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Comparing French syllabification in preliterate children and adults

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ABSTRACT
The influence of development and literacy upon syllabification in French was evaluated by comparing the segmental behavior of 4- to 5-year-old preliterate children and adults using a pause insertion task. Participants were required to repeat bisyllabic words such as "fourmi" (*ant*) by inserting a pause between its two syllabic components (/fur/-/mi/). In the first experiment we tested segmentation over a range of 49 double intervocalic consonant clusters. A similar general segmentation behavior was observed in both age groups, with a pattern that fit the predictions from a legality principle-based model of syllabification. Experiment 2 revealed that opacity between phonological and orthographic representations lead to increased ambisyllabic responses and a reduction in segmentation consistency in adults. In total, these findings indicate that syllabic forms are consistently represented from an early age, but that segmentation in metalinguistic tasks is susceptible to contamination from spelling and etymological knowledge.

The role of the syllable in both phonology and psycholinguistics has had a long and controversial history. However, it is now widely agreed that the syllable is an essential requirement for the provision of a descriptively adequate phonology (e.g., Hooper, 1972; Pulgram, 1970; Vennemann, 1988), and is central to various theories of prelexical processing or lexical access of spoken words (Segui, Dupoux, & Mehler, 1990; see a review by Kolinsky, 1998), word production (Ferrand & Segui, 1998; Levelt & Wheeldon, 1994), and early speech perception (Bertoncini, Floccia, Nazzi, & Mehler, 1995; Bijeljac-Babic, Bertoncini, & Mehler, 1993; Nazzi, Dilley, Jusczyk, Stattuck-Hufnagel, & Jusczyk, 2005; Nazzi, Iakimova, Bertoncini, Frédonie, & Alcantara, 2006). In particular, for French, it has been argued that the syllable is the prelexical unit of spoken word processing (Mehler, Dommergues, Frauenfelder, & Segui, 1981), as in other romance languages (Sebastiàn-Gallés, Dupoux, Segui, & Mehler, 1992). Alternatively, it has been suggested that syllable onsets provide an alignment point for lexical search (Content, Kearns, & Frauenfelder, 2001).

One potential problem with this seemingly intuitive unit is its definition. Given the task of counting the number of syllables in an utterance, native listeners will have little difficulty, and will generally be in agreement, even from a very early age (Liberman, Shankweiler, Fischer, & Carter, 1974). However, problems arise when listeners are asked to state exactly where one syllable ends and the other starts, with differences of opinion arising between listeners.

EARLIER RESEARCH ON SYLLABLE SEGMENTATION

Considerable efforts have been made over the past decade to evaluate the links between phonological theories and explicit syllabic segmentation in English (Titone & Connine, 1997; Treiman, Bowey, & Bourassa, 2002; Treiman & Danis, 1988; Treiman & Zukowski, 1990) and Dutch (Gillis & De Schutter, 1996; Gillis & Sandra, 1998; Martens, Daelemans, Gillis, & Taelman, 2002), revealing influences from lexical stress and the opposition between long and short vowels in both languages. Surprisingly, it is only recently that similar studies have been made for French (Content, Dumay, & Frauenfelder, 1999; Content, Kearns, et al., 2001; Floccia, Goslin, Bouketir & Bradmetz, 1999; Goslin & Frauenfelder, 2001), possibly because it is often assumed that French has clear syllabic boundaries as a consequence of its syllabic metrics (Abercrombie, 1965), unlike stress-based languages such as English.

In a broad study of French syllabification, Goslin and Frauenfelder (2001) compared the predictions of five disparate segmentation models with the segmentation responses of adult listeners. The tested models were based upon two alternative concepts of syllable segmentation, that of legality (e.g., Hooper, 1972; Kahn, 1980; Pulgram, 1970; Vennemann, 1988) and sonority (e.g., Clements, 1990; Saussure, 1916). The former states that legal syllable onsets and codas are restricted to those phonotactically possible at word–initial or word–final positions. For example, as the consonant cluster /tr/ can be found in word–initial position in French (as in the word “train,” *train*), then it follows that it may also form the onset of syllables in other positions (as in the second syllable of “citron,” *lemon*). Conversely, the cluster /rm/ does not form the onset of any word–initial syllables; therefore, it cannot legally form the onset of noninitial syllables (such as the second syllable of the word “dormir,” *to sleep*). The alternative approach, built around studies of the “sonority scale” (e.g., Saussure, 1916), known as the sonority cycle (Clements, 1990), ranks segments along a sonority scale such that the preferred syllable type shows a sonority profile that rises maximally toward the peak and falls minimally toward the end of the syllable. For example, the sonority profile for the word “citron” drops from the first vowel to a minimum at the plosive /t/, increasing with the liquid /r/ and still further with the second vowel, indicating that the second syllable should have the onset /tr/. In the example “dormir,” the liquid /r/ is more sonorous than the nasal /m/; therefore, in this case the intervocalic consonant cluster will be split between the two syllables. When compared with segmentation responses elicited from participants across a broad range of spoken nonwords containing single, double, and triple intervocalic using a syllable repetition task, it was found that models based upon concepts of legality (Dell, 1995; Laporte, 1993) were the best predictors of segmentation behavior. Of these, the model of Laporte (1993) was able to predict the listener's preferential segmentation response in all of the 57 consonant singleton/cluster types tested, encapsulating the most significant principles in French syllabic segmentation. However, there remains a potential problem concerning the task and population used in the study. As segmentation results were elicited from adult listeners using a metalinguistic repetition task, it is possible that the results could have been partially contaminated by orthographic spelling rules and conventions. This casts some doubts on the phonological foundations of the syllabification rules proposed for modeling adult behavior, and underlines the circularity of the relations among adults' segmentation strategy, phonological theories, and literacy.

SYLLABLE SEGMENTATION AND LITERACY

The potential of the onset of literacy to influence syllabification behavior on spoken words has gained considerable currency in recent years. Gillis and De Schutter (1996) observed that ambisyllabic responses[1] from 5-year-old Dutch children were more frequent in stop, than other intervocalic consonants, whereas no differences were seen with 8-year-old children. The authors offered two possible explanations for this modification: a radical change in the children's phonological representations of ambisyllabicity (lengthening vs. reduplication of the consonant) leading to the equal treatment of all consonant types, or the application of spelling rules, as stops and other consonants are syllabified identically in written Dutch (also see Ehri & Wilce, 1986).

As pointed out by Treiman et al. (2002), the influence of literacy in metalinguistic tasks could be because of the unconscious spelling of words, rather than a true modification of phonological representations. One type of orthographic irregularity that has received recent attention concerns the spelling of single intervocalic consonants in words like *panic* or *bonnet*. Both have a single intervocalic phoneme, /n/, but are represented by single or double graphemes. Using a syllable reversal task Treiman and Danis (1988) reported that American students were much more likely to duplicate the intervocalic phonemes when represented by two graphemes (see also Derwing, 1992). In a similar study with 34-month-old American preliterate children, Zamuner and Ohala (1999) found that ambisyllabic responses were significantly more frequent where intervocalic consonants were represented by double, rather than single consonants. However, this finding could not be replicated in a later study by Treiman et al. (2002) when using a first or second syllable repetition task in older children (first and second graders). A possible explanation for Zamuner and Ohala's unexpected results concerns a potential difference in the experimenter's production of the words to be repeated. Post hoc duration analyses of the first vowel–consonant in words like *mammal* or *camel* may appear to discount these concerns (Ohala, 2001, personal communication, quoted in Treiman et al., 2002). However, a closer examination of frequencies of the words that have been presented to the children forces us to reconsider this issue. It is unrealistic to expect 34-month-old children to know most of the words used (especially, *ballot*, *mammal*, *tennis*, *tarot*, *chapel*, *cabin*, *tenor*) in the experiment.

Experimenters in this study may have been aware of this fact, and therefore, may have unconsciously emphasized some aspects of these rare words (e.g., energy), leading children to produce atypical segmentation responses. Although Zamuner and Ohala did not report analyses by word frequency, Treiman et al. (2002) not only controlled word frequency but also tested older children (minimum 6 years old), who presumably possessed a larger vocabulary.

It is only recently that similar studies have been made for French listeners, with Content et al. (1999) comparing syllabification behavior in 5-, 9- and 12-year-old populations using a pause–insertion task (Experiment 1). As in previous studies, intervocalic consonants were represented in various words by either one or two graphemes. In this study, the role of sonority was also explored by examining segmentation differences between different types of consonants (liquids, nasals, and obstruants), as has been reported in English or Dutch (e.g., Treiman et al., 2002). The findings showed that 5-year-olds were insensitive to changes in written representations, giving canonic consonant–vowel (CV-CV) responses for all words. However, in 9- and 12-year-old populations responses were modulated as a function of intervocalic consonant spelling and sonority.

