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Vowel Devoicing in Contemporary French[1]

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ABSTRACT

Fagyal and Moisset (1999) suggested that vowel devoicing in standard French occurs most often in phrase-final high vowels. An experiment testing the effect of both immediate segmental context and sentence-level contextual factors was conducted to further identify the linguistic features involved. Six French speakers were recorded reading test sentences. Devoicing only occurred in sentence-final vowels, but in more contexts than expected. From a cross-linguistic perspective the distribution of devoicing in French is unusual. Final position is prosodically prominent in French, whereas in many languages devoicing is a form of vowel reduction associated with lack of prominence. Different physical mechanisms may therefore be responsible.

1 INTRODUCTION

Devoicing of vowels is a striking feature of contemporary French, but it has received relatively little attention in the linguistic literature. (In this article, 'French' refers to a dialectally-unmarked variety of the language as spoken in France.) Perhaps the most frequently-cited example of this phenomenon is the common pronunciation of *oui* with a voiced [ɯ] and a voiceless [i̥] (Laver, 1994: 345). Fónagy (1989: 247) describes the voiceless [i̥] at the end of *merci* as sounding like 'un sifflement aigu' (a sharp whistling). He gives examples from television as well as from controlled reading of texts, and suggests that the devoicing serves as a way of marking the end of an utterance. Taking Fónagy's observations as a starting point, Fagyal and Moisset (1999) collected data from ten Parisian French speakers of varying ages. Their data include both text reading and informal conversation. Although Fónagy implied that vowel devoicing is a recent development, or has recently become more frequent, Fagyal and Moisset (1999) found that their older speakers devoiced more vowels than did most of the younger speakers. They also found devoicing to be more frequent in reading than in conversation. However, in both text reading and conversation, devoicing was restricted to vowels at the end of Intonation Phrases

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ending with a pitch fall (as is typical of statements) rather than a rise (as is typical of certain types of questions). The present experiment refines the results of Fagyal and Moisset (1999), and shows that in fact it is the type of sentence (statement versus question), rather than the type of pitch contour, that conditions the likelihood of devoicing. The preference for devoicing at the end of statements, where the speaker is terminating a message, supports Fónagy's suggestion that devoicing is associated with finality.

In Fagyal and Moisset's data, devoicing only occurred at the end of an utterance. This final position is prosodically very prominent in French, usually having a lengthened vowel, as well as being associated with a characteristic intonation contour (Benguerel, 1971; Lacheret-Dujour and Beaugendre, 1999: 41, 244). Because final position is also the site of vowel devoicing, it suggests that the devoicing is associated with prominence. If devoicing in French is essentially a sentence-level phenomenon, then we would expect the main conditioning factors to be the type of phrase or sentence, the intonation pattern, and so on. If, on the other hand, vowel devoicing is a segmental property, then the chief factors influencing the likelihood of devoicing should be local phonological properties: vowel quality, the immediate context, and so on. The present experiment provides a controlled experimental test of some of the same factors that Fagyal and Moisset investigated, with the goal being to determine the relative importance of properties of the larger prosodic unit (phrase or sentence) versus properties of the immediate context. Some other factors not tested by Fagyal and Moisset were included as well (the type of sentence, the structure of the syllable), while leaving aside sociolinguistic considerations.

The association of devoicing with prominence distinguishes French from other languages that have allophonic vowel devoicing. In many other languages, devoicing occurs in prosodically weak environments. For example, in Japanese, the vowels most likely to be devoiced are unaccented high vowels surrounded by voiceless consonants (Vance, 1987). In Modern Greek devoicing occurs in unstressed /i/ and /u/ (Dauer 1980), and in European Portuguese it is also restricted to high vowels, and to pre-pausal and unstressed positions (Laver, 1994; Cruz Ferreira, 1999). Québec French also has vowel devoicing, but not in the sentence-final position where it occurs in standard metropolitan French. In Québécois, high vowels may be devoiced word-medially where they are unstressed (Walker, 1984; Déchaine, 1991), especially if surrounded by voiceless consonants (Ouellet, Tzoukerman and Ménard, 1999). In all of these languages devoicing is a form of vowel reduction: in Québécois, Greek and European Portuguese, the vowels may be deleted entirely rather than just devoiced, and in Japanese, the devoiced vowels are often almost unrealised acoustically. Devoicing is an optional process in these languages, most often applying to high vowels without prominence (stress or accent).

French shares with these other languages the fact that high vowels are the most likely targets of devoicing, but it seems difficult to interpret vowel devoicing in French as a form of vowel reduction, as it is in these other languages, since in French

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it occurs in a position of phrasal prominence. One of the goals of this experiment was to consider whether there is any reason to view devoicing as a reduction process in French, and to see how the phonological status of this process might relate to the physiological mechanisms that cause devoicing. The experimental paradigm used in this study also makes possible a more systematic investigation of the duration of the devoicing in the devoiced vowels.

