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# The Effects of Syllable Position on Allophonic Variation in Québec French /R/

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## Abstract

The value in working with natural language corpora is the ability to collect large volumes of empirical data with which to test research hypotheses. The challenge in generating these data is how to quickly and accurately, with some degree of objectivity, identify linguistic units as data points. This paper offers a description of how to adapt the Penn Phonetics Lab Forced Aligner for use with a corpus of Québec French and how to extract meaningful data from the alignment results. The results of adapting the aligner for use with this corpus of French are encouraging. Two illustrations demonstrate how to profitably use this empirical data to evaluate several hypotheses concerning the relationship and effects of syllable position on allophonic variation of /R/. The literature review indicates that, along with sociolinguistic variables such as age, and, to a lesser extent, social class, gender, and education, the most commonly cited factors potentially influencing /R/ allophony are syllabic position followed to a lesser extent by phonetic environment. There are two observations that help to motivate the current research question. Most recent sociolinguistic studies conclude that the frequency of occurrences of the apical trill is rapidly decreasing and that in the corpus used for the current study, [r] is no longer the dominant variant and posterior variants should be expected. In addition to the loss of the apical trill, a uvular approximant is now noted as a frequently occurring allophone of /R/, most common intervocalically. The results presented here do not support the hypothesis that allophonic variation is related to, or effected by, syllable position. Approximants and trills were equally likely to occur in either onsets or codas when intervocalic, and only slightly more likely to occur in complex onsets when post-consonantal. The results do support the hypothesis that approximants and trills are more sonorous than fricatives as measured by the amount of energy in their first formant and their centre of gravity. Approximants and trills had significantly higher values for energy in their first formant frequency, and significantly lower values for centre of gravity than fricatives.

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## 1 Introduction

The value in working with natural language corpora is the ability to collect large volumes of empirical data with which to test research hypotheses. The challenge in generating these data is how to quickly and accurately, with some degree of objectivity, identify linguistic units as data points. The objectives of this paper are to demonstrate that a modified version of the Penn Phonetics Lab Forced Aligner will work well with a corpus of Québec French to generate the empirical data required to evaluate a small research question on the nature of the relationship and effects of syllable position on allophonic variation. The literature review indicates that, along with sociolinguistic variables such as age, and, to a lesser extent, social class, gender, and education, the most commonly cited factors potentially influencing /R/ allophony are syllabic position followed to a lesser extent by phonetic environment. There are two observations that help to motivate the current research question. Most recent sociolinguistic studies conclude that the frequency of occurrences of the apical trill is rapidly decreasing and that in the corpus used for the current study, [r] is no longer the dominant variant and posterior variants should be expected. This means most allophones of Québec French /R/ in this corpus are dorsal and specified as [+back,+high]. In addition to the loss of the apical trill, a uvular approximant is now noted as a frequently occurring allophone of /R/, most common intervocally. It would be interesting to know whether the new approximant allophone is more sonorous in terms of phonetic qualities than the other allophones. Therefore, since many authors make reference to syllable position when describing the distribution of allophones, even as the nature of the allophones has changed, is syllable position related to allophonic variation? Furthermore, is the new approximant allophone more sonorous than the other allophones and can these differences be explained with reference to the syllable position?