In our study, we wish to address concerns over the phonological basis of French adult's syllabification behavior by examining how this representation is affected by the onset of literacy. This will be established by comparing segmentation behavior between 4- and 5-year-old preliterate children and literate adults in two experiments. In our first experiment each age group will be presented with a wide range of bisyllabic words containing double intervocalic consonants (such as the word "sergent" containing the sequence /rj/, *sergeant*[2]). In this initial test of general behavior, segmentation can be predicted on the basis of two disparate cues. The first is that the French-specific phonological syllabification model postulated by Laporte (1993) predicts /CC/ segmentation of obstruent-liquid (OBLI) clusters and /C-C/ segmentation or all other double consonant clusters. The second cue consists of written hyphenation rules (Flipo, Gaulle, & Vancauwenberghe, 1994), representing segmentation knowledge gained during literacy. Hyphenation refers to splitting a word that would otherwise extend beyond the right margin (such as *ta-ble, con-text, read-ing*), learned by French primary school pupils between 8 and 10 years of age. These rules have never been exhaustively synthesized, as French, like English, has a complex relationship between oral and written forms that produces numerous exceptions, requiring the application of the writer's intuitions or personal set of rules (Flipo et al., 1994). However, one aspect of hyphenation that appears relatively clear concerns that applied to double intervocalic consonants, which are systematically split, apart from cases where the first consonant is *stronger* than the second (p. 41). The concept *strength* in this case refers to that of sonority, obstruents being less sonorant, therefore stronger, than glides and liquids. Therefore, as with the phonological segmentation of Laporte, the hyphenation rules of Flipo et al. (1994) predict that all double intervocalic clusters should be segmented as /VC-CV/ apart from OBLI clusters, which are segmented as /V-CCV/. As both Laporte's phonological model and Flipo et al.'s hyphenation rules predict the same pattern of segmentation for double consonant clusters, the results obtained by Goslin and Frauenfelder (2001) with adult participants could be difficult to interpret, as they could be because of the application of either phonological syllabic segmentation or spelling rules. Naturally, preliterate 4- to 5-year-old children have no knowledge of hyphenation rules; therefore, a similar pattern of segmentation behavior between our adult and child groups would indicate that phonologically based segmentation behavior in adults are uncontaminated by written language rules.

The approach used in this experiment is quite different than that used by the previous researchers; instead of systematically comparing children's and adults' behavior on words varying on the regularity of their spelling, we compare the general pattern segmentation behavior of our two populations using a large set of bisyllabic words. In this way we aim to investigate the extent that any potential segmentation disparity between the two age groups can be explained by the influence of orthographic knowledge.

One aspect that we will start to examine in the first experiment, and then specifically focus upon in the second, is how orthographic opacity and transparency affects syllabification in adults and children. In transparent orthographic cases there is a direct, one/one relationship between the phonology and the orthography of the cluster (as for /tr/ in "citron," *lemon*), whereas in opaque cases the relationship is more complex, as in the case of "siffler" (*to whistle*), where the first consonant of the /fl/ cluster is represented by a double grapheme "f." These issues will be addressed in the two experiments presented in this paper.

To minimize any contamination because of experimenter expectation, all stimuli were prerecorded on tape by native French speakers who were naïve to the aims of the experiment, instead of being read aloud to the participants by the experimenters (e.g., Content et al., 1999, Experiment 1; Treiman et al., 2002). In addition, analyses of our participant's segmentation responses were also supported by supplementary controls for the possible effects of lexical frequency and morphology.

In selecting the task used to elicit segmentation responses we reviewed a number of metalinguistic tasks used in earlier studies. These were found to include syllable reversal (for the target *melon* participants repeat *lon-me*; e.g., Treiman & Danis, 1988), the repetition of first and second syllables (*me* or *lon*; e.g., Treiman, Gross, & Cwikiel-Glavin, 1992), pause insertion (*me . . . lon*; e.g., Gillis & Sandra, 1998), fragment insertion (*I say me and I say lon*, Content, Kearns, et al., 2001), and the duplication of the first or the second syllable (*memelon* or *melonlon*, Fallows, 1981; Treiman & Zukowski, 1990). Ambisyllabic responses, along with morphological or spelling influences, have been mainly found with the tasks dissociating the temporal link between the first and the second syllable, such as the syllable repetition task or the syllable reversal task. However, in a preliminary study of segmentation with preliterate children (Floccia et al., 1999) we found that young children had difficulties in these types of task, with significantly higher error rates and lower segmentation consistency in syllable repetition rather than pause insertion tasks. Moreover, replication of the obligatory onset principle (Selkirk, 1982; Venneman, 1988; see a review by Content, Kearns, et al., 2001; predicting /V-CV/ segmentation in single intervocalic consonants), the most robust of all segmentation principles, was more consistent in pause insertion tasks. Therefore, because of its simplicity and its efficacy, the pause insertion task was chosen for this study (see also Treiman et al., 2002).

EXPERIMENT 1

In the first experiment we examine and compare the general syllabification behavior of two participant groups: 4- to 5-year-old preliterate children[3] and adults. A pause insertion task was used to elicit segmentation decisions over a range of disyllabic lexical stimuli containing double intervocalic consonants. A similar pattern of behavior in preliterate children and adults will be taken as an indication that French-specific adult syllabification behavior is not contaminated by orthographic knowledge.

Stimuli

Test items. Stimuli are organized as a function of consonant type, combined from nasal (N), fricative (F), liquid (L), and plosive (P) consonants. Double consonant stimuli were organized into 16 double (e.g., FN) consonant categories, from which a subset of 11 were chosen for this experiment (PL, LP, LN, LF, PF, FP, FL, LL, PP, PN, FN). Wherever possible, each of the consonant categories was represented by 16 disyllable words, chosen to represent the widest range of possible consonant clusters. In four categories (LL, PP, PN, FN) there was not sufficient number of valid words available; therefore, a smaller number of stimuli had to be used. In total, 128 words and 49 different clusters were used, as listed in Appendix A.

In estimating children's knowledge of the stimuli used in this experiment, it was thought that French word frequency tables, such as those found in Lexique (New, Pallier, Ferrand, & Matos, 2001), were unsuitable as they are calculated from orthographic sources. Instead, we asked four preschool teachers to independently score each word as to whether the target population would (a) be able to define the word, and (b) produce the word spontaneously. The average measure intraclass correlation between the scores of the four teachers was found to be 0.879. Comparing responses for the two questions for each word we found almost a perfect correlation of scores, r (128) = 0.93, p = .000. The frequency values used in subsequent analyses were calculated from the mean of the two measures given by each of the four raters. These values were found to be significantly correlated with the frequency values found in Lexique, r (128) = 0.284, p = .001.

Distractor and training items. Eighteen distractor words containing between one and three syllables were selected such that they had similar characteristics as the test items (e.g., equal distribution of stimuli beginning with vowels and consonants, or verbs and nouns, as test stimuli) but using different intervocalic consonant clusters or singletons. Ten training items were also selected using the same criteria.

Data collection and stimuli production. Data were collected by 21 groups of second- or third-year psychology undergraduates, each of which had been carefully trained by the second author, as part of their research project. Four hours of research seminar had been especially dedicated to train them to provide the proper instructions, and to score the answers. Because of the large number of stimuli and limited attention span of the participants, each of the experimenter groups was assigned with a subset of 16 stimuli randomly selected from the 11 cluster types, plus the 18 distractors. Each group recruited a female French monolingual speaker for the production of stimuli, and was responsible for the selection of experimental

Table 1. *Experiment 1 distribution of the number of participants and valid responses across cluster categories*

	FP	FL	FN	LP	LF	LL	LN	PP	PF	PL	PN
Children											
Participants	55	16	38	36	35	38	47	38	24	21	38
Responses	417	120	33	271	257	70	338	121	173	147	54
Adults											
Participants	60	10	35	43	47	35	47	35	25	27	35
Responses	474	80	35	317	372	70	372	118	196	210	56

participants. Speakers were naïve to the aims of the experiment; they were simply asked to read from a list of words with neutral intonation, inserting a pause of 3 s between each word (each speaker read a randomized list of the 16 test stimuli, plus 18 distractors, and 10 training items). The words produced by the speakers were recorded onto tape for later presentation to experimental participants. The general design resulted in a multivariate repeated measures split-plot design with two between-group factors (age group and consonant cluster category), one repeated measures factor (cluster tokens in each category), and one dependent variable (segmentation location). In this design the distribution of participants tested per token is unbalanced as students were not equally successful in recruiting and testing participants, nor did all student groups successfully finish this study (see Table 1).

Procedure

Participants were invited to take part in a pause insertion task, consisting of the slow repetition of target words with pauses inserted between each syllable of the word. They were also asked to add rhythm to their speech by clapping their hands if necessary (see Gillis & Sandra, 1998, for a similar procedure). This task is variation of the tapping task first introduced by Liberman et al. (1974) to investigate syllabic awareness, the difference being that these authors did not require participants to repeat the target word but merely to tap for each syllable in the target word.

