Is protrusion of French rounded vowels affected by prosodic positions?

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Abstract

This paper examines whether lip protrusion is affected by initial strengthening of rounded vowels in French. Three speakers produced sentences containing the vowels /i, e, ɛ, a, y, ø, œ, u, o, ɔ/ at the beginning of different prosodic constituents: Intonational Phrase (IP), Accentual Phrase (AP) and Word (W). Using video and Qualisys motion capture data, three parameters (lip protrusion, area/lip protrusion and lip protrusion/area) are compared to characterize the labial configuration, first between [-round] and [+round] vowels, then within [+round] vowels. These three parameters are found to discriminate between [+/-rounded], to reflect some within category distinction and to show speaker-specific labial patterns. Concerning the effect of prosodic boundary, only the combined measurement of lip protrusion/area reveals a speaker dependent effect on prosodic boundaries. Two speakers out of three show a tendency to decrease lip protrusion/area in IP initial position for back rounded vowels (/o/ and /ɔ/) and for /y/. Prosodic boundary effects are discussed in terms of feature enhancement.

Index Terms: prosodic boundaries, rounded vowels, lip protrusion, French, motion capture, video.

1. Introduction

Pioneering studies on lip configuration have been undertaken by Fromkin ([1]), Fujimura ([2]) or Lindblom ([3], [4]) on American or Swedish vowels. These studies show the importance of three parameters used to describe labial configuration of vowels: lip height, lip width and lip protrusion. These parameters correspond to the three degrees of freedom of the lips as proposed by Ladefoged ([5], p. 45). Consequently, quantification of lip-geometry in the coronal plane is commonly done by measures of lip width and/or lip height and/or a combination of the two dimensions in a measurement of the area of the labial orifice. In the sagittal plan, protrusion is either measured as the protrusion of the upper and/or lower lip, and/or of the inner corner of the lips relative to a fix reference point ([1], [6], [7]).

Several studies have tried to compare these possible parameters to find out which one best captures the [+/-round] contrast ([1], American English; [6], [8] for French). In the coronal plane, lip height and lip width were found to be smaller for rounded vs. unrounded vowels ([9]), which could be interpreted in terms of area discrimination ([6], [7]). On the sagittal plan, [6]'s study showed that inter-lip corners distance compared to protrusion of the upper and lower lip better reflected protrusion and lip retraction. The fact that these results were only significant for one speaker (out of 5) underlines the necessity to study inter-speaker variability in lip protrusion.

Stevens & House ([10]) proposed a measurement combining information on both the coronal and sagittal planes: a lip area/ lip protrusion ratio. Fant ([11], p. 64) rather used the inverse lip-protrusion/lip-area ratio (P/A), defined as "*a quantitative measure of lip-rounding (which) can apparently be specified by the ratio of the effective length (...) to the area (...) of the lip section*" and therefore more directly interpretable in terms of acoustic modeling.

In French, within the [+round] category, 3 lips protrusion degrees have been proposed by Potard and Laprie [12], the most protruded vowels being the closed vowels /y/ and /u/, the intermediate being the mid-closed vowels /ø/ and /o/ and the least protruded being the mi-open vowels /œ/, /ɔ/. This relationship between protrusion and vowel height was also described by Abry, Boë & Descout, [13], who found maximal protrusion for minimal jaw height & minimal lip width in French (i.e. for /y/ and /u/). Between these 2 vowels however, Benguerel & Cowan ([14], p46) found some difference in protrusion: /u/ being more protruded than /y/.

Recently, lip protrusion has been shown to vary according to prosodic factors in French. Tabain and Perrier ([15]) found that before a strong prosodic boundary (utterance final), a final /u/ is more protruded than before a weaker prosodic boundary. In the present study, we are examining another position where strengthening is expected: the domain initial position. In a previous study ([16]), we examined the lip configuration of /i, a, y/ in the coronal plane according to 3 prosodic boundaries: Intonational Phrase (IP), Accentual Phrase (AP) and Word (W). Larger lip area, lip width and lip height were found in IP initial position for the rounded vowel /y/ but also for the unrounded /i/ and /a/, An acoustic study on these vowels showed that both the rounding contrast (estimated by F2, F3, F3-F2) and the vowel height contrast (estimated by F1) were enhanced in IP initial positions ([17]).