### 1.1 What Do Early Studies on this Segment Tell Us about the Phonetics of French /R/?

The fact that the French /R/, commonly transcribed as 'r' or 'rr', has come with more than one phonetic realization has been observed since at least the 14<sup>th</sup> century (Lancaster 1934, Haden 1955, Martinet 1962, Giauque 1976, Lozachmeur 1976). Other authors have examined the changing nature of this segment through the centuries (Lozachmeur 1976, Martinet 1962). A very early acoustic study is that of Borel-Maisonny (1942) who used an oscilloscope and cathode-ray tubes to examine the pronunciations of 'r' in eleven individuals in Paris. He expected the measurements to correspond to the theoretical notion that the segment would be constrictive, either voiced or voiceless, and with uvular vibrations brought about passively by air flow through the constriction. In fact, when examined, he found the segment articulated with a large volume of air, similar to that of a vowel, and uvular vibrations only infrequently when the intensity amplitude was high enough. He concluded that four varieties of /R/ were realized: pharyngeal, uvular, somewhat fronted or palatal, as well as vocalic /R/. He believed that it is not the place of articulation that determined the different characteristics of /R/, but rather the size of the aperture of the constriction, laryngeal voicing, and presence of vibrations. Vinay (1950), while studying Canadian French, describes /R/ as being mostly [ʁ] with appreciable frication noise. When initial, it mostly resembles [χ]. It is devoiced following voiceless plosives. He notes some subjects also make a dorsal constriction to resemble [ɣ]. Strevens (1960) judges the uvular fricatives [χ,ʁ] to be the most vowel-like of all the fricatives. Spectral analysis showed them to resemble vowels with two 'formant' peaks at 1000Hz and 2400Hz, and sometimes several other peaks at higher frequencies. Intensity analysis performed on all the fricatives ranked these uvular fricatives as intermediate in relative intensity (weaker than stridents [s, ʃ] but stronger than labials or dentals [f, θ]).

This vowel-like nature was echoed by Delattre (1969) who used x-ray images and spectrographs to examine the articulations of 'R parisien'. Delattre describes the segment not as a velar or dorsal

consonant, but a pharyngeal one with a place of articulation behind the palate. Through x-ray images, he determines that the articulation involves the root of the tongue moving towards the back wall of the pharynx, similar to [a] or [ɔ]. He is careful to note that [ʀ] is not a vowel, characterized by stable states, but a consonant, characterized by transitions and rapid changes in formant frequency. However, it is 'vocalic' in the sense that it is sonorous, resonant, open, and free from noise.

In his study, Delattre notes that the vowels /a/ and /ɑ/ have the backest/lowest pharyngeal constriction of the vowels, and consequently the highest F1. The relationship is that the smaller the space between the vocal folds and the pharyngeal constriction, the higher the resonating frequency. Still examining x-ray images, Delattre notes that during a transition of [yʀy] the tongue appears to move in a circular fashion. The trajectory into the [ʀ] is different from the trajectory out of the it. He postulates that this is to achieve the necessary uvular trill. The tongue first moves back from the [y], and then up (to allow the uvula to vibrate), and the forward towards the [y]. This circular motion can be observed on a spectrogram by the formants: a raising of F1 and lowering of F2 into the [ʀ] (and vice versa out of it). Phonetically, it is not the anteriority or height of the tongue that is reflected in these formant transitions, but rather the changing size of the pharyngeal and buccal cavities. Delattre presents spectrograms of [ʀ] in between all the non-nasal French vowels and determines that the raising of F1 and lowering of F2 is present in all.

More recently, Santerre (1982), while doing a spectrographic examination of the /ʀ/ spoken in Montréal, concluded the apical flap (a reduced version of the trill [r]) was not a real occlusion since the buccal pressure was never high enough to produce an explosive release and that the uvular trill [ʀ] shows low noise at a back place of articulation; is very sonorous and vocalic with little to no high frequency noise; and is perceived as posterior because of formant transitions.

