in the color-syllable compatible condition. Response times were fasters with sonorant codas compared with obstruent codas.

Moreover, significant effect for color-syllable overlap in the first experiment can be considered as evidence for adults' syllable-sized phonological coding. Indeed, target-letter was globally more rapidly detected for color/syllable compatible condition (561 ms) rather than for incompatible condition (605 ms). This effect emerged whatever sonority profiles. In other words, adults would easily access to phonological code when printed stimuli were well-matched with natural syllable structure. As mentioned above, the color-syllable overlap effect was maximized for the optimal sonority profile (i.e., sonorant coda and obstruent onset).

Furthermore, first experiment provided other interesting results as regards consonant status for the consonant to be detected. Indeed, response times were shorter for onset detection compared with coda detection. This effect was found whatever sonority profile. As showed in speech perception (Content et al., 2001a), syllable onset seems to be more reliable than coda. Although the present study laid on pseudowords, onset as alignment point for lexical search (Content et al., 2001a) could be extended to reading and not limited to speech perception. However, this result must be carefully considered as far as it depends on pseudwords, not on words. Finally, the interaction between 'Onset Sonority' and 'Type of Detection' emerged because the advantage of onsets over codas was maximized for obstruent onsets. It is possible to claim that obstruent onset corresponds to the optimal sonority profile, namely, a growing sonority consonant at the beginning of the second syllable.

Finally, low-error rate in Experiment 1 is rather impressive since illusory conjunction paradigm usually leads to lots of errors. Although we respected original settings from Prinzmetal et al. (1986), exposure duration (i.e., 230 ms) might have been sufficient for allowing saccade toward the pseudoword. This critical point could be more deeply investigated by manipulating exposure duration in future research.

To conclude, syllables play a critical role for phonological coding in printed material. Our data showed that sonority profile effect was not restricted to speech perception and also played an important role in reading, at least in skilled readers. I addition, we found highly consistent data across two tasks (a visual letter detection task and an audio-visual recognition task). Data consistency suggests we obtained robust effects as regards sonority profile. Adults are definitively affected by consonant phonetic characteristics. Preference was clearly given to the optimal sonority profile (Sonorant coda - Obstruent onset).

Nevertheless, we should note that consonant status and sonority effects we found were related to pseudoword material. It seems difficult to extend these data to real words. Indeed, systematic variations for sonority profile (i.e., coda sonority vs. onset sonority) are hard to establish because of the lack of balance for consonant type between words. Although this restriction, our data confirm the general idea according to which syllable (whose role is critical in reading) is widely constrained by a set of sub-phonemic characteristics.

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APPENDIX. STIMULI USED IN EXPERIMENTS 1 AND 2.

Target-stimuli used in Experiments 1 and 2

Sonority profile of the intervocalic cluster			
Sonorous-Sonorous	Obstruent-Sonorous	Sonorous-Obstruent	Obstruent-Obstruent
TORLADE	DOTLIRE	TOLPUDE	BICTADE
BIRLOTE	PITLUDE	BULPOTE	PUCTODE
PURLIDE	DATLORE	TALPIDE	DACTULE
TOLRUDE	PIDLARE	TOLDARE	DOPTILE
BILRATE	BUDLOTE	PILDORE	BITPTADE
DALRITE	TADLITE	PULDITE	DAPTOLE