In the present study, we investigate further the effect of prosodic boundary on French vowels by looking at the third dimension involved in the [+/-round] contrast: lip protrusion. Our main objective is to test whether protrusion is also affected by initial strengthening. To do so, we observed the realization of /i, e, ɛ, a, y, ø, œ, u, o, ɔ/ at the beginning of different constituents in French. In order to discriminate unrounded vs. rounded vowels and vowels within the [+round] category, we compare results obtained from the protrusion parameter only and from both ratios also involving lip area (lip-area/lip-protrusion and lip protrusion/lip-area). As an extension of previous studies carried out on the same data, we also test which parameters show speakers-specific labial patterns.

2. Material and Methods

2.1. Corpus

Articulatory realizations (lip protrusion and lip area measurements) of the rounded French vowels /y, ø, œ, u, o, ɔ/ are compared in absolute initial position of three prosodic boundaries: Intonational Phrase (IP), Accentual Phrase (AP) and Word (W).

The induction of various prosodic boundaries on the same segmental context was achieved by building sentences starting with lists of two to four names with different syntactical structures designed to force intended constituents grouping during production. Sentences such as "*D'après N1, N2 et N3 (...)*" ("According to N1, N2 and N3 (...)") were used to induce an IP boundary between N1 and N2, where Ni are existing or invented first names with selected segmental content. Sentences such as "*N1, N2, N3 et N4 (...)*" ("N1, N2, N3 and N4 (...)") were used to induce an AP boundary between N2 and N3. Word boundaries (W) between N3 and N4 were induced by building compound names in sentences such as "*N1-N2 et N3-N4 (...)*" ("N1-N2 et N3-N4 (...)"). For instance, an IP boundary in /ip#up/ context was induced using the sentence "*D'après Philippe, Oupoulo et Marie ont beaucoup dansé.*" ("According to Philip, Oupoulo and Marie danced a lot.").

All the target vowels (V) appear in a [ip#VC] sequence where V is the initial segment of a trisyllabic first name and C is the bilabial stop /p/, except for mid-open vowels in order to elicit their pronunciation as mid-closed: /œ/ and /ɛ/ are respectively followed by the labio-dental fricative /f/ and /v/ and /ɔ/ by a non labial consonant (the uvular fricative /ʁ/). Eighteen sentences (3 prosodic boundaries*10 vowels) were read in a random order by three native French female speakers (aged 25 to 40 years, with no identifiable regional accent) and repeated 16 times. Due to inconsistencies in the data acquisition revealed by a posteriori checks, some repetitions had to be discarded from analysis. Table 2 summarizes the number of renditions analyzed per vowel and prosodic position for the 3 speakers S1, S2, and S3. Given the important preparation and recording time (an hour per speaker), we could only record three speakers.

Table 2: *Number of renditions analyzed by speaker, prosodic position and vowel. Rounded vowels are analyzed separately while unrounded vowels are considered as a group.*

Vowel		S1			S2			S3		
		IP	AP	W	IP	AP	W	IP	AP	W
[-round]		69	71	77	55	57	67	63	58	65
[+round]	/y/	14	15	17	14	14	16	14	14	12
	/ø/	18	12	18	8	12	15	13	14	10
	/œ/	21	10	15	11	12	17	11	13	15
	/u/	16	18	20	13	15	19	12	14	14
	/o/	15	19	19	15	14	16	17	14	14
	/ɔ/	12	14	18	12	13	16	10	13	19

2.2. Data acquisition and processing

2.2.1. Data acquisition setup

The main device used for lip articulation data acquisition was the Qualisys, an optical motion capture system equipped with three infrared emitting-receiving cameras, allowing the acquisition of the 3D position of reflecting markers (4 mm in diameter) at a frequency of 100Hz. For the purpose of lip articulation analysis, four markers were positioned on the speaker's external lip contour as illustrated by Figure 1. Six reference markers were positioned at stable positions (nasal bridge and four positions on a helmet maintained in a fixed position during data acquisition) to enable automatic correction for head movements.

Video data at 25 fps was simultaneously acquired using a DCR PC8 Sony camera, oriented towards the speaker's face to enable a posteriori lip contour extraction.

Acoustic data was recorded with a head-mounted Shure SM10A microphone (44.1 kHz) and a Roland Edirol UA 25 sound card, together with the Qualisys-generated trigger signal, indicating the acquisition instants of 3D position for each marker and thus enabling direct synchronization between audio and motion capture data.

Video data was converted as JPEG images sequences, which were synchronized to the motion capture data through the alignment of the audio recording with the audio signal captured by the digital camera.

Figure 1. *Lip contour for speaker S1 with Qualisys markers on the external lip contour (white markers).*

2.2.2. Post-processing

As a first step, audio data were manually segmented at the utterance and phoneme level using the Praat software ([18]).