## 1.2 How Have Sociolinguistic Studies Informed our Phonetic Knowledge of this Segment?

There are numerous, well-done studies detailing the geographic and sociolinguistic distribution of /ʀ/ variation in French Canada. Vinay (1950) describes the [r~ʀ] variation as a geographic phenomenon, rather than a social one, with [r] dominating the urban locales (Western Québec, especially Montréal) and [ʀ] dominating the rural areas (mostly Eastern Québec). By the 1970's, Clermont and Cedergren (1979), reporting on the *Sankoff-Cedergren* corpus of Montréal area speakers (Sankoff et al. 1976), reported a tendency for the [r] variant to occur in syllable onsets, and for the posterior [ʀ] to occur in syllable codas. This result was confirmed in the detailed examination of phonological conditioning by Tousignant (1983, 1987a,b,c) using the same corpus. Tousignant identified six different articulations for /ʀ/ in and around Montréal, [r, ʀ, ʁ, ɹ, ɻ], the last only in English loanwords, as well as what he terms 'ʀ/ diphthongué' and 'ʀ/ chute' which correspond to Borel-Maisonny's vocalic and deleted /ʀ/, respectively. Tousignant's examination of phonetic conditioning showed that the uvular trill occurred more often in pre-vocalic position than in post-consonantal; the uvular fricative occurred more often in a post-vocalic position, or at the end of a syllable; and the apical trill seemed to appear equally in all syllabic positions. Whether the preceding or the following phoneme was a consonant or a vowel had no effect on the distribution of the uvular trill, and while some central vowels seemed to appear more frequently with the uvular fricative, the vowel quality did not appear to have any effect on the distribution of the variants. There may be some place of articulation effect influencing choice of trill: uvular trills seem to be associated with back vowels, and apical trills with front vowels. The nature of the following consonant had no effect on the choice of variant, while there seemed to possibly be a place of articulation effect observed with the preceding consonant: nasal and posterior consonants frequently preceded a uvular trill.

Using a collection of three longitudinal corpora of Montréal area speakers (*Sankoff-Cedergren* (Sankoff et al. 1976), *Montréal-1984* (Thibault and Vincent 1990), and *Montréal-1995* (Vincent et al. 1995)), Sankoff, Blondeau, and Charity discuss the changing distribution of /ʀ/ variants in a population over time (Sankoff et al. 2001). They note that innovative [ʀ] is a change from above, with higher values of [ʀ] being associated with women and with higher linguistic market indices. In a follow-up study, they found that the majority of speakers in the study tend towards categorical use of one of the two variants [r] or [ʀ] and they confirmed the earlier observations that posterior variants are used more frequently in codas than in onsets (Sankoff and Blondeau 2007, 2010). In

addition, with respect to vocalized /r/ they support earlier observations that it is limited to codas and in particular word-final position.

### 1.3 What is the Current Consensus?

French rhotics include trills, taps, flaps, fricatives, and approximants. There is no single physical property that is shared by all of them (Lindau 1980). Ladefoged and Maddieson (1996) note that they all have been intuitively represented by the letter ‘r’ and all of them have been historically related to other rhotics. Also, large numbers of rhotics may co-exist as allophonic and sociolinguistic variants of the same phoneme. The sociolinguistic literature just reviewed is agreed that the apico-alveolar trill [r] is no longer the usual form of the French /r/. Coveney (2001) describes trills, a tap, fricatives, and an approximant as variants of the phoneme. The uvular trill [ʀ] has been largely replaced by fricatives or approximants (39). Uvular [χ, ʁ] and velar [x, ʁ] fricatives exist as allophones of /r/ and often appear voiceless after voiceless consonants and voiced elsewhere (49).

Russell Webb (2004) describes the voicing pattern in detail as voiced in intervocalic environments, in a complex onset preceded by a voiced consonant, and in codas when followed by a voiced consonant, or when adjacent to a heterosyllabic voiced segment. /r/ appears voiceless in complex onsets when adjacent to a voiceless consonant, in complex codas when adjacent to a voiceless consonant, either preceding or following, or when adjacent to a heterosyllabic voiceless segment. Voicing is variable in simple onset, simple coda, and word-final cluster when preceded by a voiced consonant. In addition, especially in intervocalic position and word-finally as a simple coda, velar [ɣ] or uvular approximants [ʁ] may also be allophones of /r/ (Coveney 2001, Russell Webb 2009). Approximants, when devoiced, resemble voiceless fricatives, though with a lesser degree of friction. In informal speech, approximants appear to be becoming the principal allophone (Malderez 1997, Russell Webb 2002, Tranel 1987), though in emphatic or careful speech styles, intervocalic fricatives may be more frequent (Russell Webb 2009). It may also surface as a homorganic vowel in syllabic codas (Côté 2004).