1.1 *Phrase-level factors*

With the goal of identifying the type of factors most important in conditioning devoicing in French, a starting point is Fónagy's suggestion (1989) that devoicing functions as a marker of finality at the end of a phrase or sentence. The degree to which the end of a sentence is truly final depends on the type of sentence: statements are functionally much more final than questions, which normally expect some sort of response to follow. If Fónagy is correct, we might expect more devoicing at the end of statements than at the end of questions, making sentence type one of the factors that could condition devoicing.

Sentence type is prosodically important as a key determiner of the intonation pattern of a sentence. In an autosegmental-metrical framework (Ladd, 1996; Pierrehumbert, 1980), this intonation pattern results from the composition of a sequence of distinct tones. The contour at the end of an isolated sentence is due to the boundary tone associated with the end of the Intonation Phrase which coincides with the sentence end. The particular boundary tone that occurs is determined by the type of sentence: statements typically end with a Low boundary tone, and most questions with a High. In French, the effects of sentence type and boundary tone can be distinguished by considering Neutral Partial Questions (Di Cristo, 1998) – those using a question word such as *qui*, *quel*, *comment*, etc. – which are usually produced with a Low boundary tone, like statements. With regard to the frequency of devoicing, if Partial questions resemble statements more than other types of questions, the implication is that the nature of the boundary tone is a more important factor than sentence type. If Partial questions behave like other questions, then the statement/question distinction would be the more important factor. Boundary tone and sentence type are properties of the phrase and sentence; demonstrating a role for either would argue that devoicing is conditioned by properties of these larger units.

The four sentence types that were tested in this experiment are (i) statements; (ii) Partial questions; (iii) Echo questions; and (iv) Inverted questions. Echo questions are syntactically identical to statements, but produced with a rising intonation (a High boundary tone). Inverted questions are marked by subject-verb inversion and, like Echo questions, normally end with a High boundary tone although their overall contours differ substantially.

The factors tested that relate to the vowel's immediate phonological context are vowel identity (to confirm the preference for devoicing high vowels) and syllable structure (open or closed syllable). In the portion of Fagyal and Moisset's study

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that used a prepared text, the devoiced vowels were all in open syllables in absolute word-final position. Impressionistically this seems to be the most common context for devoicing in French, but it leaves open the possibility of devoicing in a closed syllable. The present study extended their work by including both high and low vowels (/i/, /a/ and /u/) in open and closed syllables.

2 METHOD

2.1 *Speakers*

Six speakers participated in this study, three male and three female. All were native speakers of French resident in Lyon, in southeastern France, where the recordings were made. Two of the male speakers (1M and 3M) were middle-aged university professors; the remaining four speakers were graduate students in their mid to late 20s. The two older speakers had both lived in northern France as well as in Lyon, while the four younger speakers had lived most or all of their lives in the Lyon area. None had regionally-marked speech. The speakers are identified in this article by a digit and 'M' or 'F' for male or female.

2.2 *Speech materials*

The material to be read consisted of sets of sentences which were designed so that the sentences in each set were as similar as possible except for varying sentence type. Each set consisted of four sentences all ending with the same target word: a statement, a syntactically unmarked Echo question, a Partial question, and an Inverted question. The fifth sentence in each set was a statement in which the target word was the second (rather than the final) word in the sentence. The number of syllables preceding the sentence-final target word was kept identical within each set. In the sentences where the target word was non-final, it was always preceded by a single monosyllabic word, and followed by words containing a total of nine syllables.

The experimental material consisted of ten of these sets of matched sentences, for a total of 50 sentences. The ten target words (each of which occurred in the five sentences of one set) were chosen to include several different vowels and syllable structures. In six of the target words, the final vowel was /i/. Of these, two were monosyllabic, two disyllabic and two trisyllabic. The other four target words were all monosyllabic. The measured vowel was /a/ in two of these and /u/ in two. For each combination of vowel and number of syllables, there was one target word ending in a closed syllable and one ending in an open syllable. The complete set of sentences is given in Appendix A.

The design was not completely balanced due to an oversight by the experimenter. There were no inverted questions with the vowel /u/ in a closed syllable, but there were two different partial questions with /u/ in a closed syllable.

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2.3 *Recording technique*

The sentences were presented to the speakers as six lists, with each list having the sentences in a different order. All speakers read from the same six lists. There were 50 different sentences, so the total number of sentences read by each speaker was 300. The ordering of the sentences in each list was not completely random. The ten statements and the ten Echo questions were presented in pairs as the first part of each list, with the order varied across the six lists. In the remainder of each list, the Partial questions, Inverted questions, and control sentences appeared in random order. The reason for separating out the statements and Echo questions was so the statements would aid in providing a context for the Echo questions. Although Di Cristo (1998) states that Echo questions are the most frequent type of question in contemporary French, they were judged to be potentially more difficult to produce without context than the other types of questions. Speakers were instructed to read the statement, and then read the corresponding Echo question as if they could not understand or believe the statement they had just read.

