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Acoustic Correlates of Prosodic Boundaries in French: A Review of Corpus Data

Correlatos acústicos de fronteiras prosódicas em francês: uma revisão de dados de *corpora*

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Abstract: In this article we investigate the acoustic correlates of prosodic boundaries in French speech. We compare the prosodic structure annotation performed by experts in two multi-genre corpora (Rhapsodie and LOCAS-F). A uniform analysis procedure is applied to both corpora. The results show that the main acoustic correlates of prosodic boundaries are silent pauses and pre-boundary syllable lengthening. Pitch movements contribute to the perception of boundaries but are essentially correlates of boundary function, rather than boundary strength. Two levels of four-level annotation of boundary strength in the Rhapsodie corpus (periods and packages) correspond to the two-levels of strength in the LOCAS-F corpus.

Keywords: prosody; speech segmentation; prosodic boundaries; corpus linguistics; French.

Resumo: Neste artigo investigamos os correlatos acústicos de fronteiras prosódicas da fala em língua francesa. Comparamos a anotação da estrutura prosódica efetuada por anotadores *experts* em dois corpora multigêneros (Rhapsodie e LOCAS-F). Um procedimento de análise uniforme é aplicado a ambos os *corpora*. Os resultados indicam que os principais correlatos acústicos de fronteiras prosódicas são pausa silenciosa e alongamento da sílaba pré-fronteira. Movimentos de *pitch* contribuem para a percepção de fronteiras mas são essencialmente correlatos de funções de fronteira, e não de força de fronteira. Dois dos níveis de anotação dos quatro níveis de anotação de força de fronteira do *corpus* Rhapsodie (períodos e pacotes) correspondem aos dois níveis de intensidade do *corpus* LOCAS-F.

Palavras-chave: prosódia; segmentação da fala; fronteiras prosódicas; linguística de *corpus*; francês.

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1 Introduction

The segmentation of speech into meaningful units is central to discourse comprehension. In this respect, prosody is used by the speaker to guide the listener in reconstructing the intended segmentation and understand the message. For this reason, numerous studies have been dedicated to understanding how prosodic cues are used to signal the segmentation of an utterance, and the relationship between the prosodic segmentation and other levels of linguistic analysis, such as the syntactical structure and the information structure of speech.

Researchers working on French have particularly focused on the relationship between prosodic structure and syntactic structure. Two projects have resulted in two spoken French corpora including multiple speakers in multiple communicative situations (speaking styles), with very similar research objectives: the Rhapsodie corpus (LACHERET *et al*., 2014) and the LOCAS-F corpus (MARTIN *et al*., 2014). An analysis of the properties of the prosodic boundaries annotated by experts in the LOCAS-F corpus has already been presented in Christodoulides and Simon (2015); the relevant aspects of this study are repeated here for the reader's convenience.

In this article we will compare the annotation of prosodic structure in the Rhapsodie and the LOCAS-F corpora. These annotations were performed independently, by different experts in French prosody, and following different theoretical frameworks. In this study, we are interested in calculating the acoustic correlates of prosodic boundaries based on each of the two annotations and searching for similarities and differences. Our work has both a theoretical motivation and a practical application: in order develop software tools for the automatic annotation of prosodic structure (e.g. MITTMANN; BARBOSA, 2016), appropriately-sized, publicly-available corpora are essential. We are therefore interested in exploring whether machine learning models trained on each of these two French corpora will be consistent with each other.