Participants were tested individually in a quiet room (either at school or at home) by two to three experimenters. The first experimenter explained the task: each participant was asked to take part in a short word game. With children an alien puppet spoke slowly "like a robot" segmenting all the words into syllables. It wanted to learn new words, but understood only if the children spoke like a robot as well. Children were invited to help it learn new words by repeating the recorded stimuli and adding a pause between each "part" of the word. Adult participants were simply invited to repeat the word slowly by introducing a pause at each part. Training examples with feedback were given before the task. The word syllable was not used, and with a few simple examples no further explanations were needed for most of the participants. Another experimenter recorded the answers on a scoring sheet. The experiment was tape recorded to allow verification of the written scores. For each response experimenters noted either the position of the syllable boundary (/V-CCV/, /VC-CV/, or /VCC-V/) or the category of atypical responses. Atypical responses included ambisyllabic behavior (duplication of one of the intervocalic consonants, such as /kol-lʃik/ for “colchique”), the omission or the repetition of phonemes not found in the stimuli (such as “colchi*t*e” for “colchi*qu*e”), and participant uncertainty. Reliability of experimenters’ judgment was assessed by the agreement of the other experimenters of the group present during the session (one or two additional persons). In case of a disagreement on the location of a syllabic boundary, the response “experimenter uncertainty” was reported.

Participants

Children. One hundred thirty-six children were tested successfully. The data of 58 additional children were discarded for the following reasons: lack of participant response (18), lack of interest or concentration (11), experimental error (1), misunderstanding of the task and/or error rate on test items higher than 50% (28). The remaining participants (69 girls, 67 boys) were aged 4 years and 4 months (4;4, range = 3;4–5;0), were all native French monolingual speakers from the Franche-Comté region, and had no recorded auditory problems. They all attended the second year of preschool and were tested between October and November of the same year (see Note 3). Teachers attested that none of participants had significant expertise in reading and writing with the best levels of proficiency equal to the recognition of a few words, such as their own name, and spelling out some isolated letters.

Adults. One hundred forty-seven adults (81 women, 66 men) were tested with a mean age of 25.2 years (range = 17–53). The data of two additional participants were rejected, one because of a misunderstanding regarding the task, and another because of an abnormal number of hesitations. All participants were monolingual French speakers from the Franche-Comté region, had a minimum educational level equal to that of a high school diploma, and did not suffer from dyslexia or other documented reading problems.

Results

Error rates. In children, 7.8% of the 2,187 expected responses were erroneous, of which 6.2% were phonemic errors (omission or repetition of phonemes not found in the stimulus, outside the critical cluster area), 1.4% experimenter uncertainty, and 0.7% participant uncertainty (mainly because of the participants remaining mute). Analyses of the distribution of errors across cluster types revealed that there was no significant pattern of erroneous responses, F (10, 38) $<$ 1. In adults, 1.1% of the 2,352 responses were erroneous, consisting of 0.7% phonemic errors, and 0.4% experimenter uncertainty. Only one incidence of ambisyllabicity occurred in this experiment, therefore this response will be excluded from subsequent analyses.

Rater reliability. To gain a measure of interexperimenter variability, we analyzed differences in the consistency of preferential segmentation responses (the proportion of responses given to the preferential segmentation) reported by each team for each consonant category (except LL, PN, PP, and FN groups, which were grouped because of the limited number of observations in each category). Analyses of variance (ANOVAs) with experimenter team as an interparticipant

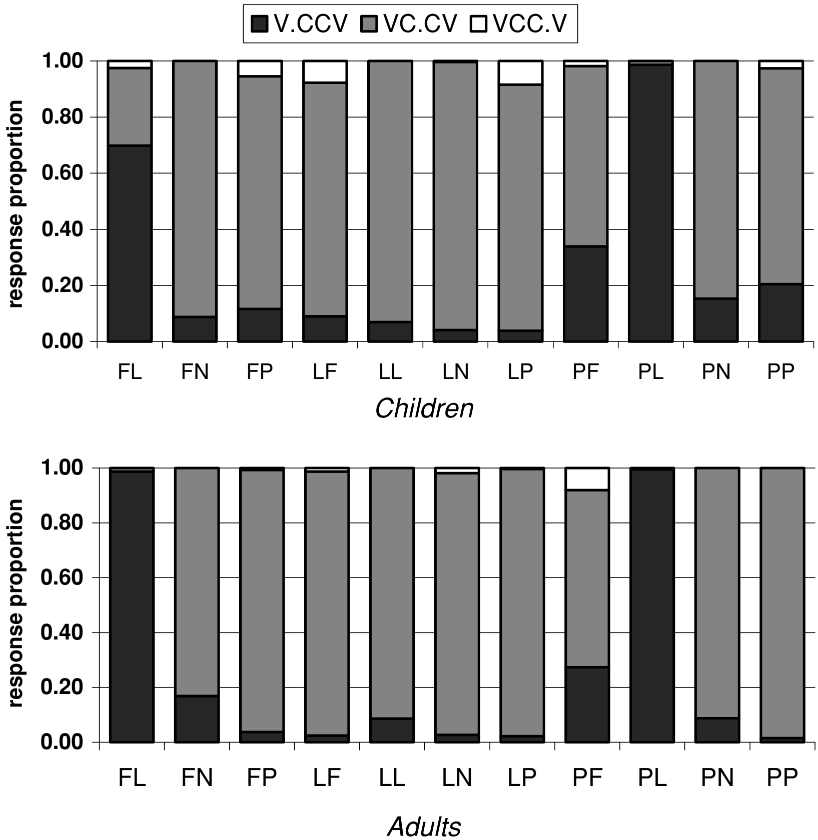

Figure 1. Experiment 1 distribution of all syllabification responses for both participant groups.

variable revealed that the effect of this factor failed to reach significance in any of the consonant cluster categories, for either adult or child responses. This shows that the use of multiple data collection teams did not have any significant effect on the distribution of the data collected.

Segmentation of consonant cluster categories. The segmentation responses for both the child and adult participant groups are presented in Figure 1. However, as the experimental data collected in this experiment was not balanced across cluster categories (responses per category = 35–474), the initial broad analyses of responses were conducted on a random selection of 35 responses for each of the categories. To verify that this random sample was representative of the whole data set, chi-square comparisons were made of the distribution of segmentation responses between the full data set and the balanced subset for each consonant category. No significant difference between responses in both adult and child groups was found for each of the categories at $\alpha = .05$ (5.991 with $df = 2$). Using this subset of responses we conducted hierarchical log-linear[4] analyses to examine the general segmentation behavior of our participants, and to establish whether there was any significant deviation in this behavior between participant groups. These analyses were performed on the frequency of the three possible segmentation responses (/V-CCV/, /VC-CV/, and /VCC-V/) between the factors of participant group (children and adults) and consonant cluster category (LL, LP, etc.). We found that for /V-CCV/ ($G^2 = 11.93$, $df = 11$, $p = .369$) and /VC-CV/ ($G^2 = 10.24$, $df = 11$, $p = 0.508$) responses, the best fitting model was provided by a main effect of consonant category. For /VCC-V/ responses null model provided the best fit ($G^2 = 31.17$, $df = 21$, $p = .071$), with no significant effect of either of the experimental factors. These initial analyses indicate that the consonant cluster category of the stimuli had a significant effect upon the segmentation behavior, and that there was no significant difference in this effect between the adult and child participant groups.

Further analyses were conducted on the full set of responses to establish how the participants segmented each of the categories. For each category, chi-squared measurements were calculated on the frequencies of *all* participant responses. For each of the consonant types in each group, the chi square was higher than critical at $\alpha = .05$ (5.991 with $df = 2$), indicating a preferential segmentation response. This revealed a /VC-CV/ preferential segmentation response for nine of the cluster types, with /V-CCV/ segmentation for the OBLI categories FL and PL. Because the low proportions of zero onset responses (3.6% of all responses) may bias these results, the chi-squared tests were repeated with the frequencies of only /V-CCV/ and /VC-CV/ responses, revealing the same pattern of preferential segmentation as before. These analyses showed a similar pattern of segmentation behavior seen in the study of Goslin and Frauenfelder (2001), where adults segmented all double intervocalic consonant clusters with a single consonant onset, apart from OBLI clusters, which were tautosyllabic.

Cluster analyses of segmentation responses. To examine the behavior of participants in greater detail, cluster analyses of the segmentation responses of individual clusters were conducted. Inspection of the grouping of segmentation behavior for particular clusters should serve to highlight localized differences between the adult and child participant groups. Fully interlinked hierarchical cluster analyses were made for each group using the same balanced subset of subject responses used in the previous log-linear analysis. These analyses were based on a count of responses for each of the three possible segmentation responses (/V-CCV/, /VC-CV/, and /VCC-V/) using a chi-squared similarity measure.