From this labeling, video frames corresponding to the production of target vowels were extracted from the JPEG sequences (video data). Four points were positioned manually on the images on the internal contour of the speaker' lips using MATLAB: at the right and left inner corner of the lips and in the middle of upper and lower lip's inner contours at the level of Cupidon's arch, following the line drawn by Qualisys markers located on the upper and lower lip.

3D positions of Qualisys markers were rotated using MATLAB to compensate the speakers' head movements and enable the analysis of measured movements in a stable plane.

2.2.3. Extraction of measurements

Lip protrusion (P) and lip area (A) were extracted at the middle of the acoustic realization of target vowels defined on the audio signal, and used to compute the ratios A/0 and P/A.

Lip area (A) was extracted from the video images, as the area of the polygon delimited by the four points located manually on the inner lip contour. (Note that the area based on the inner lip contour (video data) has been compared to the area based on the external lip contour (Qualysis markers) and was found to be more accurate and less dependent on speaker lip shape)

Protrusion (P) was measured from rotated Qualysis data as the displacement in the sagittal plane of the point located half-way between lip left and right lip corners (interpolated from lip corners coordinates), relatively to a reference point chosen as the nasal bridge. This point corresponds to the inter-lip corners distance value used in [6]. Protrusion values were normalized by subtracting the minimal value measured for each speaker, in order to obtain positive values more directly interpretable as a distance relative to a rest articulatory position as in [6].

3. Results

3.1. Comparison between [+/-round] vowels

First, in order to estimate labial configuration differences between [-round] and [+round] vowels, the effect of 'roundedness' is tested in a two-way ANOVA, with roundedness and speaker as fixed factors, and protrusion (P), area/protrusion (A/P) or protrusion/area (P/A) as dependent variable. A significant effect of roundedness is found on P ($F(1,1262)=226$, $p<.001$), P/A ($F(1,1262)=351$, $p<.001$) and A/P ($F(1,1261)=22$, $p<.001$) the interaction with speaker being significant for only two variables ($F(1,1262)=5$, $p<.05$ for P, $F(1,1262)=11$, $p<.001$ for P/A). As expected, rounded vowels have more lip protrusion, higher P/A and smaller A/P ratio than unrounded vowels ($p<.001$). Separate analysis of results for each speaker indicates that [-round] and [+round] vowels are significantly distinguished by both P and P/A for all 3 tested speakers ($p<.05$ for all effects). No effect is found on the area/protrusion (A/P) measure.

3.2. Analysis of the rounded vowels

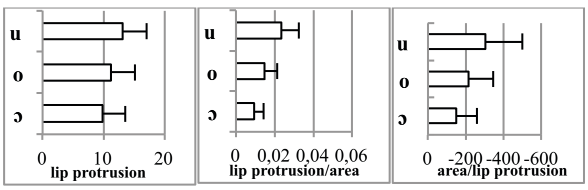
Three-way ANOVAs were used to compare the effects of 'prosodic boundary' (with 3 levels: IPi, APi, Wi), 'speaker' (with 3 levels: S1, S2, S3) and 'vowels' (with six levels: /y, ø, œ, u, o, ɔ/) on the three articulatory parameters: P, P/A, A/P.

3.2.1. Differences in labial parameters

A vowel effect is found on lip protrusion (P) ($F(5,731)=28$, $p<.001$), protrusion/area (P/A) ($F(5,731)=191$, $p<.001$) and are/protrusion ($F(5,731)=56$, $p<.001$) measurements. P and P/A or A/P don't lead to the same classification of vowels. Tukey HSD post-hoc tests show that the lips are more protruded for /y, u/ than for /ø, œ, o, ɔ/ (as illustrated by figure 2). In this latter set of vowels, /o/ shows more protrusion than the other vowels ($p<.05$). As expected, a direct link is observed between protrusion measurement and vowel height: high vowels are more protruded than lower vowels.

For the P/A parameter, /y/ has a significantly higher value than /u, ø, œ, o, ɔ/. P/A value is lower for /œ/ than for /ø/ and is also lower for /ɔ/ than for /o, u, y/ as illustrated in figure 2 ($p<.05$). Inversely, for the A/P parameter, /y/ and /u/ have significantly lower values than /ø, œ, o, ɔ/ and mid-closed vowels /o, ø/ show a lower value than their mid-open counterparts. No difference is found between /y/ and /u/.

