The psychological reality of rhythm classes: perceptual studies

Franck Ramus*, **Emmanuel Dupoux*** and **Jacques Mehler***†

* Laboratoire de Sciences Cognitives et Psycholinguistique (EHESS/ENS/CNRS)
54 boulevard Raspail
75006 Paris, France
ramus@lscp.ehess.fr

† SISSA, Trieste, Italy

ABSTRACT

Linguists have traditionally classified languages into three rhythm classes, namely stress-timed, syllable-timed and mora-timed languages. However, this classification has remained controversial for various reasons: the search for reliable acoustic cues to the different rhythm types has long remained elusive; some languages are claimed to belong to none of the three classes; and few perceptual studies has bolstered the notion. We have previously proposed an acoustic/phonetic model of the different types of linguistic rhythm, and of their categorisation as such by listeners. Here, we present perceptual experiments that directly test the notion of rhythm classes, our model's predictions, and the question of intermediate languages. Language discrimination experiments were run using a speech resynthesis technique to ensure that only rhythmic cues were available to the subjects. Languages investigated were English, Dutch, Spanish, Catalan and Polish. Our results are consistent with the idea that English and Dutch are stress-timed, Spanish and Catalan are syllable-timed, but Polish seems to be different from any other language studied and thus may constitute a new rhythm class. We propose that perceptual studies tapping the ability to discriminate languages' rhythm are the proper way to generate more empirical data relevant to rhythm typology.

1 INTRODUCTION

The perception of speech rhythm has been a subject of interest among linguists for decades. This interest comes from the observation that different languages give rise to the perception of different types of rhythm. For instance, Lloyd James [1] noted that English has a rhythm similar to that of a Morse code, while Spanish rhythm is closer to that of a machine-gun. Pike [2] attributed this difference to the fact that in English rhythm is due to the recurrence of stresses, while in Spanish it is due to the recurrence of syllables, hence the terminology "stress-timed" and "syllable-timed" languages. Abercrombie [3] further claimed that all languages should fall into one of these categories, and that rhythmical structure was based on the isochrony of the corresponding rhythmical units, that is, the isochrony of stresses for the former category and the isochrony of syllables for the latter. However, measurements in the speech signal have failed to provide empirical support for this "isochrony theory" [4, 5, 6].

Another view of speech rhythm has been advocated [6, 7, 8], according to which the different types of rhythm are due to different sets of phonological properties. Indeed, stress-timed languages authorise complex syllables and have vowel reduction, while syllable-timed languages only have simpler syllables and no vowel reduction.

Building upon this phonological account of rhythm, we proposed that the type of rhythm of a given language can be deduced from the duration of its vocalic and consonantal intervals [9]. Measurements of the duration of such intervals were made in eight languages. We found that these eight languages form three clusters, corresponding to the three traditional rhythm classes[1], thereby suggesting an acoustic-phonetic correlate of speech rhythm (Figure 1).

Naturally, the match between measurements and rhythm classes has been shown for only eight languages, so it would be desirable to extend this investigation to many other languages. In fact some research teams have already set out to do so, using the present or similar approaches [12, 13, 14, 15, 16, 17, 18]. Ideally, the results obtained through measurements should be evaluated against each language's rhythm type, as determined by independent considerations. The problem is that it is not clear what those independent considerations might be.

Indeed, as explained above, no clear criteria have

[1] In addition to stress-timed and syllable-timed languages, it has been proposed that languages such as Japanese belong to a mora-timed class [10, 11].

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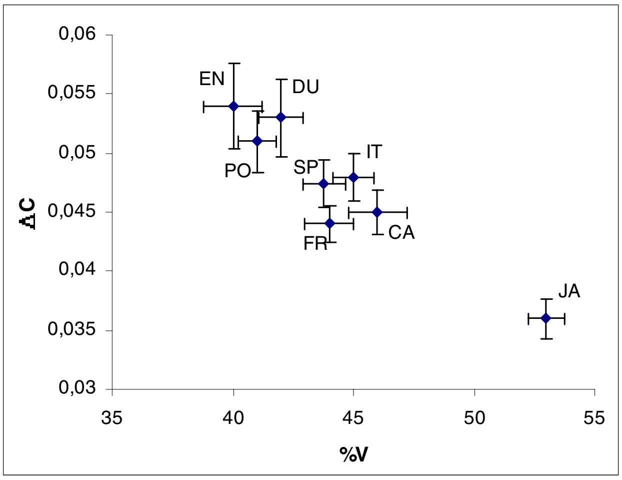

Figure 1: Standard deviation of consonantal intervals vs. proportion of vocalic intervals in 8 languages (reproduced from [9]).