The resulting dendrograms for both groups are shown in Figure 2. Deciding where to cut the stems of a dendrogram is a subjective process. However, in general, a level is sought such as to maintain the highest possible similarity level that will yield distinct clusters. An inspection of the dendrograms for both groups shows an identical grouping of stimuli in the initial clusters: those marked as 1 and 2, with a distance between clusters of 1.31 for adults and 1.15 for the children. The second cluster, consisting of stimuli from the /FL/ and /PL/ consonant categories, is typified by syllabification resulting in a double consonant onset. The first cluster consists of the remaining stimuli, those generally syllabified with a single consonant onset, as shown in Figure 3. However, it is in this first cluster that differences can be observed between the groups. Although in children there are no further distinct clusters, in adults there are two clear subclusters, marked 1.1 and 1.2, with a distance of 0.79. The segmentation responses for stimuli in cluster 1.1 are similar to those of cluster 1 in children (that is, mainly /VC-CV/). However, in cluster 1.2, consisting of stimuli /gz/, /ks/ and /tʃ/, there is a high incidence of both /V-CCV/ and /VCC-V/ responses.

A chi-squared analysis of the three possible segmentation responses showed that, in adults, there was a significant difference between the distribution of responses in clusters 1.2 and 1.1 ($p < .0001$, $\chi^2 = 371.28$, $df = 2$) and between clusters 1.2 and 2 ($p < .0001$, $\chi^2 = 217.92$, $df = 2$). In addition, a chi-squared analysis showed that there was a significant difference between adults and children for these /gz/, /ks/, and /tʃ/, stimuli ($p < .05$, $\chi^2 = 7.22$, $df = 2$). These results reveal that /gz/, /ks/, and /tʃ/ stimuli do elicit a different segmental behavior than other stimuli, and that this difference is only present in adults. The most likely explanation of the segmental behavior for the clusters /ks/ and /gz/ is orthographic bias. Both of these clusters can be represented by a single grapheme, "x," as in the words "klaxon" (/klaksɔ̃/) or "exact" (/ɛgzakt/), or a double grapheme such as the sequence "xc" ("excite," /ɛksit/), "cc" ("accent," /aksɛ̃/), or "cz" ("eczema," /egzema/). To examine the possible effect of orthography on the segmentation of the cluster /ks/ (/gz/ could not be tested as it is represented by a single word "exact") we compared the segmentation of this cluster when represented by a single grapheme ("taxi," "boxeur," "klaxon," "vexer") and a double grapheme ("accent," "action," "excite," "vaccin"). These analyses revealed that there was a significant difference in segmentation because of the orthographic representation of words in the adult group ($\chi^2 = 16.43$, $df = 1$, $p < .001$) but not in children ($\chi^2 = 1.45$, $df = 1$, $p > .05$). Furthermore, direct comparisons between children and adults revealed a significant difference in the segmentation of words represented by a single grapheme ($\chi^2 = 6.02$, $df = 2$, $p < .05$) but not in those represented by a double grapheme ($\chi^2 = 4.38$, $df = 2$, $p > .05$).

These analyses reveal a significant effect of orthographic bias in adults when double consonant clusters are represented by single graphemes. However, among the stimuli chosen for this experiment, there is a different form of orthographic opacity, when double intervocalic clusters are represented by three graphemes (e.g., "coffret," *casket*). Could this disparity, exclusively seen in the FL category, also affect segmentation behavior in adults? We compared the segmentation of the clusters represented by three graphemes ("offrir," "coffret," "affreux," "souffler," and "siffler") with that of the remaining, transparent, FL clusters. Fisher exact probability tests revealed no significant difference between these opaque and transparent stimuli in either adults ($p = 1.0$) or children ($p = .92$), suggesting that orthographic opacity only has a significant effect upon the segmentation behavior of adults when it acts to restrict the selection of the canonical phonological segmentation, as in the case of /ks/ represented by the grapheme "x."

Morphological boundaries and segmentation. Because of the nature of the task and stimuli it is possible that participants could be led to segment along morphological, rather than syllabic, boundaries. An inspection of the stimuli shows that of the 128 words used in the experiment 75 contained morphological boundaries (shown on the list of stimuli in Appendix A as boundary between normal and

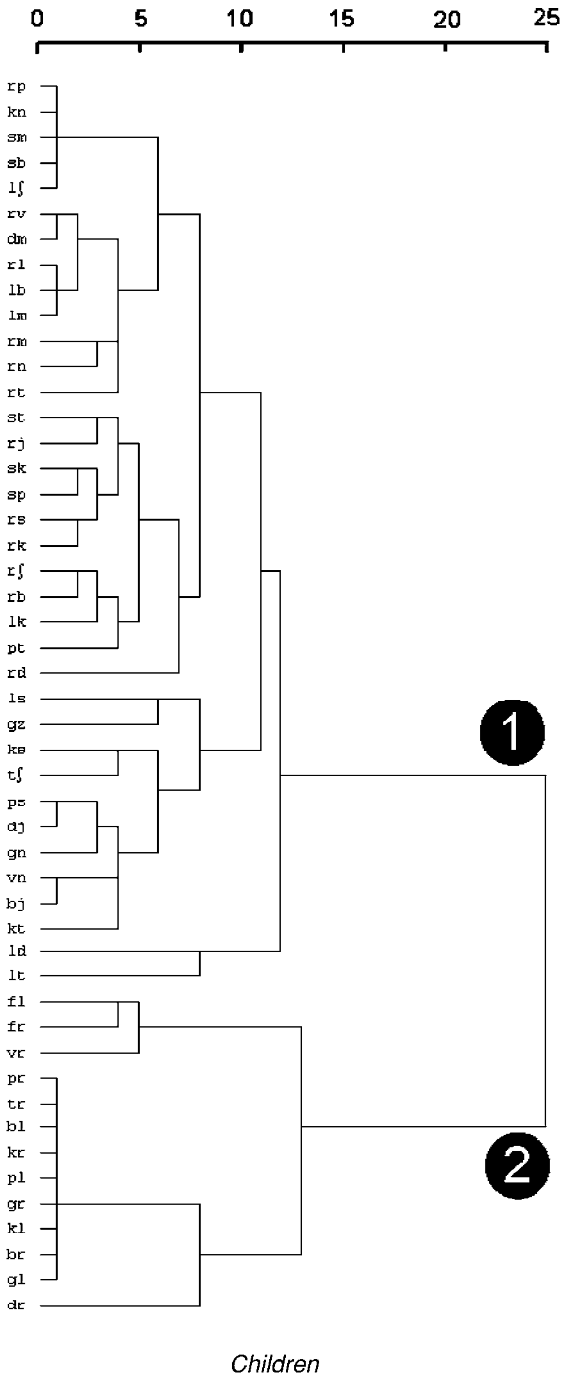

Figure 2. Experiment 1 hierarchical cluster analyses of a subset of consonant category balanced segmentation responses for each cluster.

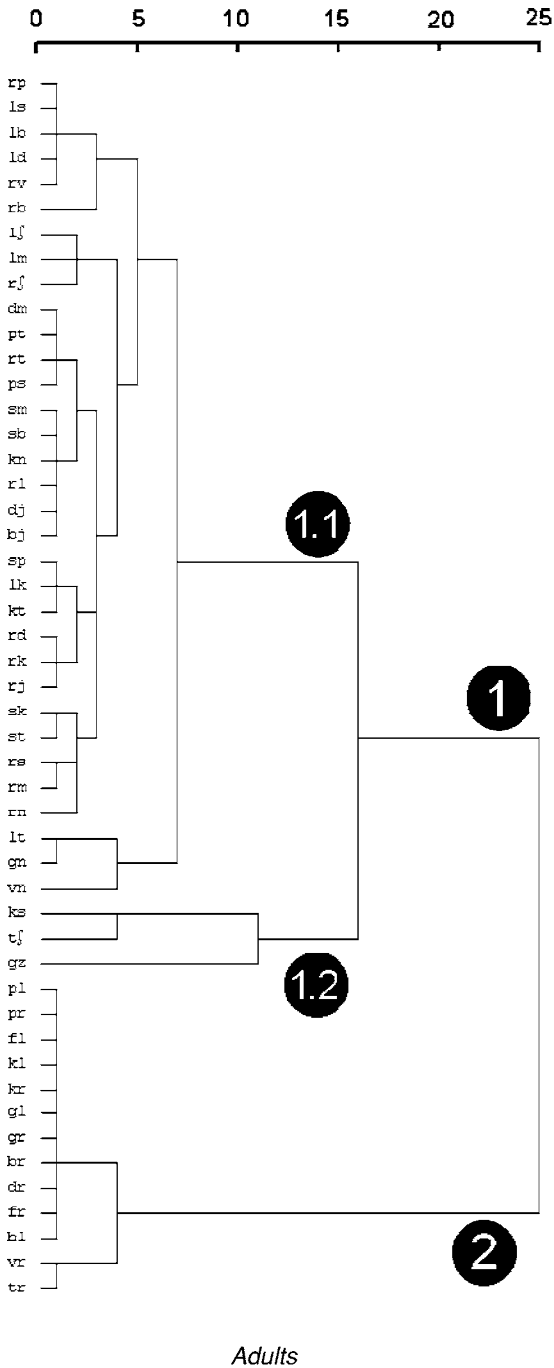

Figure 2 (*cont.*)