As for the P parameter, P/A and A/P vary with vowel height: when a higher lip area is associated with a lower lip protrusion (as observed for mid-open rounded vowels), the ratio P/A decreases and the A/P increases. Conversely, a lower lip area is associated with a higher lip protrusion (as observed for closed rounded vowels), the ratio between P/A increases and A/P decreases (as illustrated by figure 2).



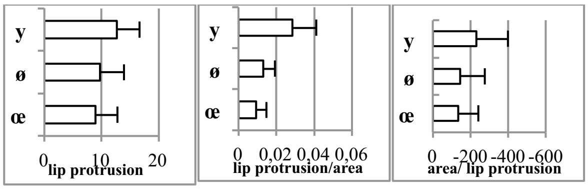


Figure 2: *Lip protrusion (top) and lip protrusion/area ratio values (bottom) for back vowels (left) and for front rounded vowels (right), all speakers pooled. Error bars represent standard deviation.*

3.2.2. Inter-speaker differences in labial configuration

A difference between speakers is found for the parameters P ($F(2,731)=66$, $p<.001$), P/A ($F(2,731)=154$, $p<.001$) and A/P ($F(2,731)=66$, $p<.001$). Tukey HSD post-hoc tests show that speakers' labial configurations are different: speaker S1 produces rounded vowels with the highest protrusion, A/P and the smallest P/A, followed by S3 and S2 (S2>*S3>*S1, $p<.001$ for all parameters) as observed in figure 3.

An interaction between vowel and speaker is found for the parameters P ($F(10,731)=6$, $p<.001$), P/A ($F(10,731)=7$, $p<.001$) and A/P ($F(10,731)=11$, $p<.001$). This interaction indicates that inter-speaker differences in labial configuration within rounded vowels are vowel-dependent.

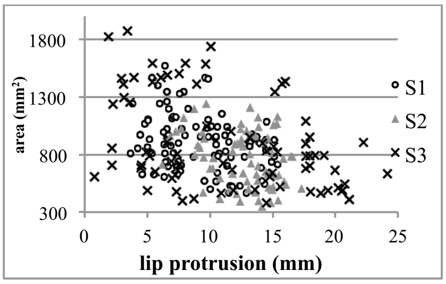


Figure 3. *Lip protrusion and area for speakers S1, S2 and S3 in IP-position, for all rounded vowels.*

3.2.3. Prosodic boundary effects

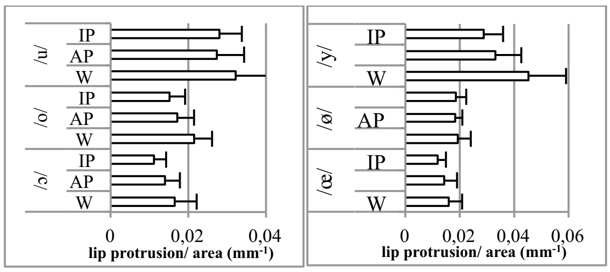


Figure 3. *Lip protrusion/area for back vowels (top) and for front rounded vowels (bottom) in IP, AP and W prosodic conditions for S2. Error bars represent standard deviation.*

A boundary effect is found for the P/A parameter ($F(2,731)=10$, $p<.001$) and for A/P parameter ($F(2,731)=5$, $p<0,05$). All vowels and all speakers pooled, a smaller P/A value is observed in IP-initial position and AP-initial positions compared to Word position (IP, AP<*W; $p<.05$). For A/P parameter, only two prosodic boundaries are distinguished with IP>W (p<0,05). Considering parameter P, no effect is found.

For A/P parameter, a two-way interaction is found between vowel and prosodic boundaries (F(10,731)=2, p<.005). Boundary effects are tested by a one way ANOVA for each vowel. No effect of prosodic boundary is found on rounded vowels except for /ɔ/ (F(2,123)=3, p<.05), where IP>*AP (p<.05).

Considering P/A parameter, a three way interaction is found between boundary, speaker and vowels (F(20,731)=2, p<.05). Boundary effects are tested by a one-way ANOVA for each speaker and vowel. The results show an effect of prosodic positions for two out of three speakers: S2 and S3. For speaker S3, as illustrated by Figure 4, only one vowel /ɔ/ shows a significant effect in IP-initial with lower P/A (vs W) (F(2,38)=5, p<.05). For speaker S2, three vowels show a significant effect of prosodic boundaries. A Tukey HSD post-hoc test shows a lower P/A in IP-initial position with IP, AP<*W for /o/ (F(2,42)=9 p<.001), for /y/ (F(2,41)=9, p<.001). For /ɔ/ (F(2,38)=5, p<.005), a lower P/A is also observed in IP-initial (vs W).