Each speaker was tape-recorded individually. They were presented with the six lists of sentences, and were given time to familiarise themselves with the sentences. The recordings were made in a sound-treated room using a Sony Professional Walkman cassette recorder. Speakers were allowed to pause between sentences at any time, and were encouraged to pause between each list. They were instructed to repeat the entire sentence in the event of a speech error or misreading. In most cases the speaker realised at once that this had happened; in a few cases the experimenter prompted the speaker to re-read the sentence.

For most speakers, satisfactory recordings were obtained of all 300 sentences in the design. However, it was discovered afterwards that Speaker 2F had inadvertently skipped three sentences, so only 297 sentences were recorded for her. For Speaker 3M, five sentences were excluded because of speaker error. Only speaker 3F made substantial numbers of errors. Because of this, she read the sentences seven times, rather than six like the other speakers. (The seventh repetition used the same list as the sixth repetition.) Tokens from the seventh reading were analysed only if one or more of the first six readings of a sentence were unusable, either because they were misreadings, or because there was a noticeable pause during the sentence. For two sentences, there were only four usable readings each; for all other sentences either five or six readings were usable. In total there were 294 usable tokens from her.

2.4 *Measurements*

The tape recordings were digitised on a Kay Elemetrics' CSL system at a sampling rate of 10 kHz. All measurements were performed using CSL except for the analysis of the pitch contours.

Several acoustic properties were measured in the final vowels of these sentences. These measurements were directed at relating devoicing with other properties of the vowel and the sentence.

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The duration of the vowel was determined from inspection of the acoustic waveform and simultaneously-displayed spectrogram. In order to facilitate measurement, as well as to maintain comparability among the words, the target words had been chosen so that all the measured vowels were preceded by voiceless stops (either [p] or [k]), and in the words with closed syllables, were also followed by voiceless stops. The starting point of the vowel was identified as the point where regular voicing began following any release burst or aspiration. If the later part of the vowel was devoiced, its endpoint was identified as the point where noise in the region of the second and third formants could no longer be distinguished from background noise. If the vowel was completely voiced, its endpoint was marked at the point where formant structure disappeared.

A vowel was determined to be (partially) devoiced if during the vowel, voicing ceased but some aperiodic energy continued to be apparent in the spectrogram at frequencies close to the frequencies of the formants during the voiced portion of the vowel. None of the speakers ever produced a vowel that was completely devoiced. In devoiced vowels, the duration of the voiced portion of the vowel was also measured, with the endpoint of the voiced portion identified as the time where the waveform ceased to be periodic.

The pitch contours for all of the recorded sentences were generated and displayed using Scicon R&D's Macquirer software package. For each token, visual inspection of the pitch contour and listening were used to determine whether the speaker had produced a high boundary tone (denoted by H%) or a low boundary tone (L%). An utterance was categorised as having a high boundary tone if it ended with at least a small rise in FO, relative to the FO on the preceding accented word. A low boundary tone was assigned if the FO fell at the end of the utterance. In some cases the FO contour was essentially flat; a H% was assigned if the final pitch sounded higher than seemed likely in the absence of any prominence. The use of the % notation, which is associated with the ToBI system of intonational labeling, is used here merely as a convenient way to distinguish different intonation patterns at the end of the sentences. It is not intended to imply a particular analysis of French intonation, nor is it intended to imply that the difference in boundary tones is the only, or the most important, difference in the intonation patterns used in different types of sentences in French.

The complete set of measures used in this study were: duration of the entire vowel, duration of the voiced portion; classification as devoiced or not devoiced from the evidence of the spectrogram; classification of boundary tone as High or Low from visual inspection of the FO contour. Additional measures were made at the same time for another study, reported in Smith (2002).

2.5 *Statistical analysis*

The categorical variables that were investigated were sentence type, vowel quality, syllable type and boundary tone. These, plus speaker identity, were used as factors in a variable rule analysis using Goldvarb (Rand and Sankoff, 1990) to determine

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the contribution of each in determining the likelihood of vowel devoicing. This type of analysis was chosen because it is appropriate for situations where multiple independent variables are being investigated for their effect on a categorical dependent variable (in this case, the presence or absence of vowel devoicing) (Sankoff, 1988).