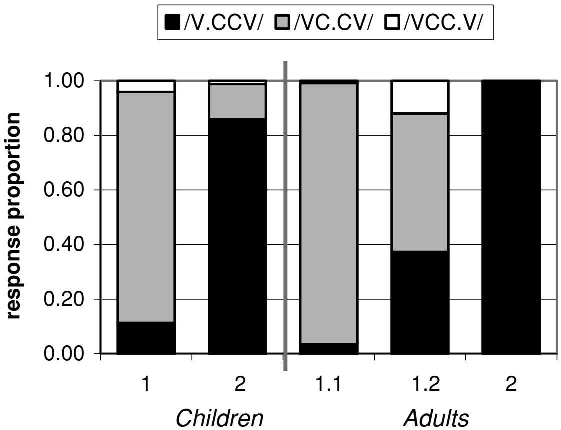

Figure 3. Experiment 1 proportion of all segmentation responses for clusters in children and adults, according to the categorization given by the cluster analysis (cluster 2: FL and PL; cluster 1: the remaining nine categories; cluster 1.1: minus /gz/, /ks/, and /tʃ/; cluster 1.2: /gz/, /ks/, and /tʃ/).

underlined text). In the majority of these cases (64 words) the morphological boundary was found at the end of the consonant cluster under analysis (/VCC-V/). For the remaining words eight had morphological boundaries that split the consonant cluster (/VC-CV/), and three before the cluster (/V-CCV/). A chi-squared comparison of the proportion of /VCC-V/ segmentation decisions across the 64 words with /VCC-V/ morphological boundaries and the control set of 53 words without morphological boundaries revealed no significant effect of morphology in adults ($\chi^2 = 1.53$, $df = 1$) or children ($\chi^2 = 0.47$, $df = 1$). For the eight words with /VC-CV/ morphological boundaries a similar comparison was made, only this time we compared the proportion of /VC-CV/ responses in these words and a control set. As before, chi-squared analyses did not reveal any significant difference in segmentation behavior between words, with or without morphological boundaries in either adults ($\chi^2 = 0.03$, $df = 1$) or children ($\chi^2 = 0.15$, $df = 1$). A statistical examination of words with /V-CCV/ morphological boundaries was not possible because of the small number of stimuli.

Word frequency and segmentation. No significant correlation was found between frequency (given by Lexique and by the preschool teachers' rating) and the consistency of segmentation decisions in the child, $r(128) = 0.105$, $p = .24$, or adult groups, $r(128) = .110$, $p = .22$.

Discussion of Experiment 1

The clearest result of this experiment is the high degree of similarity found between the segmentation responses of our participant groups, preliterate children and adults. All double intervocalic clusters were syllabified with a single consonant onset, with the exception of OBLI clusters, segmented with a double consonant onset. These findings are in agreement with those of Goslin and Frauenfelder (2001), who used a syllable repetition task with nonlexical stimuli to elicit segmentation decisions from adults. Therefore, it appears that even at the age of 4 our syllable segmentation strategies are well established and are not the result of, nor drastically changed by, the advent of literacy or further cognitive development. It also shows that the segmentation behavior observed in adults cannot be attributed to the acquisition of spelling rules such as hyphenation (Flipo et al., 1994), because preliterate children display much the same behavior without any knowledge of these writing rules.

However, more detailed cluster analyses highlighted a number of exceptions to the behavioral parity across populations, namely the atypical segmentation of the clusters /gz/, /ks/, and /tʃ/ in adults (accounting for 3 out of 49 clusters tested in this study) resulting in a high proportion of double consonant (/V-CCV/) and zero consonant onset (/VCC-V/) responses. It is suggested that for the clusters /gz/ and /ks/, this pattern of behavior is because of confusion as to whether the cluster is made of one or two segments, as orthographic knowledge is conflicting with phonological representations. Similarly, Frauenfelder et al. (1990) showed that French students took longer to detect the phoneme /k/ than /p/ in spoken words. They argued that this was because in French /k/ has multiple orthographic realizations, whereas /p/ has only one (see also Dijkstra, Roelofs, & Fieuws, 1995; Frauenfelder, Segui, & Dijkstra, 1990; Muneaux & Ziegler, 2004).

An explanation for similar differences in segmentation behavior between age groups for the cluster /tʃ/ could be related to its low frequency and foreign origins. In a search of the BRULEX lexicon (Content, Mousty, & Radeau, 1990) this cluster was only found in 28 words, all of which were imported, or derived from (mainly English) words such as “catch” or “kitchenette.” The etymological knowledge shared by adults might interfere with the normal segmental behavior of the participants, as they have to deal with conflicting segmentation cues. Therefore, it seems likely that these three atypical segmentation cases are because of the acquisition of knowledge unrelated to speech segmentation.

The prevalence of another indicator, ambisyllabicity, has been exceptionally low in this experiment. This finding is similar to that seen in a previous study by Content et al. (1999), where the segmentation responses of 5-year-old French children were also elicited using a pause insertion task (Experiment 1). They found that when segmenting intervocalic consonants, ambisyllabic responses were only found with liquid clusters (generally the most ambisyllabic segment, e.g., Content, Kearns, et al., 2001; Treiman et al., 2002), and then in only 1.6% of responses. However, in children aged 9 and up, Content et al. (1999) reported increased ambisyllabic responses in words spelled with a double grapheme (e.g., “marron”), rather than a single grapheme (e.g., “baron”). In our experiment consonants were represented by double graphemes in five words, each representing /f/ in the /fl/ and /fr/ OBLI clusters (e.g., “siffler”). However, when compared with transparent FL stimuli, no differences were found in the segmentation of these words in either adults or children. In these cases it is possible that the lack of ambisyllabic responses could relate to the presence of the double grapheme in OBLI clusters, considered highly tautosyllabic. In addition, the nature of the pause insertion task would generally prevent ambisyllabic responses as phonemic duplication produces an obvious mismatch with the target word. With syllable repetition tasks, where single syllables are repeated in isolation, the mismatch between stimulus and response evident in ambisyllabic responses can be hidden from participants (by blocking first and second syllable repetition separately), leading to a higher rate of ambisyllabic responses in various languages (Content, Kearns, et al., 2001; Gillis & De Schutter, 1996; Goslin & Frauenfelder, 2001; Treiman & Danis, 1988; Treiman et al., 2002).

In summary, a comparison of segmentation between preliterate children and literate adults revealed the same broad behavior between groups over a wide range of stimuli with only isolated discrepancies, limited to cases of possible orthographic interference, such as where graphemic and phonemic representations are at odds. In our second experiment we focus upon these potential orthographic influences, contrasting the segmentation of clusters with transparent and opaque orthographic representations in a more controlled experimental setting.

EXPERIMENT 2

The main aim of this experiment is to reexamine the potential role of orthography highlighted in the previous experiment. The syllabification of two classes of intervocalic consonant cluster will be compared: those where the relationship between phonological and orthographic representations is opaque, and the other where it is transparent. In the latter case, there is a direct, one/one, relationship between the phonology and orthography of the cluster, as in the case of the cluster /tr/ in the word "citron" ("*lemon*"). In opaque cases the relationship is more complex; for example, in the word "taxi" the intervocalic cluster /ks/ is represented by a single grapheme "x," and in "siffler" the first consonant of the cluster /fl/ is represented by a double "f.' In the latter case, both Treiman et al. (2002) and Content et al. (1999) found that syllabic segmentation was less consistent in adults but not in preliterate children.

Stimuli

The transparent class of stimuli was represented by eight words equally split between those with FL (OBLI) and PF (non-OBLI) categories of intervocalic consonant cluster. For the opaque class, the eight words were split between those with PL (OBLI) and LL (non-OBLI) clusters consonant clusters. Stimuli in each category were selected for both high frequency (according to the ratings used in Experiment 1) and the ease to which they could be represented pictorially. In the transparent category, all consonant clusters are directly represented by their graphemic counterparts (e.g., /rl/ in "horloge," *clock*). In the opaque class the PF cluster /ks/ was represented by "x" in "boxeur" (*boxer*) and "taxi" (*taxi*), /tʃ/ by "tch" in "atchoum" (*sneeze*), and /dz/ by "zz" in "pizza" (*pizza*). For the FL clusters /fl/ was represented by "ffl" in "siffler" (*to whistle*) and "souffler" (*to blow*), whereas /fr/ was represented by "ffr" in "coffret" (*casket*) and "fr" in "gaufrette" (*small waffle*). The final word, "gaufrette," was included in the opaque class as the intervocalic cluster is often misspelled as "ffr." A complete list of the stimuli used in this experiment can be found in Appendix B. Four disyllabic distractor words were chosen to represent each of the LF, FP, LN, LP, and PP categories, with four additional words containing single intervocalic consonants. Participants were presented with a randomized list of all forty of the test and distractor words.