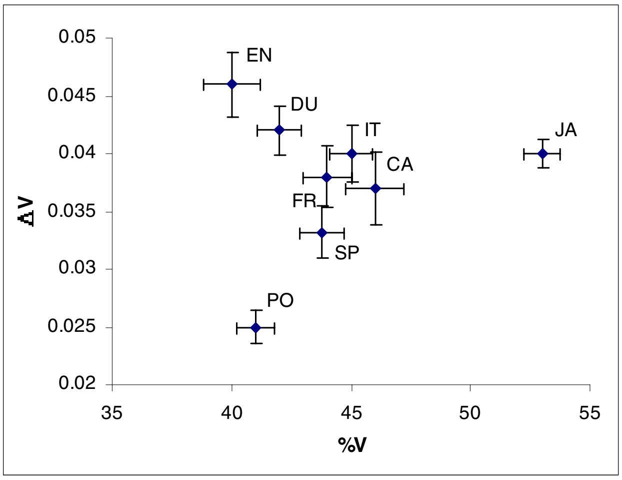

Figure 2: Standard deviation of vocalic intervals vs. proportion of vocalic intervals in 8 languages (reproduced from [9]).

emerged to classify languages in their respective rhythm classes. Some authors refer to impressionistic observations about isochrony, some to properties of the stress system, and others to syllable structure. As a result, in the literature, whereas some languages are classified by consensus (English and Dutch as stress-timed, French, Spanish and Italian as syllable-timed, Japanese as mora-timed), others have been a matter of debate (Catalan, Portuguese, Polish) [8]. Moreover, the vast majority of the languages of the world have not been classified at all.

In this paper, we will argue that perceptual studies are the proper empirical basis to classify languages into rhythm classes. We inaugurate this approach by using language discrimination experiments to decide the rhythmic status of languages such as Catalan and Polish, and subsequently to evaluate the fit between our measurements and the empirical data collected.

2 THE RAMUS, NESPOR & MEHLER (1999) DATA

Measurements of the duration of consonantal and vocalic intervals[2] were made in eight languages (English, Dutch, Polish, French, Spanish, Italian, Catalan and Japanese), with 4 speakers per language and 5 sentences per speakers. Three variables were computed from the measurements, taking one value per sentence: $\%V$, the percentage of the sentence's duration taken up by vowels; ΔV, the standard deviation of vocalic intervals within the sentence; and ΔC, the standard deviation of consonantal intervals. We found that the eight languages studied cluster in three groups along the $\%V$ and ΔC dimensions (Figure 1), and that these groups correspond to three distinct rhythm types.

While the results obtained are consistent with the consensual classification of English, Dutch, French, Spanish, Italian, and Japanese, it is not clear what to say of Polish and Catalan. If the $\%V$ variable is the best correlate of rhythm class, then Polish should be considered as stress-timed, and Catalan should be considered as syllable-timed. This is in agreement with some previous classifications but not others [19, 20, 21, 22]. Furthermore, when considering another variable, ΔV, Polish appears entirely unlike both stress-timed and syllable-timed languages, giving credit to the idea that it might be neither, or intermediate [8] (Figure 2). Obviously, the literature on rhythm does not help assess the validity of the model, nor does it help choose between its different versions.

Here we propose to fill this empirical vacuum with data from perceptual experiments. After all, the original intuitions about different types of rhythm were perceptual in nature: Lloyd James, Pike and others reported that they could hear that English and Spanish sounded different in terms of rhythm. What is needed is therefore an experimental set-up that will probe those perceptual processes in a systematic and reliable manner.

It seems plausible that if two languages have different types of rhythm, naive listeners should be able to discriminate utterances from these two languages, on the basis of the rhythmic cues. Conversely, if naive subjects can tell the difference between two languages solely on the basis of rhythmic cues, there is good reason to postulate that the two languages have different types of rhythm. Experiments that test subjects' ability to discriminate between languages therefore seem an adequate way to gather data on the typology of

[2] Consonantal intervals span sequences of consecutive consonants, while vocalic intervals span sequences of consecutive vowels.

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rhythm.

One caveat is that there are many possible cues other than rhythm that might guide the discrimination between two languages. It is therefore essential to make sure that only rhythmic cues will be available to subjects in the task. For this purpose we will adopt a method based on speech resynthesis proposed in a previous study [23], which allows to delexicalise utterances and preserve only their durational properties.