2 Related work

The prosodic segmentation of an utterance, as expressed by the prosodic boundary cues, is central to discourse comprehension (for a review, see CUTLER, 1997 and FÉRY, 2017). It has been shown that prosodic boundaries facilitate comprehension, by indicating the intended segmentation to the listener (e.g. SWERTS, 1997; CLIFTON *et al*., 2002; WATSON; GIBSON, 2005; FRAZIER *et al*., 2006). Stress, prominence and prosodic boundaries play a central role in defining the prosodic structure and arriving at a phonological description of any language (MERTENS, 2014). However, the factors contributing to the perception of prosodic segmentation are not completely understood. Phonological theories differ in the number of prosodic segmentation levels, and consequently on the number of prosodic boundary strengths. Consequently, there is no consensus on a universally-accepted, objective method of segmentation of utterances into prosodic units. Corpus resources with prosodic annotation have been compiled over the past years, including: for English, the AixMARSEC corpus (AURAN *et al*., 2004) and the Boston University Radio News Corpus (OSTENDORF *et al*., 1995); for French, Italian, Portuguese and Spanish, the C-ORAL-ROM collection of corpora (CRESTI; MONEGLIA, 2005); and the Spoken Dutch Corpus (SCHUURMAN *et al*., 2003).

Although most models on French prosody admit at least three degrees of prosodic boundaries and a hierarchy of three levels of units (JUN; FOUGERON, 2000; MERTENS, 1993; ROSSI, 1999; DI CRISTO, 1999), most large-scale corpus annotations are limited to one or two degrees (e.g. the C-ORAL-ROM corpus). Furthermore, there is evidence that listeners perceive prosodic boundaries as a gradual phenomenon and in relative terms, i.e. they perceive a boundary as stronger or as weaker than the previous one.

As discussed in detail in Wagner *et al*. (2015), research on prosodic prominence can be grouped into three main perspectives: a functional, a physical and a cognitive perspective. A similar categorisation can be applied to research on prosodic segmentation, given that a prosodic boundary will render the syllable (or, more generally speaking, the right edge of a larger prosodic unit) on which it is realised prominent, in the sense that this syllable (or right edge) will stand out from its environment by virtue of its prosodic characteristics.

A functional perspective on prosodic prominence and segmentation focuses on its communicative and core linguistic functions; this approach lends itself to a categorical classification: a syllable is prominent or not, a prosodic boundary is present or not. This is the approach taken in phonological theories, that discretise the perception of boundaries and use a small number of prosodic boundary strengths (e.g. major, intermediate, minor) to define a hierarchy of prosodic units. A physical perspective will treat prosodic prominence and prosodic segmentation as a continuous rather than a categorical phenomenon, similar to a psycho-acoustic scale. Under this approach, perceptual experiments help in identifying a number of signal-related correlates to the perception of prominence or segmentation; these correlates are continuous physical quantities (e.g. duration, fundamental frequency, voice source features etc) that combine (e.g. using a linear combination formula) to give a "degree" or "score" of perceived prominence or boundary strength. A cognitive perspective focuses on perceptual processing, i.e. the way in which these phenomena are interpreted and contribute in higher-level cognitive processes. These processes are shaped by linguistic knowledge and situation-specific expectations. The cognitive perspective relies on both the functional perspective and the physical perspective. Wagner *et al*. (2015) argue that these perspectives are complementary, that they are "different parts of the same elephant".

In the present study, we investigate the acoustic correlates of prosodic boundaries on the basis of annotations on two corpora. We are therefore taking an intermediate route between a physical perspective and a functional (and, to some extent, a cognitive) perspective. The expert annotators of these corpora were all native speakers of French and indicated the presence of prosodic boundaries based on their perception, influenced by the speech signal, their linguistic knowledge and their top-down expectations, and working within a specific functional model that determined the number of prosodic boundary strengths used in the annotation (four-level vs. two-level).

Previous research (e.g. MO *et al*., 2008; MO, 2008; WAGNER; WATSON, 2010) suggests that silent pauses, duration, f_0 movement and phonation type are the most salient cues to prosodic boundaries. Those cues are known to be language-specific to some extent. In French, since the primary (final) accent is located on the last syllable of a prosodic unit, it co-occurs with the prosodic boundaries (cf. DI

CRISTO, 2011). However, this does not mean that French listeners cannot distinguish between prominence and prosodic phrasing, as shown in perception experiments by Astésano *et al*. (2012). Experiments with naïve listeners have identified silent pause duration, syllable duration and pitch movements as relevant acoustic correlates of prosodic prominence and prosodic segmentation in French (e.g. PORTES, 2002; SMITH, 2011).