## 2 The ANQ Corpus

The resources described in this section were compiled in order to systematically extract linguistic data from a corpus of natural language. Accumulating the linguistic data required to test and evaluate hypotheses can be a time consuming and labor intensive job. While there exist many computational tools available to the professional linguist, it is often the case that the unique needs of a specific research project are not adequately covered by available software. One of the goals of this paper is to illustrate how several freely available tools can be used to generate the data required for empirical analysis. The data used for the current study comes from the Hansen archives of political debate. Both audio and text files of the debates that occurred in the Assemblée nationale du Québec for the week of June 12–16, 2007 were obtained. Contained in this data are more than six hours of speech data from 61 speakers (43 males and 18 females). All of them are *députés de l'Assemblée nationale du Québec* and from different regions of Québec. The current version of the paper makes use of twenty-six speakers. These speakers are between the ages of 24 and 67, have several years of post-secondary education, and have served as elected representatives for between 1 and 31 years. While the study described in Section 3 does not take advantage of the sociolinguistic factors available in this corpus, many of the sociolinguistic factors commonly cited as being involved in /r/ allophony appear well controlled for in this corpus. Clermont and Cedergren (1979) describe speaker age as being the most important factor, followed by social class, gender, and education. Already in 1971, younger speakers from the Montréal area (<35) showed higher instances of [ʀ] than older speakers, and by 1984 all ages showed significant increases in [ʀ] as compared with [r] (Sankoff and Blondeau 2007). This age cohort is well represented in the ANQ corpus. Additionally, all speakers in the ANQ corpus share a similar social class and levels of education.

## 2.1 Penn Phonetics Lab Forced Aligner (P2FA)

The Penn Phonetics Lab Forced Aligner (Yuan and Liberman 2008) is an automatic phonetic alignment toolkit based on HTK, the Hidden Markov Model (HMM) toolkit maintained by the Cambridge University Engineering department. Both are distributed for use free of charge. P2FA takes as input an audio .wav file along with a corresponding .txt orthographic text file and produces a Praat TextGrid with interval boundaries for segments and words on two tiers.

The pronunciation dictionary used for this study is a modified and expanded version of Lexique version 3 (New et al. 2001, 2004). Lexique is a database that provides >135,000 words of French including orthographic and phonemic representations, syllabification, parts of speech, gender and number, frequency, and associated lemmas, etc. This information is stored in tables that can be downloaded or searched online. Lexique is an open database to which everyone is encouraged to participate.

The phonemic inventories of Canadian French and American English are not completely incompatible. There are 69 English monophone models supplied with P2FA. These include all of the consonant phones, as well as variously stressed vowel phones. A great many of these phones occur in French as well. These models could be used without modification. However, appropriate HMM's needed to be found within the P2FA set to map the French phonemes that do not occur in English. This set includes the nasal vowels, front rounded vowels, and several consonants, the most important of which is /r/. Additionally, the P2FA model set uses the ARPA notation and, as explained earlier, the dictionary includes just IPA style. The mapping of phones from French onto English HMM proceeded in several steps. First English phone models likely to be similar to a French one were identified. Using this mapping test files were submitted to the aligner. Small snippets of actual audio from the data were used in conjunction with a small mock dictionary containing a target sound transcribed with the English phones to test which model produced the best time alignment. When presented with multiple pronunciation entries, HTK evaluates each candidate and determines the most likely pronunciation encountered. For example, to determine the best English HMM model to use with /r/ the audio snippet *Le premier ministre... le rapport... général* transcribed orthographically in a text file as [le premier ministre {sil} le rapport {sil} général] was submitted to the aligner. This particular phrase was created in order to submit to HTK the various phonological environments expected to show variation: syllable initial in a cluster or as a simple onset, intervocalic, and syllable final as a simple coda or in a cluster. The multiple dictionary entries for each /r/ token contained the different English phone choices following from what is understood about the phonetics of this segment in these positions: it should have a back place of articulation, is most likely a fricative, but may appear as an approximant. Therefore the candidates are the regular retroflex approximant of English (R), the glottal fricative (HH), a labio-velar approximant (W), an alveolar fricative (DH), and a lateral (L). After several runs to eliminate discrepancies it was apparent that the aligner consistently chose the pronunciation candidate containing the glottal fricative in every environment. This choice was fortuitous as [h] is not a phoneme in the French inventory.