3 LANGUAGE DISCRIMINATION EXPERIMENTS

Our measurements on eight languages have made predictions about the discriminability of 28 pairs of languages. Rather than testing all of them, we have concentrated on a few pairs that seemed more theoretically interesting. We have earlier demonstrated that English and Japanese rhythms can be discriminated [23]. Now, we will concentrate on English and Spanish as prototypical examples of stress-timed and syllable-timed languages respectively, and study the relationship between these two reference languages and Polish and Catalan. Dutch will also be included to assess the possibility of within-class discrimination. We will therefore investigate the discrimination of the following languages pairs:

Exp. 1: English-Spanish A clear across-class pair;

Exp. 2: English-Dutch A clear within-class pair;

Exp. 3-4: Polish-English and Polish-Spanish Comparison of an unclassified language (Polish) with the two reference languages;

Exp. 5-6: Catalan-English and Catalan-Spanish Comparison of an unclassified language (Catalan) with the two reference languages;

Exp. 7: Polish-Catalan Comparison of the two unclassified languages.

3.1 METHODS

3.1.1 MATERIAL: Sentences were selected from a multi-language corpus initially constituted by Nazzi [24, 25] and extended for the present study (Polish and Catalan). In this corpus, 54 sentences of each language were read by four female native-speakers. We selected 5 sentences per speaker, thus constituting a set of 20 sentences per language. Sentences were selected in such a way as to minimise differences across languages: they were thoroughly matched in number of syllables (from 15 to 19 syllables per sentence, with an average of 17), and had comparable durations, except for Polish (see below) (Table 1). The measurements described above were performed on these very sentences [9].

	English	Dutch	Spanish	Polish	Catalan
Duration	2852	2948	2840	3034	2856
St. Dev.	207	174	243	330	285

Table 1: Average duration across sentences of the different languages (in milliseconds).

In order to ensure that only the relevant cues are made available to the subjects in language discrimination experiments, we developed a speech resynthesis technique, allowing to selectively degrade or preserve the phonological and prosodic properties of speech [23]. Basically, each sentence is resynthesised by feeding its phonetic transcription, the duration of each phoneme and the fundamental frequency curve into an adequate speech synthesiser. Here, we use MBROLA [26][3], which performs the synthesis through concatenation of diphones, using a French diphone database. Phonological properties of the synthesised sentences are manipulated by modifying the input data to the synthesis. Here we only use one of the four types of manipulation documented in [23], called *flat sasasa*: all consonants are replaced by /s/ and all vowels are replaced by /a/; the fundamental frequency is ignored, and replaced by a constant one at 230 Hz. This way, the synthesised stimuli can only convey the rhythmical properties of the original sentences[4].

Incidentally, the resynthesis process gives total control over the duration of the sentences. We used this feature in order to reduce the differences found across languages, and eliminate the possibility that subjects might discriminate languages on the basis of duration differences. As we noted earlier, Polish had longer sentences than other languages on average; furthermore, there were important differences between the four speakers. To reduce these differences, the four Polish speakers' sentences' durations were multiplied respectively by 1, 0.92, 0.9 and 0.93 (i.e., all consonantal and vocalic intervals had their duration multiplied by the given factor). Subsequent measurements performed on the resynthesised sentences ensured that no significant differences in duration remained across Polish speakers nor across the five languages. Informal listening revealed no perceptible difference or artifact as a result of sentences having their duration modified.

3.1.2 PROCEDURE: For each language pair, we used the 20 sentences selected for each language, resynthesized in the *flat sasasa* manner as described above. All experimental protocols were programmed on a PC using the EXPE language [27][5].

[3] MBROLA is freely available from http://tcts.fpms.ac.be/synthesis/mbrola.html.

[4] In fact, only durational aspects of rhythm are preserved, in accordance with our measurements. Variations of intensity that might contribute to rhythm are ignored here. Sample stimuli can be heard on http://www.lscp.net/persons/ramus/resynth/ecoute.htm.

[5] EXPE is freely available from http://www.lscp.net/expe/expe.html.

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Instructions informed the subjects that they were to distinguish two exotic languages, Sahatu and Moltec.