3 Method

3.1 Corpora

The Rhapsodie corpus is a corpus covering multiple speaking styles and was created with the objective of studying the relationship between prosodic phrasing and syntax in French. The corpus samples were mainly collected from existing French corpora, including the PFC corpus (DURAND *et al*., 2009), C-PROM (AVANZI *et al*., 2010) and CFPP (BRANCA-ROSOFF *et al*., 2012). The corpus contains 57 short samples (the average sample duration is 5 minutes) for a total of 3 hours of speech and 33,000 tokens. The corpus samples were balanced across four dimensions: the degree of speech planning, the degree of interactivity, the communication channel, and the main discourse strategy used by the primary speaker (oratory, argumentative, descriptive, or procedural); the corpus contains both monologues and dialogues.

In the Rhapsodie corpus, the syntactic annotation is articulated in two levels, called "micro-syntactic" and "macro-syntactic" by the authors; the main theoretical framework posits the use of "pile structures" to represent the syntactic relations of short segments of continuous speech, including self-corrections and other types of disfluencies. The prosodic annotation includes: prosodically prominent syllables annotated by experts based on their perception, using two levels (weak and strong); an annotation of disfluencies at the syllable level. (e.g. lengthening); and a prosodic structure annotation composed of intonational periods, intermediate packages, rhythmic groups and metrical feet. A perceptual boundary annotation was abandoned by the project due to poor inter-annotator agreement (LACHERET *et al*., 2014). The four-level annotation was performed within the Autosegmental-Metrical theoretical framework.

The LOCAS-F corpus is similarly a corpus covering multiple speaking styles, including both monologues and dialogues, and was also created in order to study the relationship between prosody and syntax in French. The corpus contains 48 samples organised in 14 different speaking styles; its duration is 3.5 hours and it contains approximately 43.000 tokens. Samples from the C-PROM corpus were reused in the LOCAS-F corpus; the reused samples are 3 radio news broadcasts, 3 political public addresses, 3 scientific conference presentations, 2 radio interviews and 3 monologue narrations of life events; 75% of the C-PROM corpus is included in LOCAS-F, and C-PROM samples make up 25% of the LOCAS-F corpus.

In the LOCAS-F corpus, the syntactic annotation is articulated in two levels: a sequential, non-overlapping grouping of tokens into "functional sequences" that are further grouped into dependency clauses (a clause consisting of its root and all its dependent elements). The prosodic annotation was performed by two expert annotators. Each word was marked as being followed by a strong PB (///), an intermediate PB (//), or as not followed by any boundary (0). The annotators used the code "hesi" to indicate that they perceive the speaker was hesitating: this includes filled pauses (e.g. "euh") and drawls. A function was also attributed to each PB, based on the shape of the corresponding intonation contour. Four types of contours were used: C (continuation), T (final prosody), S (suspense) and F (focus). This annotation was primarily based on the annotators' perception; however, they did have visual access to the pitch contour as displayed in *Praat* (BOERSMA; WEENINK, 2017). In cases of disagreement, the annotators listened to the relevant section once again and agreed on the final prosodic boundary and contour label. Note that a "focus" contour is related to the fact that the annotator perceived an element of the utterance as being made salient, and not necessarily on a definition of prosodic prominence.

The Rhapsodie corpus is available under a Creative Commons license and can be downloaded from the project's website (www.projet-rhapsodie.fr). The LOCAS-F corpus is not publicly available; our analyses are based on the version of the corpus that was made available to us for the study presented in Christodoulides and Simon (2015) and our subsequent work on the corpus.