The influence of these factors on the extent (duration) of devoicing in each vowel was also investigated. For each devoiced vowel, the percentage of its duration that was devoiced was calculated. All the devoiced vowels in this experiment were *finally* devoiced. That is, the vowels began with vocal fold vibration, which was followed by a period of voiceless noise at and above the frequency of the second formant during the voiced portion of the vowel. This noise is characterised by greater energy at the frequencies corresponding to the second and third formants, but a complete absence of energy at lower frequencies. The end of the vowel was identified as the time at which this noise was no longer distinct from background noise. In analysing the amount of duration that was devoiced, a percentage was used, rather than the raw number of milliseconds, because the various factors under investigation have previously been shown to affect the overall durations of the vowels (Smith, 2002). The percentage duration devoiced was used as the dependent variable in an Anova performed using the statistical package SAS.

3 RESULTS

Speaker 3M never devoiced any vowels, so his data are not included in any further analysis. Also excluded are all vowels in non-final position, since no speaker devoiced any of them. This finding supports Fónagy's suggestion that vowel devoicing is associated with utterance finality.

3.1 *Final pitch patterns produced by the speakers*

As expected, all speakers produced all statements with a low final pitch. However, there was more variation than expected in the final pitch patterns produced in the three types of questions. Figure 1 shows the percentage of each type of question that the speakers produced with a pitch rise (High boundary tone).

The expected pattern for the Partial questions was a pitch fall, which was the case for the majority of tokens. The graph shows, however, that speakers 2M, 2F and 3F all produced approximately 20% of their Partial questions with a pitch rise. The Echo questions and Inverted questions were expected to have a final rise. Most of the speakers showed a very clear tendency to produce a rise, the exception being speaker 2F, who produced almost half of her Inverted questions with a pitch fall. Because they are almost equally divided between pitch rise and fall, Speaker 2F's Inverted questions may provide the best test for distinguishing the effects of sentence type and pitch pattern on the likelihood of devoicing.

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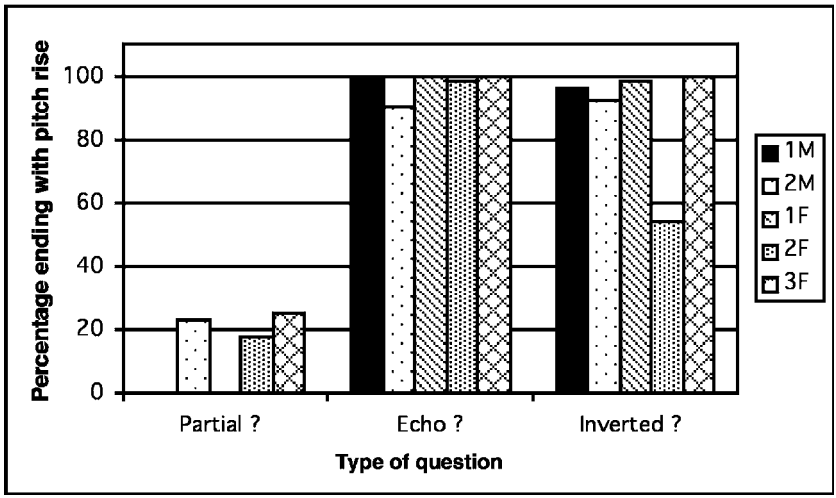


Figure 1. *The percentage of tokens of questions which were produced with a sentence-final rise in pitch (H%), for the five speakers who did devoice some vowels.*

Table 1. *Number and percentage of tokens devoiced for each vowel quality, for all six speakers*

	Number devoiced	n	%
/a/	10	360	2.8
/i/	126	1072	11.8
/u/	28	359	7.8

3.2 *Patterns of devoicing*

Overall, the patterns observed in this experiment were similar to those reported by Fagyal and Moisset (1999), but with greater variability. In the present data, few if any patterns were consistent throughout the entire data set. For example, neither Fagyal and Moisset nor Fónagy reported any occurrences of devoicing with low vowels, but in the present data, this did occur, albeit much less often than with high vowels. Table 1 shows the frequency with which devoicing occurred in the three different vowels that were tested.

Of the ten devoiced /a/'s in the data set, nine were produced by speaker 3F and one by speaker 2F. In contrast, all five speakers produced devoiced /u/'s, although the total of these was only 28.

Fagyal and Moisset also seem to imply that devoicing is only possible in open syllables; the present data show more variability in this dimension as well. Devoicing was much more frequent in open than in closed syllables, but did occur in both

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Table 2. *Number and percentage of tokens devoiced for each sentence type, for all six speakers*

	Number devoiced	n	%
Statement	86	360	23.9
Partial?	32	388	8.2
Echo?	29	357	8.1
Inverted?	17	321	5.3

syllable types (open: 144 of 898 tokens = 16.0%; closed: 20 of 893 tokens = 2.2%). Only the female speakers produced devoiced vowels in closed syllables, with speaker 2F producing 17 of the 20.