We previously used a categorisation task where subjects were presented sentences one by one, were trained to correctly classify the two languages on half the sentences, and then tested on the other half [23]. Pilot experiments led us to adopt a potentially more sensitive task, the odd-ball task (AAX). Here, two sentences of the same language are played as a context, then a third sentence is played either in the same language or in a different one, and the subject should respond Same or Different. Thus this task requires only the immediate comparison of series of three sentences, with no training and no generalisation.

For each language pair, two sets of sentences are defined including 2 speakers per language; they form the context set (AA in AAX) and the test set (X in AAX). The experiment includes two blocks of 20 trials each, during which the context language is held constant. At the beginning of each block, subjects are told which language (Sahatu or Moltec) is the context language. Block order is counterbalanced across subjects. For any given trial, the two context sentences are drawn randomly from the context set, subject to the constraint that they are uttered by two different speakers. The test sentence is also drawn randomly from the test set, and each test sentence is played only once per block. Within a trial, sentences are played with an inter-stimulus-interval of 500 ms. Subject are then required to press a key to indicate whether they thought the third sentence was expressed in the same language as the previous two. They receive feedback after each trial.

3.1.3 PARTICIPANTS: A total of 168 subjects participated, 24 in each experiment[6]. They were students aged between 18 and 30 and were all French native speakers.

3.2 RESULTS

A signal detection theory approach was followed in order to take into account response biases. Percent correct scores were therefore converted into hit and false alarm rates as follows: hit rate is the proportion of correct "same" trials and false alarm rate is the proportion of incorrect "different" trials. As in [23], hit and false alarm rates were then converted to A' discrimination scores. A' is a variant of d' which requires less stringent assumptions. A' varies between 0 and 1, with chance level being 0.5[7]. Table 2 presents the results for all experiments. Except where noted, p-values were obtained from two-tailed one-sample t-tests with test value 0.5.

	A'	St. Dev.	p
Exp. 1: English-Spanish	0.65	0.14	0.007^a
Exp. 2: English-Dutch	0.49	0.11	0.71
Exp. 3: Polish-English	0.59	0.15	0.009
Exp. 4: Polish-Spanish	0.74	0.08	< 0.001
Exp. 5: Catalan-English	0.58	0.13	0.004
Exp. 6: Catalan-Spanish	0.48	0.14	0.42
Exp. 7: Polish-Catalan	0.57	0.15	0.03

[a]This level of significance was obtained through a binomial test, as the distribution was not normal.

Table 2: Results of language discrimination experiments using *flat sasasa* stimuli.

Overall, all the language pairs except for English-Dutch and Spanish-Catalan were discriminated significantly above chance level.

As expected, English and Spanish were easily discriminated by listeners, confirming that the rhythmic differences between these prototypical stress-timed and syllable-timed languages are real and perceivable. In contrast, discrimination of English and Dutch sentences was at chance level, as expected from two languages belonging to the same rhythm class. Moreover, the scores were significantly higher for English-Spanish than for English-Dutch (Mann-Whitney U=114, $p < 0.001$). Considering the strictly rhythmical nature of the *flat sasasa* stimuli, this suggests that our method is adequately sensitive to the major rhythmic differences giving rise to the rhythm classes.

Polish was discriminated both from English and from Spanish, suggesting that its rhythm is neither entirely stress-timed, nor strictly syllable-timed.

Catalan, on the other hand, was discriminated from English but not from Spanish. Moreover, Catalan-Spanish discrimination scores were significantly lower than English-Spanish scores (U=103, $p < 0.001$), but not different from English-Dutch scores. Overall, this suggests that Catalan is not rhythmically different from Spanish, and is therefore a syllable-timed language.

Finally, the successful Polish-Catalan discrimination is consistent with the idea that Catalan is syllable-timed while Polish is not.

3.3 DISCUSSION

These results are only partly consistent with Nespor's hypothesis [8] that both Polish and Catalan are intermediate languages. This hypothesis originated from the observation that Catalan had simple syllable structure (like syllable-timed languages), yet had vowel reduction (like stress-timed languages), whereas Polish presented the opposite combination. One possible rea-

[6]In fact, there were 23 subjects for Polish-Catalan and 25 for English-Dutch.

[7]Let H be the hit rate and F the false alarm rate:

$$\text{If } H \geq F, \text{ then } A' = \frac{1}{2} + \frac{(H-F)(1+H-F)}{4H(1-F)}$$

$$\text{if } H < F, \text{ then } A' = \frac{1}{2} - \frac{(F-H)(1+F-H)}{4F(1-H)}$$

See [28] for further details.