3.2 Data analysis

Both corpora were imported into *Praaline* (CHRISTODOULIDES, 2014) for processing and to render the annotations comparable. The TextGrids and XML files of the Rhapsodie corpus are publicly available on the project's website; the LOCAS-F corpus is already stored as a *Praaline* SQL database but it is not yet publicly available.

We enhanced the available annotations in the corpora by applying *DisMo* multi-level annotator (CHRISTODOULIDES *et al*., 2014) and the *Prosogram* series of scripts for intonation stylisation (MERTENS, 2004). An automated script was used to extract all potential prosodic boundary sites, i.e. all syllables at the right boundary of a multi-word unit (as annotated by *DisMo*). The script calculates multiple prosodic measures on each syllable, including:

- the duration of a subsequent silent pause, excluding the pauses at turn-taking;
- relative duration: the duration of the last syllable divided by the average duration of the 2, 3, 4 and 5 previous syllables;
- relative pitch: the difference between the pitch (in semitones) of the last syllable and the average pitch of the 2, 3, 4 and 5 previous syllables;
- intra-syllabic pitch movement (in semitones)

The script also includes the information on the part-of-speech tag attributed to the corresponding token, and the corresponding expert annotation (by indicating whether the syllable marks the boundary of a specified unit).

The coding for prosodic units that will be used in the rest of the article is as follows: for the Rhapsodie corpus, four levels of annotation PER for periods, PCK for packages, GRP for groups and FT for feet; for the LOCAS-F corpus: B2 are boundaries of intermediate strength, B3 are strong boundaries, and HES indicate hesitations inhibiting the perception of a boundary. Syllables not marking a prosodic boundary are indicated by the symbol 0 (zero).