Procedure

In this experiment only one speaker and experimenter was used to record and present the stimuli, with each participant presented with a complete set of stimuli from both conditions. Stimuli were produced by a female speaker from Besançon, who was naïve to the aims of the experiment. As in the previous experiment a pause insertion task was used to elicit segmentation responses. After a response was given, participants were also asked to indicate an understanding of each of the words by pointing to a representative pictogram from a choice of two, to ensure that analyses of segmentation would only bear on lexically represented stimuli. All responses were recorded and later analyzed by the two independent raters, each noting the position of the syllable boundary (/V-CCV/, /VC-CV/, or /VCC-V/) or one of a number of predefined categories of atypical responses.

Participants

The group of preliterate children comprised 13 4- to 5-year-old French monolinguals, including eight girls, from the Besançon region. These participants had a mean age of 4 years and 4 months (4;4, range = 3;4–4;10) and were selected using the same criteria as the previous experiment. The responses of 6 additional children were collected but later discarded because of lack of participant response (two), a misunderstanding of the task (one), an error rate of greater than 25% (three). In the adult group, 19 participants were tested, having a mean age of 26 years (range = 20–54), although the data from 1 participant was rejected because of a high overall error rate (>25%). As in the previous experiment, all of the adults had a minimum educational level equal to that of a high school diploma and did not suffer from dyslexia or other documented reading problems.

Results

Error rates. In children, 23% of the 208 responses were erroneous, consisting of 10% participant uncertainty (participants remaining mute, repeating a word different from the target item, or omitting or repeating phonemes not found in the stimulus, outside the critical cluster area), 3.8% experimental error, and 6.7% because of picture misidentification. The analysis of the distribution of errors across consonant cluster categories showed that there was no significant pattern of erroneous responses ($p > .05$). In the adult group, only a single error was recorded (0.3% of all responses). For the remaining responses the reliability of the raters judgment was found to be 100% for the adult group and 99.85% for the child group ($\kappa = 0.993$). Items scored differently by the two raters were removed from subsequent analyses.

Ambisyllabicity. In this experiment, a significant number of ambisyllabic responses were reported in both adults and children. In all of these cases the initial consonant of the cluster was found to be ambisyllabic, resulting from responses such as /sif/-/flɛ/ for the word “siffler” (/siflɛ/). In adults, ambisyllabic responses were found exclusively in the opaque categories, with 9 (12.5% of responses) in FL and 12 (16.9%) in PF categories (comparison of ambisyllabicity in opaque and transparent categories: $\chi^2 = 22.82$, $df = 1$, $p < .001$). In children, six ambisyllabic responses were reported (15.8% of responses), limited to the opaque PF category, resulting in a higher occurrence rate in this category as compared to any other (Fisher exact probabilities: PF-PL, $p = .006$; PF-FL, $p = .011$; PF-LL, $p = .025$). Comparisons of ambisyllabic responses in adults and children revealed an increased prevalence of these responses in the adult population for the cluster FL only (Fischer exact probability = .025). In summary, both adults and children gave ambisyllabic responses in the opaque category, but this was restricted to the PF clusters in children.

Segmentation pattern. For the OBLI clusters, χ^2 goodness of fit tests on the distribution of responses revealed a significant preference for /V-CCV/ segmentation for both transparent category PL (adults: χ^2 goodness of fit = 116.86, $df = 2$, $p < .001$; children: $\chi^2 = 94$, $df = 2$, $p < .001$) and opaque category FL (adults: $\chi^2 = 51.52$, $df = 2$, $p < .001$; children: $\chi^2 = 66.62$, $df = 2$, $p < .001$). For the non-OBLI stimuli the transparent category LL was segmented as /VC-CV/ (adults: $\chi^2 = 116.08$, $df = 2$, $p < .001$; children: $\chi^2 = 53.54$, $df = 2$, $p < .001$), but the opaque category PF was segmented as /V-CCV/ (adults: $\chi^2 = 23.02$, $df = 2$, $p < .001$; children: $\chi^2 = 38.69$, $df = 2$, $p < .001$; see Figure 4).

At first glance, preferential segmentation for the opaque, PF, cluster would appear to be at odds with the findings of the first experiment, where there was a preference for /VC-CV/ segmentation in adults and children. However, these differences are likely to reflect differences in the distribution of stimuli that make up the category in each experiment, as the stimuli representing the category in this experiment were chosen specifically for the susceptibility to orthographic influence. Indeed, a direct comparison of the segmentation responses for PF stimuli found in both experiments (the words "atchoum," "boxeur," and "taxi") showed no significant differences between the responses to these stimuli between Experiments 1 and 2 in adults (Fischer probability test, $p = .74$). However, the same comparison yielded a significant outcome in children ($p = .0012$), with a greater proportion of /V-CCV/ responses in Experiment 2 (88% responses) than Experiment 1 (44% of responses).[5] In summary, children and adults displayed similar segmentation behavior for all four types of clusters, reproducing results of Experiment 1, with the exception that children exhibited an unexpected number of /V-CCV/ responses for the opaque PF clusters.

Segmentation consistency. Segmental consistency was examined by comparing the distribution of segmentation responses between the preferred segmentation and the sum of other valid segmental responses. A log-linear analysis was used to compare the frequency of the preferred segmentation responses between the factors of participant group (children and adults), OBLI status (OBLI and non-OBLI clusters), and orthographic transparency (opaque and transparent clusters). The best fitting model for segmental consistency was provided by an interaction between participant group and orthographic transparency, plus an interaction between OBLI status and orthographic transparency ($G^2 = 1.79$, $df = 2$, $p = .408$). Further analyses were also conducted to explore the effects underlying these interactions. In adults, cross-comparisons of opaque (PF and FL) and transparent (LL and PL) categories revealed that the OBLI/non-OBLI status of the categories had no significant bearing upon consistency. However, responses across transparent

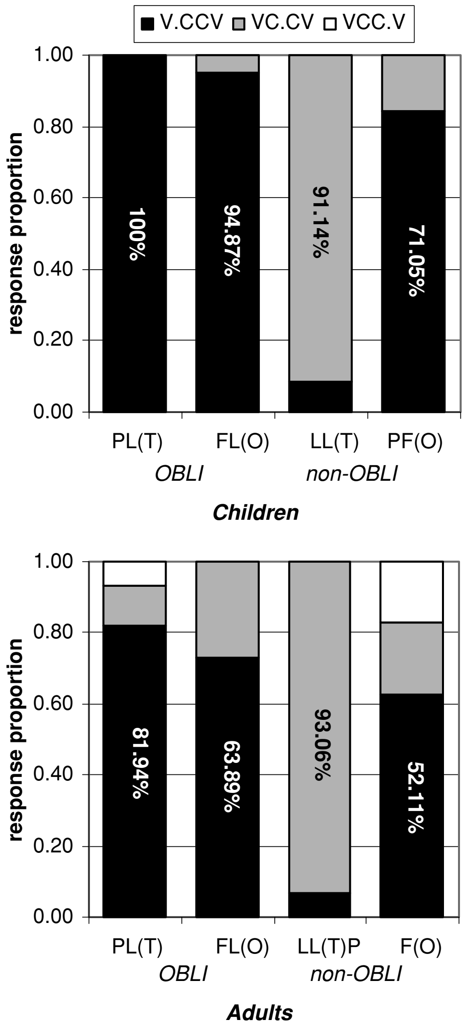

Figure 4. Experiment 2 distribution of syllabification responses (with consistency percentages for preferred segmentation response) across both participant groups for consonant categories with opaque (O) and transparent (T) orthographic representations.

categories were found to be significantly more consistent than opaque categories ($\chi^2 = 12.18$, $df = 1$, $p < .001$). Contrastively, children's segmental uncertainty appears to be strictly limited to the PF category. They were more inconsistent in this category than in any other categories (Fisher exact probabilities: PF-PL, $p < .001$; PF-FL, $p = .006$; PF-LL, $p = .037$), whereas no significant difference could be found between the segmental consistency of any of the other clusters (LL, PL, and FL). Finally, comparisons of segmentation consistency between adults and children revealed that the only significant difference between the age groups were found in the OBLI categories FL (Fischer exact probability = .02) and PL (Fischer exact probability = .007), where consistency was higher in the child population. In summary, these analyses show that children and adults were more inconsistent with opaque categories than transparent ones, but that in children, this inconsistency was restricted to the PF clusters.

