RHYTHM TYPOLOGY: ACOUSTIC AND PERCEPTIVE STUDIES

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To cite this version:

Paolo Mairano. RHYTHM TYPOLOGY: ACOUSTIC AND PERCEPTIVE STUDIES. Linguistics. Università degli studi di Torino, 2011. English. NNT : . tel-00654261

HAL Id: tel-00654261
https://theses.hal.science/tel-00654261
Submitted on 21 Dec 2011

Università degli Studi di Torino
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Scuola di Dottorato in Studi euro-asiatici: indologia, linguistica, onomastica
Curriculum in Linguistica, Linguistica Applicata e Ingegneria Linguistica
XXIII ciclo

RHYTHM TYPOLOGY:

ACOUSTIC AND PERCEPTIVE STUDIES

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Anni accademici: 2007-2008 / 2008-2009 / 2009-2010
Settore scientifico-disciplinare di afferenza: L-LIN/01

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Acknowledgments

The accomplishment of my PhD and of the drafting of this thesis would have never been possible without the help, assistance and support of many people.

First of all, I am grateful to Antonio Romano (aka Tonino) for following me along my PhD, for his constant precious advice, for the opportunities he granted me, for the confidence he set in me, and, in general, for all the support he gave me during these three years: this work would have been unthinkable without that.

Of course, I am debtor to the PhD school in Linguistics, Applied Linguistics and Linguistic Engineering of the University of Turin, and to much of its staff. In particular, I would like to thank Carla Marello and Virginia Pulcini for their involvement and for the opportunities they granted me, Mario Squartini and Manuel Barbera for their valuable pieces of advice within my research. A word of mention for my PhD colleagues Lea Glarey, Cristina Colet and Mauro Costantino with whom I shared stimulating discussions, for Adriano Allora, who re-introduced me to computer programming and to Linux and for Maria Chiara Felloni and Daniele Avesani who provided me with precious feedback for the perceptive tests.

I am very thankful to Sigurður Pétursson (University of Iceland) for his outstanding hospitality when I was in Iceland and to the staff of *GIPSA-Lab* and of the University of Grenoble 3 *Stendhal* for receiving me within my PhD. The warm welcome I was reserved at the *Centre de Dialectologie de Grenoble* by Michele Contini, Elisabetta Carpitelli, Jean-Pierre Lai, Giovanni Depau, Maria Goudi and Silvia Gally has no equal. I am full-heartedly thankful to Maria Goudi for her constant scientific and moral support and for feeding me during the drafting of this thesis, to Giovanni Depau and Jean-Pierre Lai for sharing their office with me and for the interesting discussions we had, to Anna Ghimerton for reading and correcting most of my thesis, to Kristina Grabsky for her pieces of “typographic” advice.

Last but certainly not least, I am grateful to my parents for the support they gave me, to Elisabetta, Fabrizio, Marta, Daniela and Patrick for helping me when in need and to my flat mates Arnaud, Morgane and Camille for their joyful and truly rewarding company in the final year of my PhD. In a quite singular sort of way, I would also like to thank Sophie for a much needed turn of the screw.

A Chiara
che ha dato una direzione alla mia vita e
che ha dovuto imparare la pazienza quando a suo papà toccava lavorare per la tesi,

e a zio
che non ha visto la fine del mio dottorato, di cui però andava fiero.

1.

Introduction

1. Introduction

1.1 Rhythm

Rhythm is generally said to play an important role in human behaviour as it is connected to numerous human activities, such as breathing, walking, dancing, playing, and so no. When referring to rhythm, we usually associate it to auditive phenomena, but this is not always the case: for instance, as reported by Eriksson (1991), repeated visual patterns can also be described as rhythmical. However, in spite of the pervasiveness of rhythm and the apparent straightforwardness of its concept, it is not at all easy to define it.

In its simplest form, rhythm could perhaps be described as a regular succession of events. This definition accounts for the rhythmicity of some human activities mentioned above, such as breathing and walking, and for heartbeat and repeated visual patterns. But it does not fully explain what is meant by rhythm in activities such as dancing and playing. To account for these activities, one needs to add something to the definition given above:

> *Rhythm is the structure of intervals in a succession of events.*
> *(Allen, 1972:72)*

The "structure" refers to a possible hierarchy or a grouping among the events in succession; moreover, the two aspects composing rhythm (structure and succession) tend to go hand in hand. In music[1], for instance, the succession is given by bars (which recur at regular intervals), while the structure is given by the notes, which can carry the beat in certain positions, but not in others (they are therefore organised hierarchically). Similarly, in poetry, the regular succession of lines is counterbalanced by a hierarchical organisation among syllables, which tend to form groupings composed of one stressed syllable and one or more unstressed syllables.