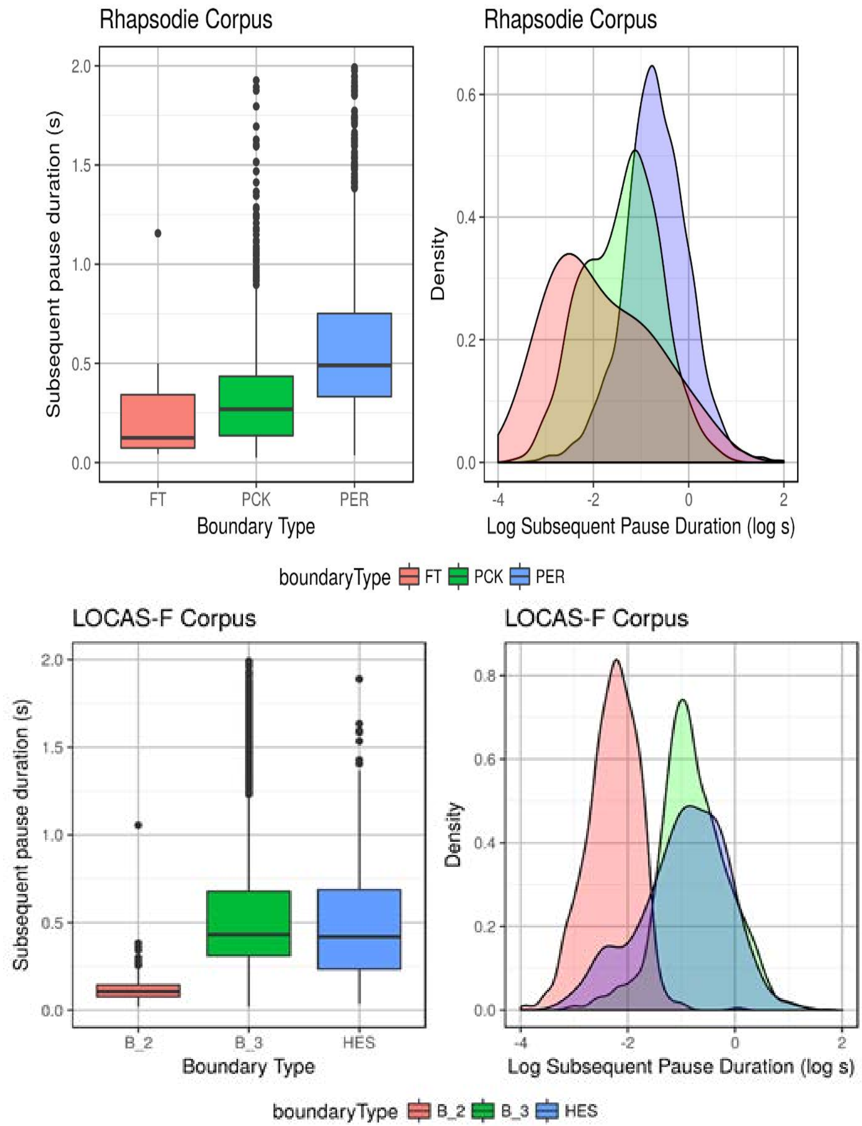
4 Results and discussion

In the following section, we will present the results of the statistical analysis of the measures extracted as described in the previous section, for each corpus.

4.1 Subsequent silent pause

The presence or absence of a silent pause immediately after a prosodic boundary appears to be the most important cue in distinguishing between boundaries of different strength (cf. also section 4.5 on the relative importance of the correlates). Figure 1 presents the distribution of the length of the subsequent silent pause for each type of prosodic boundary in each corpus. The original pause duration values have been used in the boxplots on the left; while the density distribution plots are based on the logarithmic transformation of pause duration. Since the typical distribution of pause durations is positively skewed, this transformation aims at approximating a normal distribution in log-time (see HELDNER; EDLUND, 2010 for a discussion of this method).

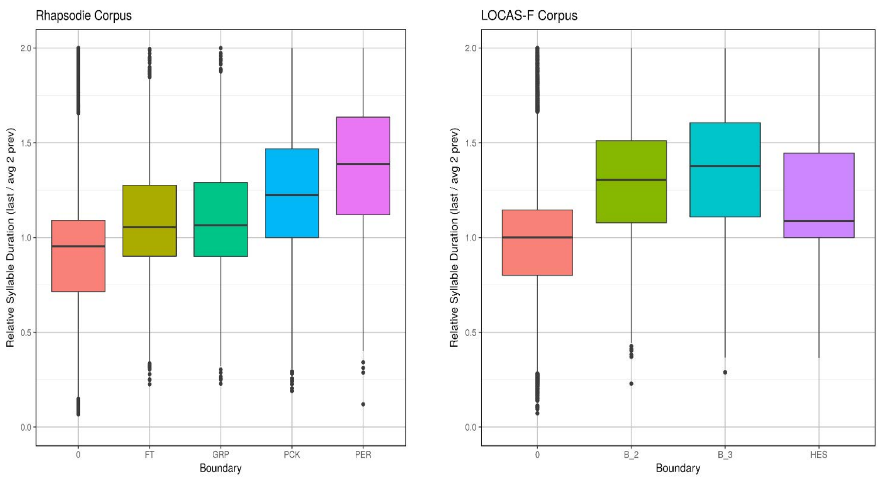
FIGURE 1 – Duration of the subsequent silent pause for each boundary type (feet, packages and periods in Rhapsodie; and B2, B3 and hesitations in LOCAS-F). On the left, the distribution is shown in seconds; on the right the duration has been log-transformed



4.2 Syllable lengthening

Syllables immediately preceding a prosodic boundary are often lengthened. We define the relative syllable duration as the ratio of the syllable duration at the unit end divided by the average duration of the previous two syllables. This ratio is a dimensionless quantity; a ratio of 1 indicates no lengthening, a ratio greater than 1 indicates lengthening and a ratio less than 1 indicates a local acceleration. Figure 2 shows the distribution of the relative syllable duration of the syllable immediately preceding each boundary type in each corpus. We observe that stronger prosodic boundaries are correlated with stronger syllable lengthening. In the Rhapsodie corpus, we observe that the last syllables of feet and groups are only slightly lengthened (it should be noted that syllable lengthening is also an acoustic correlate of syllabic prosodic prominence in French) and that the last syllables of packages and periods are lengthened. The pre-boundary syllable lengthening of packages in Rhapsodie is similar to the pre-boundary syllable lengthening of B2 boundaries in LOCAS-F, while the boundaries of periods in Rhapsodie correspond to the boundaries of B3 strength in LOCAS-F.