Morphology and frequency analysis. Out of the 16 test stimuli, 6 were monomorphemic and 10 bimorphemic, with a morphological boundary at the end of the intervocalic consonant cluster (/VCC-V/; apart from "horloge," where the morphological boundary splits the cluster). As in Experiment 1, chi-squared analyses revealed that there was no significant difference in the relative frequency of /VCC-V/ responses (adults: $\chi^2 = 1$, $df = 1$, $p = .31$; children: $\chi^2 = 0$, $df = 1$) for words that had a morphological boundary at this point, and those that did not. In addition, no significant correlation between frequency (taken from Lexique or from preschool teachers) and segmental consistency was found for either child, $r(16) = .14$, $p = .55$, or adult groups, $r(16) = .21$, $p = .43$.

Discussion of Experiment 2

In this experiment we explicitly examined the role of orthography upon syllabification by contrasting the segmentation of clusters with either an opaque or transparent relationship between orthography and phonology. The results showed that in adults there was a significant reduction in segmental consistency and an increase in ambisyllabic responses when intervocalic clusters are represented by an opaque orthographic form. With preliterate children indicators of segmental uncertainty were limited to a single category, the opaque category PF. Not only was segmentation consistency found to be significantly lower in this category than any of the others, it was also the only category to provoke ambisyllabic responses in children. However, it is unlikely that this uncertainty stems from the influence of orthography, as the segmentation consistency for the other opaque category (FL) was no different to that of the two transparent categories.

When taken in isolation, it is difficult to explain why children should have special difficulties in segmenting the stimuli chosen to represent the PF category in this experiment. However, if we turn the problem on its head and widen our analyses to examine where we *do* find highly consistent segmentation, we find that all of the other stimuli used in this experiment contained liquid consonants. For half of these categories the special segmental status of liquid consonants is already well established, as they combined with obstruent consonants to form tautosyllabic OBLI clusters. In the final case, the category LL, the close association between the preceding vowel and the first liquid consonant would also ensure consistent segmentation (/VC-CV/).

Evidence for the special segmental status of liquid consonants in French originates from a study of Content, Meunier, Kearns, and Frauenfelder (2001), who attempted to replicate the "syllable effect" crossover interaction of Mehler et al. (1981) using a wide range stimuli. In both studies participants were asked to detect /CV/ and /CVC/ targets in /CV-CV/ and /CVC-CV/ auditorily presented carrier words. In the original study of Mehler et al. (1981) the initial (pivotal) intervocalic consonants were always liquid consonants, whereas Content, Meunier, et al. (2001) tested a range of pivotal consonants from stop, fricative, and liquid classes. They found that the requisite components of the crossover interaction were only found when a liquid pivotal consonant was used, pointing to the privileged segmental role of liquid consonants in indicating potential syllable boundaries. A reexamination of segmentation consistency results of Experiment 1 also supports this hypothesis. We found that the average consistency for clusters that did not contain liquid consonants (FN, FP, PF, PN, and PP categories) was 88.2% in adults and 78.3% in children. This was significantly lower than OBLI (PL and FL) categories, with 99.3% consistency in adults ($\chi^2 = 31.11$, $df = 1$, $p < .001$) and 99.2% in children ($\chi^2 = 6.12$, $df = 1$, $p = .013$), or categories with an initial liquid consonant (LF, LL, LN, and LP), with 96% consistency in adults ($\chi^2 = 42.3$, $df = 1$, $p < .001$) and 90% in children ($\chi^2 = 40.92$, $df = 1$, $p < .001$). Moreover, a simple statistical investigation of French phonotactics indicates that liquid consonants are more prevalent than might be expected. Of all /CVC-CV(C)/ words found in the French lexicon Lexique (New et al., 2001), we found that nearly twice as many words with liquid pivotal consonants as those without (1,979 with liquid first consonant, 1,051 with other types of consonant) and that the total frequency of the former words (8,413) was nearly 3.5 times greater than the latter (2,458). Therefore, any syllabification mechanism that relies upon the presence of liquid consonants for accurate segmentation would be effective in a large majority of cases. This could indicate that the relation between liquid consonants and syllabification is so powerful that segmentation consistency drops when this cue is absent, requiring the listener to fall back upon other less effective cues.

Why ambisyllabic responses were virtually absent in Experiment 1 and more frequent in Experiment 2 is more difficult to explain, although the distribution of distractors in the two experiments could have a potential role in this disparity. In Experiment 1, over 56% of the words presented to the participants were distractors, the majority containing only a single intervocalic consonant, compared to only 16% in Experiment 2 (four words out of 24 distractors). It is possible that the relatively high frequency of words using single intervocalic consonants in Experiment 1 has acted to suppress the spontaneous tendency toward ambisyllabic responses.

CONCLUSIONS

The main aim of this study was to investigate concerns over the phonological basis of French syllabification behavior after the onset of literacy. In Experiment 1, a wide range of stimuli were used to capture the general segmentation behavior of preliterate children and literate adults, whereas Experiment 2 focused upon the contrast between clusters with transparent and opaque orthographic forms. The global segmentation behavior in the two populations was found to be broadly similar, highlighting the phonologically based origins of syllabic representations throughout the intervening development. Participants demonstrated a significant preference for /VC-CV/ segmentation for non-OBLI clusters, and /V-CCV/ for OBLI clusters (Goslin & Frauenfelder, 2001; Laporte, 1993). However, exceptions to this general pattern of segmentation behavior were first noted in

Experiment 1, and subsequently confirmed in Experiment 2, in cases where the relationship between phonological and orthographic representations was opaque. When phonological and orthographic representations are at odds, the discrepancy between these forms was shown to cause segmental uncertainty in adults, resulting in reduced segmentation consistency and ambisyllabicity. Whether the influence of literacy in segmentation tasks is caused by the unconscious spelling of words or modification of phonological representations, once access to word orthography has become an automatic routine in late childhood, remains an empirical question (Treiman et al., 2002).

The important role that liquid consonants play in guiding syllable segmentation was highlighted in both experiments. In the minority of cases where these consonants are not present, such as in the PF category, there is a corresponding reduction in segmentation certainty. Liquid clusters seem to provide a preferential segmentation cue in French (Content, Kearns, et al., 2001; see Discussion of Experiment 2). Could this cue be generalized across other languages?

Usually defined as nonnasal sonorant consonants, liquids are common phonemes across languages, and were found in 96% of the 317 languages studied by Maddieson (1984). Various metalinguistic tasks point to higher levels of cohesion between liquids and preceding vowels than other consonants in English (e.g., Treiman et al., 2002; Treiman & Cassar, 1997), Dutch (Gillis & De Schutter, 1996), and French (Content et al., 1999; Content, Kearns, et al., 2001; Goslin & Frauenfelder, 2001). This behavior follows the preferred syllable structure proposed by Vennemann (1988), where the coda of a syllable should be higher in sonority than its onset, making liquids perfect candidates for the coda position of syllables in any language.

However, whereas Content, Meunier, et al. (2001) established that liquid pivotal consonants elicit robust syllabic effects in French, similar studies in other languages offer mixed results. In Catalan and Spanish, robust syllabic effects were obtained using a mixed set of liquids, fricatives, and nasals as pivotal consonants (Bradley, Sanchez-Casas, & Garcia-Albea, 1993; Sebastian-Galles et al., 1992), whereas Cutler, Mehler, Norris, and Segui (1986) failed to elicit any syllabic effect in English with liquids as pivotal consonants. It is possible that the role of liquids is particularly important in French because of its status as a syllable-timed language (e.g., Abercrombie, 1967; Ramus, Nespor, & Mehler, 1999), with the reputation for clear syllable boundaries. Actually, this property also leads to extensive resyllabification, resulting in frequent asynchronies between word and syllable boundaries. The most typical case is known as "liaison," which describes the insertion of a consonant between a word ending in a vowel and another starting with a vowel.[6] In this context, there is a strong necessity for a French listener to use complementary cues to locate word boundaries, such as acoustic/phonetic information, lexical regularities, or context (Bannert, 1998; Spinelli, McQueen, & Cutler, 2003). However, in the presence of liquid clusters, it is unlikely that listeners would even require these additional acoustic cues to word boundaries. Boë and Tubach (1992) analyzed 20 hours of French adult speech, reporting that 99.7% of all liaisons are /n/, /t/, and /z/, with the remainder shared between /p/, /ʀ/, and /d/. Therefore, because liquids are very uncommon as liaison consonants, it appears that the privileged role of these phonemes in guiding syllable segmentation may also be extended to the search for cases of syllable and word synchrony.

These results, along with similar observations regarding inter- and intraindividual variations in syllabic segmentation consistency (see Goslin & Frauenfelder, 2001), add to the growing body of evidence inconsistent with current deterministic models of segmentation. There is growing evidence that stored perceptual representations used in prelexical and lexical processing must encompass significant extraneous acoustic variations (e.g., Clopper & Pisoni, 2004; McMurray, Tanenhaus, Aslin, & Spivey, 2003; Nguyen & Hawkins, 2003), which would be more suited to stochastic modelling. Similarly, a variable segmentation environment is more suited to a stochastic model of syllabification that can combine conflicting evidence to predict where a syllable boundary is likely to be located, based on known syllabification cues. Such a model could also be capable of integrating new information during development, such as that acquired through literacy, and might explain the specific changes in segmentation behavior seen in our study.