Moreover, the structure of rhythm is not always given by exclusively acoustic phenomena, but it also has a "subjective" component. For instance, it has been reported (see Allen, 1975, among others) that listeners tend to hear a hierarchy even when it does not exist, *i.e.* they tend to perceive groupings on a succession of identical stimuli. This phenomenon is called *subjective rhythmisation* and emerges, for example, in the onomatopoeia used in various languages to describe the sound of the pendulum: although the acoustic features of its beats are the same, it is usually described as if formed by a grouping of two sounds: *tic-tac* in French and Italian, *ticktack* in Swedish and *tick-tock* in English (this case is reported by Eriksson, 1991). Finally, there seem to be some constraints on the perception of rythmicity:

> *When we hear a sequence of pulses that is neither too rapid nor too slow we hear it as rhythmic* [...]. *As long as the minimum time between pulses is greater than about 0.1 s, so that successiveness and order are perceivable, and the maximum is less than about 3.0 s, beyond which groupings do not form, we will impose some rhythmic structure on the sequence.*
> *(Allen, 1975:76)*

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[1] For sake of simplicity, I shall refer to the music that developed within the Western culture in the last centuries. Other types of music are also rhythmical of course, but their structure can be conceived differently from what is sketched in the text.

In summary, rhythm can be considered to appear in regular successions of events between 0.1 s and 3.0 s and to be composed of a structure (in terms of hierarchy or of groupings) which is either present acoustically, or which is superimposed by the hearer on the succession of events.

1.2 Speech rhythm

Although the claim that speech is characterised by a rhythmical component is universally accepted, there is far less consensus as to what should be identified as the rhythmic unit and as the carrier of rhythmic beat in spoken language. In the light of the considerations sketched in the preceding section, if we want to identify rhythm in speech, we have to search for something that is either structured or recurrent within a limited time range:

> *Language is produced by humans and is perceived by humans, and it appears to be governed by the same rhythmic constraints as other human motor and perceptual behaviors. These constraints thus set limits on the kinds of rhythms we can expect in languages of the world: they should be simple in structure, confined largely to successions and alternations, depening on the relationship between syllables and stress-accent in the language; the rate of succession of syllables and rhythmic groups should be in or near the range og 0.2 - 1.0/s.*
> *(Allen, 1975:82)*

This idea, after all, is the same that stands at the base of the conception of metre in poetry. Metres fulfil the requirements in that they are *simple structures* composed of *regular successions* of *stresses* and *syllables*, resulting in *alternations* of stressed and unstressed syllables. Furthermore, stresses and syllables fall precisely within the relevant time range. In effect, the study of speech rhythm has long been associated with metrics and poetry. Aristotle, in *The Art of the Rhetoric*, made an early attempt to describe the rhythm of language, using metric concepts to describe the different speech styles of the people (e.g. the iambic metre was said to be the rhythm of the common people, the trochaic that of rhetoricians, etc.).

Although the question of metre is still of interest today, many phoneticians of the last century have shifted the focus of research on two other issues. One consisted in finding an acoustic correlate of the perception of the rhythm beat: results in this field are not utterly uniform, but there seems to be general agreement on the importance of the vowel onset[2] (see Allen, 1972 and 1975). At any rate, it is the second issue, which concerns the alleged regular ocurrence of syllables and/or stresses, that retained most of the attention through the years.

1.3 Rhythm typology

The two categories of *stress-timed* and *syllable-timed* languages have been introduced by Pike (1945) referring to the impression that stresses seem to occur at

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[2] One remarkable alternative theory introduces the so called *p-centre* (perceptive centre), developed initially by Morton et al. (1976).

regular temporal intervals in English, while syllables seem to have similar durations in Spanish. Abercrombie (1967) drew on the distinction, also on the basis that the different rhythmic structure of these languages seems to be reflected by the metrical units adopted in poetry: Germanic languages count the length of verses in feet, while Romance languages use the syllable as the basic metric unit. This view had a great fortune in the following years, but various instrumental experiments failed to give evidence of isochrony at the foot or at the syllable level (some of them are reviewed in chapter 3).