FIGURE 2 – Relative syllable duration (duration of the last syllable of a unit divided by the average duration of the previous 2 syllables) for each boundary type and corpus



4.3 Relative pitch and intra-syllabic pitch movement

In this section we will examine the intonation contours associated with prosodic boundaries. Figure 3 shows the distribution of the measure of relative pitch, defined as the difference between the mean pitch of the last syllable of a unit, and the average of the mean pitch of the preceding two syllables, in semitones relative to 1 Hz. These distributions are shown separately for prosodic boundaries with a rising intonation (relative pitch > 0) and a falling intonation (relative pitch < 0).

FIGURE 3 – Relative pitch (mean pitch of the last syllable of a unit minus the average of the mean pitch of the previous two syllables) for each boundary type and corpus. All pitch values are calculated on Prosogram-stylised syllables and are in semitones relative to 1 Hz

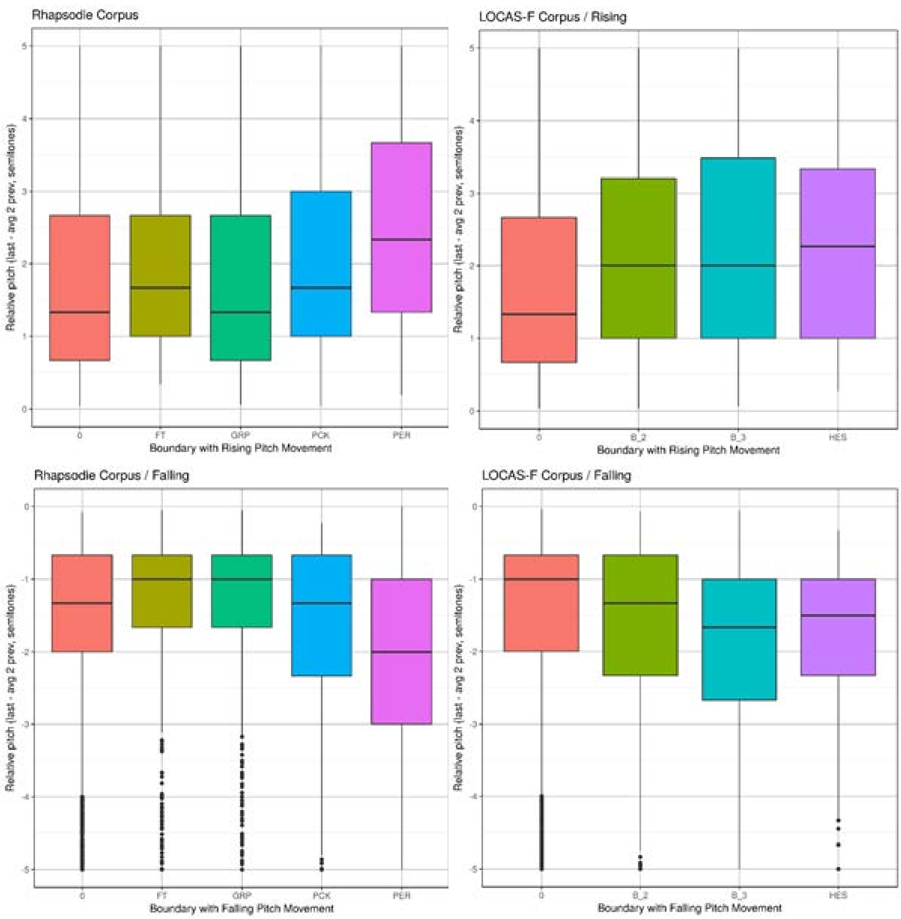
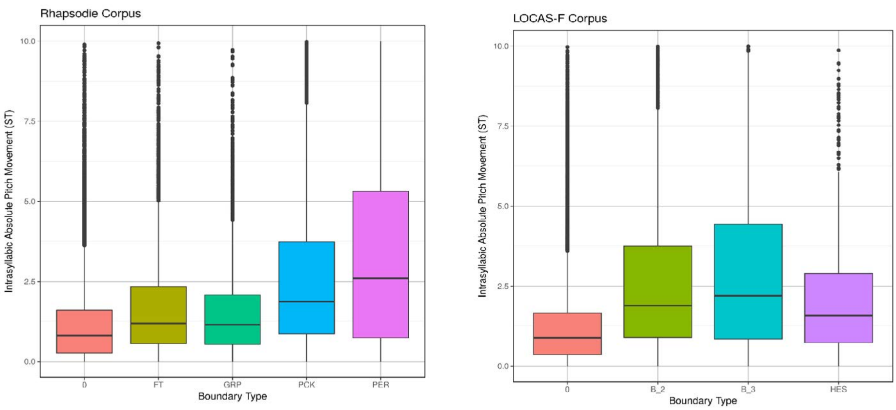