As can be seen in Figure 1, Sentence type and Boundary tone are strongly confounded in this experiment, but they do not coincide in all cases and were analysed separately. Results for Sentence type are given in Table 2, which shows that devoicing was more frequent in statements than in any of the question types.

For all speakers, the sentence type with the highest frequency of devoicing was statements. In the other sentence types, the different speakers showed different patterns of devoicing. Speaker 1F only devoiced in statements. The two male speakers devoiced in statements and partial questions. Speakers 2F and 3F devoiced in all sentence types.

Given this preponderance of devoicing in statements, the occurrence of devoicing with different Boundary tones is largely predictable. Sentences ending in a Low boundary tone (statements and most Partial questions) were devoiced 16.3% of the time (113 out of 693 tokens), whereas sentences ending in a High boundary tone (questions) were devoiced 7.0% of the time (51 of 733 tokens). Only speakers 2F and 3F devoiced any sentences with a High boundary tone – a context in which Fagyal and Moisset (1999) did not observe any devoicing at all.

3.3 *Variable rule analysis*

The data were analysed using GoldVarb in order to determine which factors contributed to determining the likelihood of devoicing. The five factors tested were Speaker identity, Sentence type, Boundary tone, Syllable type and Vowel quality. The likelihood of devoicing the vowel was analysed using the stepwise binomial procedure. The weights of the four factors that were selected as significant are listed in Table 3 in the order they entered into the regression. A larger weight implies a greater tendency for devoicing to occur in that environment.

These results show that both factors relating to the local phonological context (syllable type and vowel quality) and a factor relating to a larger linguistic unit (sentence type) are significant contributors to the likelihood of devoicing. Perhaps

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Table 3. *Results of the variable rule analysis, showing the factors in the order they were selected as significant*

Factors		Weight
Syllable type	open	0.797
	closed	0.201
Sentence type	Statement	0.815
	Partial?	0.453
	Echo?	0.412
	Inverted?	0.262
Speaker	1M	0.476
	2M	0.359
	1F	0.277
	2F	0.543
	3F	0.818
Vowel quality	/i/	0.638
	/u/	0.467
	/a/	0.176

the most important result is that the boundary tone was not a significant factor. Because boundary tone and sentence type are highly correlated, they would not be expected to both make independently significant contributions to the likelihood of devoicing. Recall from Table 2 that devoicing was approximately equally likely in Echo questions (which usually have a H% boundary tone) and in Partial questions (which usually have a L% boundary tone). This result shows that Partial questions were more like other questions than they were like statements, with which they share a L% boundary tone. This suggests that intonation per se may not be relevant in determining the likelihood of devoicing.

3.4 *Duration of devoicing*

It was hypothesised that in addition to differences among contexts as to how frequently devoicing occurred, there would also be differences as to how much of each vowel was devoiced. The prediction was that contexts that favour devoicing would favour it in both ways: it would be more frequent, and a larger portion of each vowel would be devoiced. As explained in the Methods section above, comparisons were made among the vowels in terms of the percentage duration devoiced, to compensate for independent differences in duration among contexts and speakers.

The percentage duration devoiced was analysed only for the 164 devoiced vowels. As is apparent from the results for likelihood of devoicing, these devoiced tokens

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Table 4. *Analysis of variance for the combined data of the 5 speakers who devoiced vowels. Only sentences containing devoiced vowels were included in this analysis. The main effects tested were sentence type (Statement, Partial question, Echo question, Inverted question), vowel (/a/, /i/, /u/), syllable type (open or closed), and repetition number (1st to 6th). The significance level was .05; 'ns' indicates that the p value was greater than .05*

Effect	df	F	*p*
sentence type	3, 139	0.08	*ns*
vowel	2, 139	0.38	*ns*
syllable type	1, 139	10.60	<.01
repetition	5, 139	1.55	*ns*
sentence type × vowel	5, 139	0.76	*ns*
sentence type × syllable type	3, 139	2.28	*ns*
vowel × syllable type	1, 139	2.51	*ns*

were very unevenly divided among the various speakers and contexts. Using the factors of sentence type, syllable type and vowel quality to specify the different contexts, for many combinations of these factors there were no devoiced vowels at all. Therefore, it is impossible to test all interactions among the factors. The percentage duration devoiced as the dependent variable. This analysis used the mixed model Anova procedure in SAS (Littell, Milliken, Stroup and Wolfinger, 1996). A mixed model is a type of Anova appropriate for experiments where multiple measures are made on the same experimental units, in this case, the speakers. Speaker identity was treated as a random effect: this treats the set of speakers in the experiment as representatives of the general population of speakers. Repetition number (whether the measurement was of the 1st, 2nd ... 6th reading of the sentence) was treated as a within-speaker factor.