## 2.2 Acoustic Measurements

The literature anticipates three main variants of /r/ in this data: fricatives, trills, and approximants. Three measurement points for each /r/ token were established. One point in each of the neighboring segments, and one at the mid-point of the /r/. The intensity contour was used as a guide to place these three points. The lowest point on the intensity contour marked the mid-point of the /r/ token. For neighboring phones, the point was placed depending on the nature of the segment. For plosives, the moment of release was chosen. Many times, but especially following voiced plosives, there was a short vocalic episode following the release. This was ignored. For continuants, the point was placed at that point on the intensity contour just beyond the downward dip of the /r/. For neighboring sonorant phones, including vowels, nasals, and laterals, the point was placed at the peak of intensity before the downward contour of the /r/ token began. For each point, a 10ms window of time was centered, .05ms on either side, and ten values for each measurement were taken and averaged together. Values for intensity, the first three formants, band energy in the bandwidth

of each formant, and center of gravity (stop-filtered at 500Hz to remove the effects of voicing) were extracted. In addition, the percentage of change for each of these values between segments was calculated.

### 3 Illustration of Resources: Québec French /R/

The literature review indicates that many authors refer to syllable position when describing allophonic variation of /R/. Additionally, /R/ deletion patterns are frequently explained with reference to the syllable position. If it is found that allophonic variation and syllable position are related, or that changes in syllable position are associated with changes in the phonetic qualities of allophones, the research hypothesis will be supported and the relationship and effects of syllable position on allophonic variation should continue to be explored. If instead the null hypothesis is accepted, suggesting that allophonic variation is not related to syllable position or that changes in syllable position are not associated with changes in phonetic qualities, alternative explanations for /R/ allophony will need to be proposed.

Exploratory analyses of these data revealed that most allophones of /R/ differed from each other in terms of the measurements for energy in their formant frequency bands and their centers of gravity. Both fricatives were significantly different from either trills or approximants in some, or all, of these measurements. However, none of these four measurements, either alone or in combination, was able to determine a significant difference between trills and approximants. For this reason, it was decided to make a two-way distinction between fricatives, on the one hand, and trills and approximants on the other. It seemed appropriate to choose the feature [sonorant] as the distinguishing feature between these two groups. While it may be debatable whether the uvular trill forms a natural class with the approximant, for the purposes of this illustration it seems clear that, acoustically, trills and approximants were more like each other than either was to fricatives.

This section contains two illustrations, each testing a different research hypothesis that relates to the larger research question regarding the relationship and effects of syllable position on allophonic variation of Québec French /R/. The first illustration makes use of contingency tables and chi-square tests to examine the distribution of [ $\pm$ son] allophones to test the relationship between syllable position and allophonic variation. The second illustration is a multivariate factorial analysis of variance to test for differences in formant energy and center of gravity between both syllable position and [ $\pm$ son] specification.

#### 3.1 The Relationship between Syllable Position and Allophonic Variation

This experiment examines the relationship between syllable position and allophonic variation under two different conditions. Because our tokens were coded according to both syllable position (SimpleOnset, SimpleCoda, etc) and context (V\_V, C\_V, etc) we can isolate two different conditions under which to test our hypothesis while controlling for either syllable position, or context. In the first condition, context is held constant as either V\_V or C\_V allowing us to test the relationship of syllable position and allophonic variation without the confound of different phonetic contexts. In the second condition, syllable position is held constant as either SimpleOnset or SimpleCoda allowing us to test the relationship between syllable position and allophonic variation across different contexts. If the relationship between syllable position and allophonic variation exists, we expect to find significant  $\chi^2$  values in condition one, indicating a relationship between syllable position and allophonic variation since context, being held constant as either V\_V or C\_V, can have no effect. We expect to find no significant  $\chi^2$  values in condition two, again indicating a relationship between syllable position and allophonic variation since a change in context does not result in a significant change in distribution given that the syllable position has not changed.

A total of 4 contingency tables was constructed (2 for each of the 2 conditions). Individual chi-square tests were performed on each table to determine the effects of syllable position on allophonic variation. For each chi-square test performed, the null hypothesis remains the same:  $H_0 : \chi^2 = 0$ , which indicates that the observed distribution of allophones is not significantly different from the

expected distribution of allophones if there is no relationship between the two factors. For each chi-square test performed, the alternative hypothesis also remains the same:  $H_1 : \chi^2 > 0$ , indicating that the observed distribution of allophones was significantly different from the expected distribution of allophones had there been no relationship between the two factors.