Figure 4 shows the distribution of the intra-syllabic pitch trajectory measure, i.e. the sum of absolute pitch intervals within syllabic nuclei divided by duration (in ST/s). A higher value indicates a syllable that will be perceived as more prominent, standing out of its neighbouring syllables. We observe that, in the Rhapsodie corpus, the last syllables of packages and periods have a significantly higher intra-syllabic pitch trajectory (with period-final syllables having a greater value than package-final syllables), while in the LOCAS-F corpus, the syllables associated with boundaries of both strengths (B2 and B3) have a higher trajectory than non-boundary syllables.

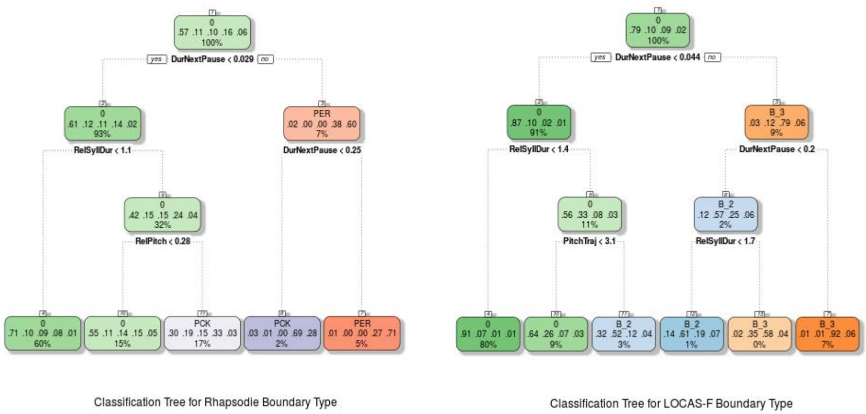
FIGURE 4 – Absolute intra-syllabic pitch movement (i.e. the sum of rising and falling intra-syllabic pitch movements, in semitones relative to 1 Hz)



4.4 Classification trees and relative importance of acoustic correlates

In order to evaluate the relative importance of each acoustic correlate in determining whether a syllable will be perceived as marking a prosodic boundary of a specific type, we calculated classification trees, using the `rpart` package, in the R statistical software system. The predictors for the classification algorithm were the acoustic correlates examined in the previous sections: the duration of the subsequent silent pause (if any), the relative duration of syllable compared to the previous two syllables, the relative mean pitch compared to the previous two syllables and the pitch trajectory. The resulting classification trees are shown in Figure 5.