The Anova results in Table 4 show that syllable type alone had a significant effect on the percentage duration devoiced. The prediction that the same factors would influence the percentage duration devoicing as the likelihood of devoicing is not really borne out. While sentence type, vowel quality and syllable type were all significant for the likelihood of devoicing, only syllable type also had a significant effect on the percentage duration. However, its effect was as predicted: open syllables were more likely to be devoiced, and when they were, they were devoiced for a greater percentage of their duration. The mean percentage duration of devoicing for the open syllables was 47% (n = 144) and for the closed syllables 17% (n = 20).

As discussed above, the speakers varied substantially as to how likely they were to devoice vowels. They also varied in the percentage duration of devoicing, but there did not seem to be a relation between the percentage of tokens that were

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Table 5. *Number and percent of vowels that were devoiced, and the mean percentage of the total duration of each of those vowels that was devoiced*

Speaker	Number devoiced	Percent devoiced	Mean percent duration devoiced
1M	28	9.3	60.2
2M	20	6.7	28.5
1F	15	5.0	64.1
2F	33	11.1	28.5
3F	68	23.1	44.1

devoiced by a speaker, and the percentage of their duration for which they were devoiced. These means are given in Table 5.

While speaker 1F had the lowest percentage of devoiced vowels, she had the highest percent duration of devoicing, but speaker 2M, who had the next lowest percentage of devoicing, had one of the lowest percent duration of devoicing. Speaker 3F, who devoiced the most often, had an intermediate value for the percent duration of devoicing. The conclusion must be that the percent duration of devoicing that a speaker produces is independent of the likelihood that they devoice a vowel in the first place.

4 DISCUSSION

4.1 *Relative importance of different factors*

As suggested by Fagyal and Moisset (1999), a variety of factors are relevant to determining whether a vowel will be devoiced in French. Several of these factors had a less categorical effect in the present experiment than was expected following Fagyal and Moisset's descriptions. Syllable structure was found to be the strongest factor in determining both the likelihood of devoicing and the percentage duration for which a vowel was devoiced, but even this was not categorical. For certain speakers, devoicing was possible in the less-favoured closed syllable environment: it was just less frequent and shorter. Devoicing was also observed in some low vowels, another environment where it is much less common but not impossible.

A substantial addition to our understanding of the influences on devoicing is the finding that devoicing is favoured because a sentence is a statement, rather than because it has a Low boundary tone. This finding is crucially supported by the similarity in likelihood of devoicing among all types of questions, regardless of their boundary tones. The importance of sentence type rather than intonation contour could be interpreted as support for Fónagy's supposition that devoicing serves as a mark of finality. The difference in purpose between statements and questions may be relevant. In read text, the type of spoken material analysed here, each

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statement conveys a complete piece of information, whereas a question is at least hypothetically seeking a response. It would be interesting to see if in conversation, where sentences commonly occur that are not grammatically or informationally complete, devoicing is found mostly in those sentences that do convey a complete, finished message.

One of the goals of this study was to determine whether similar factors condition vowel devoicing in French as in some of the other languages where it occurs. These results show that, as in the other languages, the local phonological context is important, especially vowel quality, although the specific contexts where devoicing is favoured are not identical in French and in the other languages discussed. However, French is like the other languages in that prominence is relevant, with the difference being that devoicing in French occurs in the highly prominent sentence-final position in contrast to the non-prominent positions where it occurs in the other languages. The importance of sentence type in conditioning devoicing in French cannot be directly compared with the other languages because of a lack of information. Relatively little research has focused on the interaction of 'grammatical' factors such as sentence type with prosodic and segmental structure.

4.2 *What mechanism is at work?*

As noted earlier, the prosodic prominence of the sentence-final position where devoicing occurs in French makes it seem less like a weakening process, as it seems to be in other languages. Another approach to deciding whether it should be viewed as weakening or not, is to consider the physical mechanisms which cause devoicing.

Voicing is produced by vibration of the vocal folds. The principal requirements for achieving this are (i) the vocal folds must be sufficiently approximated that it is possible for them to vibrate provided that (ii) the subglottal pressure exceeds the supraglottal pressure by a sufficiently large margin. If either one of these requirements is not met, the sound produced will not be phonetically voiced. (See Smith, 1997 for further discussion of possible causes of devoicing.) Since in the present experiment voicing always ended partway through the devoiced vowels, the conditions in the speaker's vocal tract must have changed during the vowel so that one or the other of these requirements ceased to hold true.