After these failures, some linguists (Bertinetto, 1977, and Dauer, 1983, among others) attributed the impression of stress-timing or syllable-timing to structural properties of languages, such as the absence vs. presence of vocalic reduction and a complex syllabic structure. Relying on these theories, Ramus, Nespor & Mehler (1999)[3] and Grabe & Low (2002) proposed acoustic correlates of these phonological properties based on vocalic and consonantal durations. The authors claimed that their measures allowed for a scalar characterisation of languages on the basis of rhythm properties.

The validity and the stability of the acoustic correlates (soon re-baptised *rhythm metrics*) have soon been tested in other studies (e.g. Schmid, 2001) then gradually introducing new variables, such as different speech rates (e.g. Dellwo & Wagner, 2003), spontaneous conversation (e.g. Barry & Russo, 2003), a larger number of speakers (e.g. Galves *et al.*, 2002, and Rouas & Farinas, 2004) with different and sometimes controversial results. Some authors have proposed modifications of the formulae (e.g. Dellwo, 2006, and Benton, 2010), or have applied the formulae to different durations, such as voiced and unvoiced intervals (e.g. Galves *et al.*, 2002) or feet and syllables (e.g. Wagner & Dellwo, 2004, and Asu & Nolan, 2006), or have proposed new metrics that are based on different rationales (e.g. Bertinetto & Bertini, 2008[4]). Despite some criticisms and a few failures (e.g. Barry & Russo, 2003, and Arvaniti, 2009), these measures and the perspectives they offer have raised (and are still raising) a growing interest within the scientific community: various authors have used them with the aim or in the attempt of categorising different languages, different language varieties (e.g. Schmid, 2004, Romano *et al.*, 2010, Giordano & D’Anna, 2010, within the linguistic area of Italy) and even to detect the interference of the rhythm properties of L1 on productions by L2 speakers (e.g. White & Mattys, 2007). The latest developments in this field include some attempts to merge the two aspects of speech rhythm (namely, the segmental and the accentual levels) into multi-layer models (see Bertinetto & Bertini, 2010, and O’Dell *et al.*, 2010).

1.4 Presentation of the thesis

The thesis is collocated within the research frame sketched above. It is mainly concerned with rhythm typology and presents a number of experiments on and with the main rhythm metrics, most of which exploit the same data (a corpus of audio samples that have been gathered and labelled precisely for this purpose). However, the structure of the thesis is conceived in a slightly peculiar way. It is not split into two parts (the first expounding the state of the art, the second presenting the results

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[3] From now on, Ramus et al. (1999).

[4] However, their index is still based on a modification of the rPVI formula (see chapter 3).

of one or more experiments), as it is customary, but mingles the two together. Every chapter deals with one or more aspects of rhythm typology and contains, first, a survey of the theoretical studies that have approached the topic, then, an analysis of the experiments or tests conducted. Of course, some chapters concentrate in outlining previous approaches as well as theoretical issues, whereas others focus on the methodology and the analysis of some experiments. But the two aspects are always present, except for chapter 4.

The following chapter unfolds the research in the field of rhythm typology, from its beginning to present day models, by following the thread of the traditional dichotomy that opposes stress-timing and syllable-timing. In the end, I shall present a minor experiment that was inspired by some recent studies (namely Wagner & Dellwo, 2004, and Asu & Nolan, 2006). Despite using the formulae of rhythm metrics, I have chosen to illustrate it in that chapter because it deals with the inter-onset distance (*i.e.* a certain conception of the syllable), a unit which has been abandoned by mainstream modern approaches, but which has been the focus of past research (together with the inter-stress distance, *i.e.* the foot).

Chapter 3 zooms to rhythm metrics. The main studies on this topic are outlined along an illustration of the formulae of the most frequently used metrics as well as a discussion of practical and methodological issues. Subsequently, I shall present and analyse the results of the metrics for the data I gathered, which presently include 61 speakers of 21 languages. It can be said that this chapter constitutes the core of the thesis.

Chapter 4 is the most technical one and deals exclusively with the illustration of *Correlatore*, a program that I have developed with the aim of accelerating the process of computing rhythm metrics. It is divided into two parts, the first one explaining how to use it, the second one illustrating its implementation and discussing the difficulties encoutered.

Chaper 5 treats the theme of variation, which is recurrent in linguistics, from an unusual perspective, *i.e.* rhythm variation and variability. It is not meant to exhaust the topic, rather it is intended to introduce it, as it seems that studies of this type are still rare. After a discussion of the two aspects, it presents the results of the metrics on selected data samples and tries to outline a framework which, I believe, might open interesting perspectives.