Tables 1 and 2 help to illustrate the results obtained under the condition where context was held constant. When the context was held constant as V\_V, syllable position had no significant effect on the distribution of allophones. When the syllable position was SimpleOnset, 67% of the tokens were [+son]. When the syllable position was SimpleCoda, 69% of the tokens were [+son]. A chi-square test of the relationship between syllable position and allophone produced  $\chi^2(1) = .043$ , which is not statistically significant at  $p = .836$ . This is associated with an odds ratio of 0.93, indicating that the odds of being [+son] are approximately equal in both syllable positions.

	SimpleOnset	SimpleCoda	Totals
+son	195(196)	33(32)	228
-son	95(94)	15(16)	110
Totals	290	48	338

Table 1: Contingency table of distribution according to [ $\pm$ son] and syllable position for intervocalic context (V\_V). Expected frequencies are listed in parentheses.

When the context was held constant as C\_V, syllable position had no significant effect on the distribution of allophones. When the syllable position was SimpleOnset, 20% of the tokens were [+son]. When the syllable position was ComplexOnset, 29% of the tokens were [+son]. When the syllable position was ComplexCodaC2, 10% of the tokens were [+son]. A chi-square test of the relationship between syllable position and allophone produced  $\chi^2(2) = 3.788$ , which is not statistically significant at  $p = .150$ . The odds ratio for [+son] allophones in the two onset positions was 1.68, indicating that it is approximately one and a half times more likely to find a [+son] allophone in a ComplexOnset as opposed to a SimpleOnset in this context.

	SimpleOnset	ComplexOnset	ComplexCodaC2	Totals
+son	2(3)	60(56)	2(5)	64
-son	8(7)	143(147)	18(15)	169
Totals	10	203	20	233

Table 2: Contingency table of distribution according to [ $\pm$ son] and syllable position for post-consonantal context (C\_V). Expected frequencies are listed in parentheses.

Tables 3 and 4 help to illustrate the results obtained under the condition where syllable position was held constant. When the syllable position was held constant as SimpleOnset, context had a significant effect on the distribution of allophones. When the context was V\_V, 67% of the tokens were [+son]. When the context was C\_V, only 20% of the tokens were [+son]. A chi-square test of the relationship between context and allophone produced  $\chi^2(1) = 9.569$ , which is statistically significant at  $p = .002$ . This is associated with an odds ratio of 8.2, indicating that the odds of having a [+son] allophone are substantially higher in the intervocalic condition. This large odds ratio would indicate that we are talking about a meaningful difference between the two conditions.

	V_V	C_V	Totals
+son	195(190)	2(7)	197
-son	95(100)	8(3)	103
Totals	290	10	300

Table 3: Contingency table of distribution according to [ $\pm$ son] and context for SimpleOnset syllable position. Expected frequencies are listed in parentheses.

When the syllable position was held constant as SimpleCoda, context had a significant effect on



the distribution of allophones. When the context was V\_V, 69% of the tokens were [+son]. When the context was V\_C, 0% of the allophones were [+son]. A chi-square test of the relationship between context and allophone produced  $\chi^2(1) = 18.333$ , which is statistically significant at  $p = .00002$ . This is associated with an odds ratio of 27.5, indicating that the odds of having a [+son] allophone are substantially higher in the intervocalic condition. This large odds ratio would indicate that we are talking about a meaningful difference between the two conditions.

	V_V	V_C	Totals
+son	33(26)	0(7)	33
-son	15(22)	12(5)	27
Totals	48	12	60

Table 4: Contingency table of distribution according to [ $\pm$ son] and context for SimpleCoda syllable position. Expected frequencies are listed in parentheses.