The explanation that Fagyal and Moisset (1999) propose for devoicing in their experiment involves a violation of the second of these requirements. In keeping with their idea that the devoiced high vowels become voiceless fricatives (rather than simply voiceless vowels), they suggest that the oral constriction narrows during these devoiced vowels. Narrowing of the oral constriction allows less air to escape from the mouth, with the result that more air becomes trapped in the oral cavity, increasing the supraglottal pressure so much that a pressure differential cannot be maintained. One drawback to this explanation is that although raising the tongue during a high vowel causes narrowing of the oral constriction, potentially leading to a fricative, devoicing was not limited to high vowels, either in Fagyal and Moisset's

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experiment or in the present study. Raising the tongue during a mid or low vowel results in a higher vowel, not a fricative. This explanation therefore could not account for all cases where devoicing occurs.

In prosodically prominent positions, such as the final position where these devoiced vowels occur, articulatory movements are generally larger and/or longer than in positions without prominence. In a study of tongue movement in French, Loevenbruck (1999) observed 'hyper-articulation' of syllables in prominent positions at the beginning and end of accentual phrases. The tongue movements associated with the vowels in these syllables were larger than in phrase-medial syllables. In Loevenbruck's data, the tongue moved to a higher position for /i/ in a prominent position than for a medial /i/, and to a more open position for an /a/ associated with phrasal prominence than for one which was not. Thus prominence can have essentially opposite effects in high and low vowels: its effect on high vowels is compatible with the explanation of devoicing as resulting from increased supraglottal pressure, but this is not a possible explanation for low vowels. The data in Loevenbruck (1999) show a single measurement point in each vowel, so they do not reveal whether the articulators changed position during the prosodically prominent vowels. A change of some kind would be necessary in order for the vowels to be partially devoiced, as they were in the present experiment. Furthermore, Loevenbruck's finding of more extreme articulations in prosodically prominent vowels suggests that these vowels are articulatorily 'strong'. If narrowing of the oral constriction is a cause of devoicing in these vowels, it represents a strengthening, not a weakening.

Apart from an increase in supraglottal pressure, another possible reason for failure of the second condition for voicing is a fall in subglottal pressure, so that it no longer exceeds the supraglottal pressure. Subglottal pressure could fall if the amount of air expelled from the lungs decreased. While subglottal pressure does decrease during the course of a sentence (Gelfer, Harris and Baer, 1987), normally it does not reduce so much that voicing cannot be produced at the end of a sentence. Since, in the present experiment, only a portion of the final vowel is devoiced in each sentence, a fall in subglottal pressure is not a very likely explanation.

Failure of the first condition for voicing implies that the vocal folds changed position so that they became too open to permit vibration. The vocal folds are open when the vocal tract is at rest, or during respiration. Anticipation of an open rest position is a possible explanation for the devoiced vowels in this experiment because they all occurred at the end of a sentence. An opening of the vocal folds does not require active movement on the part of the speaker. It could result from a relaxation of the muscles that normally contract to bring the vocal folds close together for voicing. If these muscles relax their contraction, the folds will tend to separate. Such relaxation is often assumed to take place at the end of a phrase or utterance; Lacheret-Dujour and Beaugendre (1999: 244) propose that phrase-final lengthening in French results from a 'relaxation finale'. Unfortunately, although such relaxation and the resulting separation of the vocal folds seems a likely explanation for devoicing, the acoustic data obtained in the present experiment do

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not make it possible to determine if these speakers' vocal folds did indeed move apart.

In summary, it seems that either or both of the conditions for voicing may fail in these devoiced vowels. Separation of the vocal folds can potentially explain the devoicing of any kind of vowel, particularly at the end of a sentence. An increase in supraglottal pressure due to a raised tongue position may cause devoicing in high vowels, but does not explain devoicing in mid and low vowels. Since devoicing can occur in any vowel height, glottal opening must also be included as a possible cause. The greater frequency of devoicing in high vowels may be explained by the fact that there are more possible causes for devoicing in high vowels than in non-high vowels. However, none of these explanations account for the greater frequency of devoicing in /i/ than in /u/.

5 CONCLUSIONS

Devoicing in French vowels was most frequent in high vowels in open syllables at the end of a statement. However, devoicing was found to be possible in a wider variety of vowels and contexts than previously reported, which may mean that more than one physiological mechanism is involved.

Syllable type, vowel quality and sentence type were all found to be relevant in determining the likelihood of a vowel devoicing, but only syllable type made a significant difference to the percentage duration of devoicing in a devoiced vowel. The speakers varied considerably, but there did not seem to be any correlation between how likely an individual was to devoice, and the percentage duration of devoicing that they produced.

The data support the suggestion by Fónagy that devoicing is a way for speakers to indicate finality. None of the sentence-medial vowels in the experiment were devoiced, so it is clearly correlated with final position. Furthermore, the tendency to devoice much more often in statements than questions also supports the notion that devoicing marks the end of the speaker's message.