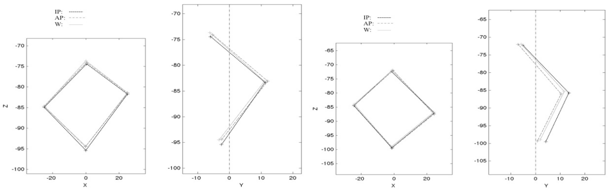


Figure 4. *Mean positions of the motion capture markers placed on lips corners and upper/lower lips in IP, AP and W prosodic position, in the coronal (left) and sagittal planes (right, inter-lip corners position plotted instead of right and left corners). Top: /y/ for S3; Bottom: /ɔ/ for S2.*

4. Conclusions

In this study, we compared the ability to reflect differences in [+/-round] contrast of three parameters: lip protrusion measured as the displacement of lip corners in the sagittal plane (P), and two parameters defined as a ratio between this displacement and lip area: area/protrusion (A/P) [10] and protrusion/area (P/A) [11]. Values were compared on French rounded (/y, ø, œ, u, o, ɔ/) vs. unrounded (/i, e, ɛ, a/) oral vowels.

As expected, the protrusion parameter alone (P) indicates that rounded vowels are more protruded than unrounded vowels. Within rounded vowels, our results replicate results of [12] and [14], confirming that high vowels /y/ and /u/ are the most protruded and that mid-open vowels /œ, ɔ/ are the least protruded. A difference in protrusion between front and back rounded vowels of the same height is also found, though not for the vowel pairs /o-ø/ described by [12] and /u-y/ described by [14]: back mid-high /o/ is found to be more protruded that its front counterpart /ø/, while protrusion of /u/ and /y/ are not significantly different.

Similar differences were found for the protrusion/area ratio (P/A), except a distinction between /ø/-/œ/ and /y/-/u/ (with /ø/>*/œ/ and /y/>*/u/). For the parameter A/P, no distinction between closed vowels /y/ and /u/ is found. These results are in line with [12] ad [13], which showed that protrusion variations are aperture-dependent. As expected, rounded vowels are characterized by a larger P/A ratio, due to their longer protrusion and smaller lip area: mid-open vowels /œ, ɔ/ show the lowest P/A or the highest A/P values while /y/ corresponds to the highest P/A or the lowest A/P values.

Contrarily to [6], who found significant differences in protrusion measurements between French [+round] vs. [-round] vowels for only 1 speaker out of 5, this contrast was reflected by all speakers. However, large inter-speaker differences were found within [+round] vowels. This latter result underlines the need for speaker-dependent analyses of lip rounding measurements.

Our objective was to investigate whether lip protrusion of rounded vowels is affected by initial strengthening. Results on three parameters show that lip protrusion alone is not affected by initial strengthening: French rounded vowels do not vary in lip protrusion between IP-, AP-, and W-initial positions. For the parameter A/P, the effect of prosodic position is observed on only one vowel, all speakers pooled. Although a speaker-dependent effect of prosodic position is found for P/A on three vowels, both parameters do not reflect the expected hierarchy between different prosodic domains: no clear distinction emerges between Accentual Phrase and Intonational Phrase, contrary to results of [17], [19], [20]. This effect on P/A can be attributed to variations in lip area across prosodic positions, as measured in [21]: in this study, both unrounded and rounded vowels in French were found to have a larger lip area in IP-initial position, indicating an increased distinction between [+/-round]. The comparison of results obtained from protrusion alone, protrusion/area and area alone indicate that the lip protrusion does not counterbalance the increase of lip area in IP-initial position.

Articulatory data on lip articulation can be discussed in the light of previous acoustic results on rounded vowels. As observed in [17], the front vowel /y/ shows a lower F3 and a lower F3-F2 distance in IP-initial position. A clear enhancement of the feature [+ back] was observed from the narrowing of the F2-F1 distance for /o/ and /ɔ/. Such narrowing of the F2-F1 distance, which contributes to enhancing the distinction between front and back vowels, might be linked to the lower P/A observed in the present study. Weak variations observed in lip protrusion are in line with Tabain & Perrier studies ([15], [22], [23]) in which spectral and articulatory variations were found for domain final boundaries, showing that final position urges acoustical target reaching for vowels. Further articulatory investigations (especially on tongue articulation) would be necessary to better describe initial strengthening on rounded vowels.

This paper shows that, although lip protrusion can be considered as a major articulatory feature of rounded vowels, this parameter is not affected by prosodic boundaries. This result contributes to our understanding of domain-initial vowel articulations with regard to spatial expansion.

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