These results are interesting since they are the opposite of what we would expect if syllable position and allophonic variation were related. The  $\chi^2$  values from the four tables, taken together, do not provide support for the hypothesis that allophonic variation is related to syllable position. However, the categorization of [ $\pm$ son] was done manually and therefore, subjectively. The experimenter coded each token according to whether they perceived a fricative, trill, or approximant. It would be interesting to test whether the tokens labeled [ $\pm$ son] do differ along some of the acoustic measurements extracted from the corpus and if these measurements are affected by syllable position, even if the distribution of them may not be. This has the added benefit of verifying the reliability of the experimenter's judgment. If the experimenter was not consistent in their categorization, there would be no significant difference between [ $\pm$ son] allophones.

### 3.2 The Effect of Syllable Position on Formant Energy and Center of Gravity

As explained earlier, exploratory data analysis on this corpus revealed that values for the amount of energy in the first three formant frequency bands along with the values for center of gravity (filtered to remove the effects of voicing) were able to produce a two-way distinction in allophones. Trills and approximants were not significantly different from each other on any of these measurements. The  $\chi^2$  values from illustration one suggest that the distribution of [ $\pm$ son] allophones may not be related to syllable position. We can explore this relationship further by evaluating the differences between [ $\pm$ son] allophones with respect to a combination of the acoustic values. A plausible combination could be the energy in the first formant (EF1) and the center of gravity (COG) since both of these values relate to measurements of both energy and frequency. Allophones categorized as [+son] include both the trills and the approximant ([r, R, ʀ]). Allophones categorized as [-son] include the fricatives ([ʁ, ʒ]). Allophones that are [+son] should have higher values for EF1 and lower values for COG. Allophones that are [-son] should have lower values for EF1 and higher values for COG. A two-way between subjects multivariate analysis of variance using the values for EF1 and COG as dependent variables and both Syllable (four levels: Simple Onset or Coda, Complex Onset or Coda) and Feature (two levels: [ $\pm$ son]) as independent variables will allow us to determine the main effects of both the independent variables, along with the interaction of these two variables combined. There are two research hypotheses to be tested. The first is that values for EF1 and/or COG will vary according to syllable position:  $H_1 : \mu_{Onset} \neq \mu_{Coda}$ . Support for this hypothesis could provide evidence in support of the claim that allophonic variation can be described in terms of syllable position. The second research hypothesis is that [+son] allophones (in this paper, trills and approximants) and [-son] allophones (fricatives) will differ in terms EF1 and/or COG:  $H_1 : \mu_{+son} \neq \mu_{-son}$ . Support for this hypothesis provides evidence in support of the claim that allophones of /R/ differ in terms of the amount of energy in specific frequency bands and that this difference can be expressed in terms of the feature [ $\pm$ son].

581 tokens from the corpus were used for this illustration. Only tokens from the intervocalic (V\_V) or post-consonantal (C\_V) context were used and each was tested separately. This was in

order to evaluate the effects of Syllable without the confounding effects of context. All tokens were categorized as either [+son] (r, ʁ) or [-son] (ʁ, ʒ). This gives a 2 x 2 factorial design for the V\_V condition, and a 3 x 2 factorial design for the C\_V condition. Table 5 displays the mean ratio values for each level of our factors. Standard deviations are given in parentheses. Separate analyses of variance were run for each of the two context conditions (V\_V or C\_V).

V_V		EF1	COG
SimpleOnset	+son	1.248(0.891)	1459(432)
	-son	0.724(0.682)	1690(445)
SimpleCoda	+son	1.067(0.675)	1258(303)
	-son	0.859(0.860)	1350(296)
C_V		EF1	COG
SimpleOnset	+son	0.807(0.615)	1483(336)
	-son	0.400(0.403)	1739(530)
ComplexOnset	+son	0.975(0.699)	1516(502)
	-son	0.531(0.546)	1760(625)
ComplexCodaC2	+son	0.876(0.772)	1106(338)
	-son	0.435(0.700)	1751(550)

Table 5: Summary of means and standard deviations for EF1 and COG.