As far as the relative importance of different conditioning factors, it seems clear that both the immediate context and the phrase-level structure are important. Since devoicing only occurred in the prosodically prominent sentence-final position, it appears that French is different from other languages where vowel devoicing is associated with *non*-prominent positions. However, this conclusion is subject to certain caveats. The non-sentence-final words that were tested in this experiment were also in a prosodically prominent position, as they occurred at the end of an intonational group (Di Cristo, 1998), so it is the position at the end of the sentence, not the prominence, which increases the likelihood of devoicing. One way to test whether prosodic prominence is a requirement for devoicing would be to test sentence-final vowels that do not have prominence. The only such vowels in French are word-final schwas. However, these are not comparable to full vowels as their realisation is extremely variable. So a conclusive test of the importance of prominence in conditioning devoicing in French may be unattainable.

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Interestingly, the boundary tone associated with the end of the sentence did not have a significant effect on the occurrence of devoicing. Prominence in French is expressed largely through intonation. Factors such as lengthening, increased amplitude and high pitch that are associated with stress in English are associated in French with syllables that are prominent in the intonational structure. The lack of effect of the boundary tone in this experiment could be taken as suggesting that intonational structure, and possibly therefore prominence, is not important in conditioning devoicing in French. Rather, its association with the end of a message implies that it is a reflex more of the function of the sentence than of its prosodic structure. This suggests a view of devoicing in French quite unlike the general interpretation of devoicing in other languages, where it is closely related to stress or accent. In any case, this study has added French vowel devoicing to the list of phonetic effects that can be conditioned by 'non-phonological' factors. The amazing variability of pronunciation is not due to randomness on the part of speakers, but to the interactions among the large number of factors that influence these pronunciations. Many more such influences remain to be explored.

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APPENDIX A: SENTENCES READ IN THE EXPERIMENT

In the tables that follow, the code preceding each row indicates the sentence type (S = statement, E = Echo question, I = Inverted question, P = Partial question, N = target word non-final). In this list, the sentences with the same target word are grouped together, and the target word is underlined. In the actual experiment, the sentences were presented, one per line, in six different orders as described in the Methods section, and there were no codes or underlining.

Target vowel /i/

	Word-final open syllables:	Word-final closed syllables:
S	Le chat tigré regardait la pie.	L'alpiniste est arrivé au pic.
E	Le chat tigré regardait la pie?	L'alpiniste est arrivé au pic?
P	Quel animal regardait la pie?	Quand est-ce qu'il est arrivé au pic?
I	Le chat a-t-il regardé la pie?	Mathieu est-il arrivé au pic?
N	La pie donnait à manger à ses petits.	Le pic de Mont-Blanc s'élève à l'horizon.
S	Marie corrige encore des copies.	C'est un joli costume très typique.
E	Marie corrige encore des copies?	C'est un joli costume très typique?

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P	Quand est-ce qu'elle corrigeait ces copies?	De quelle région est-ce une coiffe typique?
I	A-t-elle corrigé toutes les copies?	Ce costume est-il vraiment typique?
N	Les copies de cette classe sont toujours très mauvaises.	C'est typique de la région au nord de Quimper.
S	Il serait mieux qu'elle les recopie.	Ce lézard est vraiment atypique.
E	Il serait mieux qu'elle les recopie?	Ce lézard est vraiment atypique?
P	Pour quel prof est-ce qu'elle les recopie?	Pourquoi ce lézard est atypique?
I	Faut-il vraiment qu'elle les recopie?	Ce lézard est-il très atypique?
N	Elle recopie ses notes que le chien a déchirées.	C'est atypique d'une région montagneuse comme ici.

Target vowel /a/

	Word-final open syllables:	Word-final closed syllables:
S	La jeune fille belge n'en veut pas.	Le chat tigré lavait ses pattes.
E	La jeune fille belge n'en veut pas?	Ton chat tigré lavait ses pattes?
P	Pourquoi est-ce qu'elle n'en veut pas?	Quel chat vient de laver ses pattes?
I	Les gâteaux n'en veut-elle pas?	Le chat a-t-il lavé ses pattes?
N	«Ne pas entrer dans le bureau principal.»	Les pattes du chat tigré sont toujours très sales.

Target vowel /u/

	Word-final open syllables:		Word-final closed syllables:
S	Le caniche porte un joli collier autour du cou.	S	Tous les amateurs de foot vont aux matchs de la Coupe.
E	Le caniche porte un joli collier autour du cou?	E	Tous les amateurs de foot vont aux matchs de la Coupe?
P	Quel collier est-ce que le caniche porte autour du cou?	P	A quelle date sera le début des matchs de la Coupe?
I	Le caniche noir a-t-il un collier autour du cou?	P	Dans quel pays va-t-on jouer les matchs de la Coupe?
N	Le cou du chien est entouré d'un collier.	N	La Coupe du monde aura lieu le mois prochain.

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