APPENDIX A

Stimuli used in Experiment 1 showing target intervocalic cluster, multiple morphemes, and English translations

	LF		FL		FP		LN		LP
/lʃ/	**colchique** *colchicum*	/fl/	**gifl*er*** *to slap*	/zb/	**rosbif** *roast beef*	/lm/	**calm*er*** *to calm*	/lb/	**cul*bute*** *somersault*
/ls/	**vals*er*** *to waltz*	/fl/	**gonfl*er*** *to inflate*	/sk/	**basket** *basket ball*	/lm/	**film*er*** *to film*	/ld/	**sold*at*** *soldier*
/rj/	**argent** *money*	/fl/	**ronfl*er*** *to snore*	/sk/	**biscotte** *rusk*	/lm/	**palm*ier*** *palm tree*	/lk/	**alcool** *alcohol*
/rj/	**courg*ette*** *courgette*	/fl/	**siffl*er*** *to whistle*	/sk/	**bis*cuit*** *biscuit*	/rm/	**arm*ée*** *army*	/lk/	**calcul** *calculus*
/rj/	**sergent** *sergeant*	/fl/	**souffl*er*** *to blow*	/sk/	**casq*uette*** *cap*	/rm/	**armoire** *wardrobe*	/lk/	**volcan** *volcano*
/rj/	**urg*ence*** *emergency*	/fr/	**affreux** *horrible*	/sk/	**masq*uer*** *to mask*	/rm/	**charm*ant*** *charming*	/lt/	**alt*esse*** *highness*
/rs/	**berc*eau*** *crib*	/fr/	**coffr*et*** *casket*	/sk/	**risq*uer*** *to risk*	/rm/	**dorm*ir*** *to sleep*	/rb/	**arbitre** *referee*
/rs/	**cerc*eau*** *hoop*	/fr/	**gaufr*ette*** *small waffle*	/sp/	**espace** *space*	/rm/	**fourmi** *ant*	/rb/	**corbeau** *crow*
/rʃ/	**cherch*er*** *to look for*	/fr/	**offr*ir*** *to offer*	/sp/	**espion** *spy*	/rm/	**marmite** *marmite*	/rd/	**ardoise** *slate*
/rs/	**garç*on*** *boy*	/fr/	**refrain** *chorus*	/sp/	**espoir** *hope*	/rm/	**perm*is*** *license*	/rd/	**pardon** *sorry*
/rʃ/	**march*er*** *to walk*	/vr/	**avril** *april*	/sp/	**resp*ire*** *to breathe*	/rn/	**carnet** *note book*	/rk/	**orchestre** *orchestra*
/rs/	**mart*ien*** *martian*	/vr/	**chevr*euil*** *roe deer*	/st/	**castor** *beaver*	/rn/	**corn*et*** *paper cone*	/rk/	**parking** *carpark*
/rs/	**ours*on*** *bear cub*	/vr/	**couvr*ir*** *to cover*	/st/	**histoire** *story*	/rn/	**dernier** *last*	/rp/	**serpent** *snake*
/rs/	**perc*er*** *to puncture*	/vr/	**givr*er*** *to frost*	/st/	**pastèque** *water melon*	/rn/	**journ*al*** *newspaper*	/rt/	**cartable** *schoolbag*
/rʃ/	**perch*er*** *to perch*	/vr/	**livr*et*** *booklet*	/st/	**post*er*** *to post*	/rn/	**tourn*er*** *to turn*	/rt/	**tartine** *slice of bread*
/rv/	**serv*ir*** *to serve*	/vr/	**ouvr*ir*** *to open*	/st/	**rest*er*** *to stay*	/rn/	**vernis** *varnish*	/rt/	**tortue** *turtle*

APPENDIX A (*cont.*)

	PF		PL		LL		PP		PN
/bj/	**objet** *object*	/bl/	**oubli** *forgetting*	/rl/	**parl*er*** *to speak*	/kt/	**lect*ure*** *reading*	/dm/	**ad*mire*** *admire*
/dj/	**gadget** *gadget*	/bl/	**tabl*eau*** *blackboard*	/rl/	**hor*loge*** *clock*	/kt/	**act*eur*** *actor*	/gn/	**magn*um*** *magnum*
/gz/	**exact** *correct*	/br/	**abri** *haven*	/rl/	**guirlande** *garland*	/kt/	**facteur** *postman*	/kn/	**techno** *techno*
/ks/	**accent** *accent*	/dr/	**adresse** *address*	/rl/	**hurl*er*** *to scream*	/kt/	**doct*eur*** *doctor*		
/ks/	**act*ion*** *action*	/dr/	**en*droit*** *place*		FN	/kt/	**dict*ée*** *dictation*		
/ks/	**box*eur*** *boxer*	/gl/	**igloo** *igloo*	/sm/	**cosm*os*** *cosmos*	/pt/	**septembre** *september*		
/ks/	**ex*cite*** *excite*	/gr/	**maigr*ir*** *to lose weight*	/vn/	**ovni** *ufo*	/pt/	**capt*ure*** *capture*		
/ks/	**klaxon** *horn*	/gr/	**tigr*é*** *striped*						
/ks/	**taxi** *taxi*	/kl/	**boucl*er*** *to curl*						
/ks/	**vaccin** *vaccine*	/kl/	**é*clair*** *lightning*						
/ks/	**vex*er*** *to upset*	/kr/	**ecr*ire*** *to write*						
/ps/	**ab*sent*** *absent*	/pl/	**e*pluche*** *to peel*						
/ps/	**capsule** *cap*	/pl/	**rempl*ir*** *to fill up*						
/ps/	**ob*serve*** *to observe*	/pr/	**caprice** *caprice*						
/tʃ/	**atchoum** *sneeze!*	/tr/	**citr*on*** *lemon*						
/tʃ/	**scotch*er*** *to use adhesive tape*	/tr/	**montr*er*** *to show*						

Note: The second morpheme is underlined.

APPENDIX B

Stimuli used in Experiment 2 showing target intervocalic cluster, multiple morphemes, and English translations

	PF		PL		LL		FL
/ks/	**box*eur*** *boxer*	/tr/	**autruche** *ostrich*	/rl/	**parl*er*** *to speak*	/fl/	**siffl*er*** *to whistle*
/ks/	**taxi** *taxi*	/bl/	**tabl*eau*** *blackboard*	/rl/	**hor*loge*** *clock*	/fl/	**souffl*er*** *to blow*
/tʃ/	**atchoum** *sneeze*	/tr/	**citr*on*** *lemon*	/rl/	**guirlande** *garland*	/fr/	**coffr*et*** *casket*
/dz/	**pizza** *pizza*	/tr/	**maîtr*esse*** *teacher*	/rl/	**hurl*er*** *to scream*	/fr/	**gaufr*ette*** *small waffle*

Note: The second morpheme is underlined.

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NOTES

1. Ambisyllabicity refers in this study to the case where an intervocalic medial consonant is a single segment that is in the coda of the first syllable and in the onset of the second one. For example, an ambisyllabic response will be reported if "pan . . nic" is produced when asked to slowly repeat the word *panic*.
2. In examples, the written French word is displayed as "bateau," the phonetic form as /bato/, and its English written translation as *boat*.
3. Children in this study followed the French educational norm, attending preschool for 4 days a week from the age of 3. In these schools children are taught the basis of numeracy, social skills, and play word and musical games. The acquisition of reading and writing knowledge only begins in earnest at the age of six in primary school. More information on the level of literacy skills in these children can be obtained by writing to the corresponding author.
4. Log-linear models are a class of statistical techniques used for the analysis of categorical-dependent variables (nominal or ordinal), and as such, are more suited to the analyses of our results than the usual ANOVA analyses. These methods can be used to investigate relationships similar to those identified by chi-squared contingency tables, but can also reveal interactions between multiple experimental factors. In hierarchical log-linear analysis all possible models are tested to find the simplest model in which observed and expected frequencies do not differ significantly. The fit is measured by Pearson's χ^2 (G^2), a low G^2 value indicating a good fit, significant if the probability of the fit is greater than .05.
5. Closer examination of segmentation responses for constituent stimuli of this cluster in Experiment 2 ("taxi," "atchoum," "boxeur," and "pizza") did not reveal any significant differences within the category ($p > .05$). The majority of segmental responses for each of the words was for /V-CCV/, the only departure being the word "atchoum," where our adult participants did not arrive at a significant preferred segmentation ("atchoum": χ^2 goodness of fit = 2.33, $df = 2$, $p = .31$). Therefore, although atypical, the segmentation of the PF category appears internally consistent.
6. For instance, the sequence "petit artichaut" (*small artichoke*) will be produced as /pøti.tartiʃo/, although "petit" and "artichaut" in isolation are produced as /pøti/ and /artiʃo/.

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