The multivariate analysis of the V\_V condition indicated a main effect of Syllable on the combined dependent variables ( $F(1, 334) = 7.478, p < .001$ ). There also was a significant main effect found for Feature ( $F(1, 334) = 20.607, p < .001$ ). There was no significant interaction between Syllable and Feature ( $F(1, 334) = 1.071, p = .344$ ). Examining the univariate statistics for the V\_V condition revealed that most of the main effect found for Syllable was due to the significant effect of Syllable on COG ( $F(1, 334) = 14.270, p < .001, \omega = .04$ ). There was no significant effect found for Syllable on EF1 ( $F(1, 334) = .340, p = .560$ ). Thus, intervocalic codas had significantly lower centers of gravity than intervocalic onsets. When looking at differences in COG between intervocalic onsets and codas,  $\hat{d} = 0.59$  indicating values for COG in codas were more than half of one standard deviation lower than onsets. The main effect found for Feature was due to the effects on both EF1 and COG. There was a significant effect found for Feature on EF1 ( $F(1, 334) = 25.605, p < .001, \omega = .07$ ), as well as on COG ( $F(1, 334) = 18.775, p < .001, \omega = .05$ ). Intervocalic [+son] allophones had significantly higher values for EF1 and lower values for COG than [-son] allophones. When looking at these differences between [ $\pm$ son] allophones,  $\hat{d} = .59$  and  $.51$  indicating that [+son] allophones were approximately one half of one standard deviation larger in values for EF1, and lower in COG than [-son] allophones.

The multivariate analysis of the C\_V condition indicated no significant effect of Syllable on the combined dependent variables ( $F(2, 237) = .631, p = .641$ ). There was a significant effect found for Feature ( $F(2, 237) = 15.497, p < .001$ ). There was no significant interaction between Syllable and Feature ( $F(2, 237) = .219, p = .928$ ). Examining the univariate statistics for the C\_V condition revealed that the main effect found for Feature was due to the effects on both EF1 and COG. There was a significant effect found for Feature on EF1 ( $F(1, 237) = 26.522, p < .001, \omega = .10$ ), as well as on COG ( $F(1, 237) = 9.757, p = .002, \omega = .03$ ). Post-consonantal [+son] allophones had significantly higher values for EF1 and lower values for COG than [-son] allophones. When looking at these differences between [ $\pm$ son] allophones,  $\hat{d} = .74$  indicating that EF1 values for [+son] allophones were approximately three quarters of one standard deviation larger. The effect size was smaller for COG with  $\hat{d} = .44$ . COG values for [+son] allophones were almost one half standard deviation lower than [-son] allophones.

These results are interesting, but should be interpreted cautiously. These results indicate support for the hypothesis that allophones do differ in terms of values for EF1 and COG and that this difference could be expressed in featural terms as [ $\pm$ son]. Trills and approximants have higher values for EF1 and lower values for COG than fricatives and these values are not significantly affected by changes in syllable position. These results give mixed support for the hypothesis that changes in

syllable position will effect changes in values for EF1 or COG. Intervocalically there was a significant effect found for syllable position, although this effect was limited to just changes in center of gravity. Intervocalic codas showed significantly lower values for COG than onsets and this was true for all allophones regardless of their [ $\pm$ son] specification. Syllable position had no effect on values for EF1 in either the intervocalic or post-consonantal condition.

## 4 Conclusion

This paper offered a description of how to adapt the Penn Phonetics Lab Forced Aligner for use with a corpus of Québec French and how to extract meaningful data from the alignment results. The results of adapting the aligner for use with this corpus of French are encouraging. The /R/ illustration demonstrated how to profitably use this empirical data to evaluate several hypotheses concerning the relationship and effects of syllable position on allophonic variation of /R/. The results from the tests of the distribution of [ $\pm$ son] allophones, along with the results from the analysis of variance, did not support the hypothesis that allophonic variation is related to, or affected by, syllable position. Approximants and trills were equally likely to occur in either onsets or codas when intervocalic, and only slightly more likely to occur in complex onsets when post-consonantal. The results from the analysis of variance do support the hypothesis that approximants and trills are more sonorous than fricatives as measured by the amount of energy in their first formant and their center of gravity. Approximants and trills had significantly higher values for energy in their first formant frequency, and significantly lower values for center of gravity than fricatives.

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