FIGURE 5 – Classification Trees for each corpus and boundary type



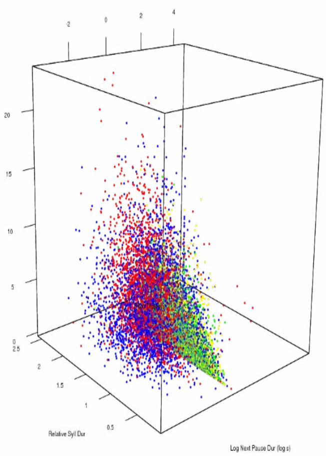
We observe that the most important acoustic correlate for the perception of a prosodic boundary, in both corpora, is the subsequent silent pause duration. The next predictor, among the acoustic correlates, is the relative syllable duration, that effectively captures final lengthening of boundary syllables. Silent pause length and syllable lengthening distinguish between the presence and absence of a prosodic boundary and between boundary strengths (PCK and PER in Rhapsodie; B2 and B3 in LOCAS-F). Predictors related to pitch were found to be less important in both linear regression models: relative pitch distinguishes between no boundary and PCK boundary in the Rhapsodie corpus; and pitch trajectory distinguishes between no boundary and B2 boundary in LOCAS-F.

These corpus-based results on the acoustic correlates of prosodic boundaries are compatible with and confirmed by the series of experimental studies presented in Christodoulides *et al*. (2018). In this series of experiments, naïve listeners and expert annotators were asked to indicate the presence of a prosodic boundary in real-time, by tapping on a computer keyboard. The analysis of their responses, with a similar methodology (linear regression trees) shows that the most important correlate was the duration of the subsequent silent pause, followed by the co-occurrence of a major syntactic boundary, followed by final syllable lengthening and finally pitch movement. The relative importance of the predictors is the same for the corpus-based analysis and the experiments, given that in the corpus-based analysis we are only considering signal-based (acoustic) correlates.

4.5 Clustering of different boundary types

Finally, Figure 6 presents a three-dimensional scatter plot, where each point corresponds to a syllable marking a prosodic boundary, of each of the four strengths defined in the Rhapsodie corpus. The points are colour-coded as follows: red represents period boundaries, blue represents package boundaries, green represents group boundaries, and yellow represents feet boundaries. The x axis is the log-transformed duration of the subsequent silent pause, the y axis is the relative syllable duration (as defined in section 4.2) and the z axis is the pitch trajectory (as defined in section 4.3). We observe that feet and group boundaries cluster together and that package and period boundaries cluster together, with period boundaries often being separated by way of the silent pause duration. This concurs with the results of the classification trees for the corpus.

FIGURE 6 - Scatter plot of syllable acoustic correlates for different types of prosodic boundaries in the Rhapsodie corpus. The boundaries are colour-coded as follows: periods – red; packages – blue; groups – green; feet – yellow.



5 Conclusion

In this article we have analysed two spoken French corpora, both containing samples from multiple speakers and speaking styles, and both having been annotated by experts for prosodic units and prosodic boundaries.

We have shown that the main acoustic correlates of prosodic boundary strength are the presence of a subsequent silent pause and pre-boundary lengthening, in this order of importance. Pitch movements (relative pitch and intra-syllabic pitch movement) are indicative of prosodic boundary function, rather than strength; however, stronger prosodic boundaries (e.g. period boundaries in the Rhapsodie corpus) tend to correlate with larger pitch movements.

With respect to our initial research question, on the relationship between two annotation systems for prosodic boundaries in French, which were developed independently from one another, we note that the two stronger boundary types in the Rhapsodie corpus are very similar to the intermediate and strong boundaries in the LOCAS-F corpus. Apart from its theoretical interest, this finding will facilitate the development of automatic automation tools, by training machine learning models on the Rhapsodie corpus.

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