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son for the divergence between Nespor's hypothesis and our empirical data on Catalan is that her observations are qualitative, referring to the absence or presence of particular phonological properties. However, in order to predict the rhythm of a language, one may need to quantify those properties. Indeed, Catalan may well have vowel reduction, but in order to understand the impact this fact has on overall rhythm, it must be weighed by the frequency at which it occurs, and by the degree to which vowels are actually reduced. When this quantitative weighting is carried out, maybe it appears that Catalan is in fact little different from Spanish, which would be one way to explain our results.

In fact, this quantitative approach to phonological properties is precisely what our measurements achieve [9]. Indeed, in our measurements, the durational aspects of vowel reduction are captured by the variable ΔV (vowel reduction increases the variability of the duration of vocalic intervals). This variable clearly separates Polish from English and Dutch, which can be explained by the absence of vowel reduction in Polish (see Figure 2). On the other hand, ΔV does not separate Catalan from syllable-timed languages, suggesting that vowel reduction in Catalan does not quantitatively impact on this variable. This is consistent with our perceptual results which suggest that vowel reduction in Catalan is not enough to make it depart from syllable-timing.

In our previous study, we made predictions about which languages should be discriminated, on the basis of the variable $\%V$ [9]. In general our predictions were consistent with the groupings shown on Figure 1; in particular, we successfully predicted that Catalan should be undistinguishable from Spanish, but we failed to predict that Polish could be discriminated from English. However, once ΔV is taken into account, Polish separates from English and Dutch (Figure 2), and our measurements correctly predict all the perceptual results we have collected (see [29] for detailed simulations).

The present experiments therefore support the idea that vocalic and consonantal intervals' duration may account for rhythm classes, and motivate the inclusion of the variable ΔV into this acoustic/phonetic model of rhythm.

The notion that Polish might be an "intermediate" language deserves further commentary. If intermediate is to be understood in the sense of falling *between* the stress-timed and syllable-timed languages, then this idea is supported neither by our perceptual experiments nor by our measurements. Indeed, results do not suggest that the perceptual distances between Polish and English, and Polish and Spanish, are any smaller than the perceptual distance between English and Spanish (no significant difference in any of those comparisons; see Table 2). Similarly, our measurements illustrated in Figure 2 do not situate Polish between stress-timed and syllable-timed languages, but in a place of its own. Therefore, both measurements and perceptual experiments suggest that Polish may belong to an altogether distinct rhythm class from the three previously established, yet to be defined and studied. Although this notion may seem unorthodox, at least it is consistent with some phonological analyses [8].

A final caveat is that our approach has so far focused exclusively on durational correlates of speech rhythm; we have deliberately ignored any potential contribution of intensity variations, both in our measurements and in the stimuli we have synthesised for perceptual experiments. It must be true in general that duration and intensity variations are correlated, but it is also well-known that, for instance, languages differ in the way they use duration and intensity to signal phonological properties such as stress or quantity. It can therefore not be excluded that a similar quantitative, cross-linguistic study of intensity variations might provide yet another dimension for the study of rhythm classes. If this were the case, the perceptual relevance of this new dimension could at least be assessed using the method we have set out here, by running new language discrimination studies using resynthesised stimuli which would mimic the intensity variations of real sentences.

4 CONCLUSION

Based upon their intuitions on what they heard, linguists have postulated that rhythmical properties of languages are not arbitrary, but may be sorted into a few classes, namely the stress-timed, syllable-timed and mora-timed languages. We have sought to provide an empirical basis for this notion, first by performing acoustic/phonetic measurements in the speech signal [9].

As too little empirical data was available to independently evaluate this approach, we have now taken another step: to conduct perceptual experiments testing listeners' ability to discriminate languages' rhythm. On the basis of a still limited data set, we have provided evidence that both approaches converge, and can account for rhythmic differences and similarities already well documented across languages.

Furthermore, this method can provide tentative answers to unresolved questions of linguistic typology. Here, our results suggest that Catalan is a syllable-timed language, while Polish is neither stress, syllable, nor mora-timed; instead, our results may well motivate the postulation of a new rhythm class.

With only eight languages studied so far, it is too early

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to say whether measurements based on durations of vocalic and consonantal intervals may provide a definitive account of rhythm typology. However, we submit that the often impressionistic observations recorded in the linguistic literature are insufficient to evaluate competing theories; instead, perceptual experiments investigating the discriminability of languages' rhythm by naive listeners should be the yardstick by which theories of speech rhythm will be measured.

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