Chapter 6 touches on perception, which has been said to stand at the basis of the distinction between stress-timing and syllable-timing. Despite this claim, in fact, only few studies have investigated the ability of naive listeners to discriminate between languages belonging to different “rhythm classes”. After a review of the (mainly modern) studies on the perception of rhythm, I will discuss the format and the controversial results of a perceptive test which has been administered to 43 listeners. A final discussion on different aspects of rhythm metrics and on future perspectives will of course close the thesis.

I shall now raise a terminological point. After numerous studied failed to find evidence of isochrony, many authors working in this field have taken their distance from the terms *stress-timed* and *syllable-timed*, adopting other (more or less original) solutions (see, for instance, the “label inventors” reviewed by Bertinetto, 1989). However, it has to be noted that these two terms do not necessarily evoke isochrony: they simply suggest that the rhythm of the two groups of languages is based on stresses vs. syllables[5]. For the time being, there seems to be no proof of the opposite: I shall therefore maintain the use of these terms, which have the advantage of being universally understood.

Finally, I would like to warn the reader that, in countercurrent to the present trend, I shall stubbornly follow British English spelling conventions (except, of course, in quotations, where I shall respect authors' choices). This has been consciously brought to exasperation to include forms like *to analyse, to visualise, to realise* and *to fulfil*, which seem to be long forgotten even in England. I have tried to stick meticulously to my purpose: should any deflection be found in the text, it has to be imputed to Microsoft Word's spellchecker, which apparently did not approve of my choice and attempted to sabotage it in all possible ways.

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[5] This is valid in English. In Italian, for example, the terms *isosillabico* and *isoaccentuale* do evoke isochrony and, therefore, they have usually been avoided in the publications by Mairano & Romano (2008 and following).

2.

Nearly 100 years of stress-timing and syllable-timing

2. Nearly 100 years of stress-timing and syllable-timing

2.1 Introduction

Research on speech rhythm has mainly (though not exclusively) been concerned with the search for a characterisation of languages on the basis of the distinction between stress-timing and syllable-timing. Such a distinction is based on the perceptive impression that stresses should occur at regular intervals in some languages, and that syllable durations should be fairly constant in some other languages (the theory of isochrony). After empirical data disproved the existence of isochrony, many authors set out to provide alternative visions, claiming that the impression of stress-timing and syllable-timing was given by structural properties of the languages (cf. Bertinetto, 1977 and following and Dauer, 1983) that accounted for their classification to one or the other rhythm class. More recently, some authors (cf. Ramus *et al.*, 1999, and Low *et al.*, 2000) proposed some acoustic measures to reflect these structural properties (at segment and/or syllable level), so that empirical data could be tested with a more explicit model. Besides, other authors provided rhythm models that accounted for the accentual level of speech rhythm (see O'Dell & Nieminen, 1999). The latest attempts include the development of multi-layer models meant to account for both levels of speech rhythm.

In the following pages, I shall try to provide a sketch of the research on these topics, from the quest for isochrony that characterised the first studies in this field, to more recent approaches.

2.2 Stress-timing vs. syllable-timing

I shall now present a survey of the main studies which have been carried out in the field of stress-timing and syllable-timing. It is not meant to be exhaustive, rather I shall present the most significant steps in a mainly chronological order following the evolution of research in this field.

2.2.1 The pioneers

Although the terms "stress-timed" and "syllable-timed" were introduced by Pike (1945), the existence of two different rhythm groups of languages had already been noticed earlier. Eriksson (1991) reports that the 18th century phonetician Joshua Steele had already put forward the idea that stresses in English occurred at fixed temporal intervals. His claim was supported only by intuition as, obviously, no tools were available at that time to provide instrumental evidence. In the 20th century, Classe (1939) tried to provide experimental evidence of the existence of regular inter-stress intervals in English, but he had to conclude that their duration is not independent of the number of syllables composing them: isochrony only emeerges under special circumstances. Lloyd James (1940) used a vivid expression to distinguish between languages characterised by a *machine-gun rhythm* (*i.e.* syllable-timed languages) and languages characterised by a *Morse code rhythm* (*i.e.* stress-timed languages).

2.2.2 The classics: Pike and Abercrombie

As has been previously mentioned, Pike (1945) was the first to use the terms *stress-timed* and *syllable-timed* languages, which many authors still use today. He claimed that the duration of inter-stress intervals in stress-timed languages are more or less constant and, therefore, independent of the number of syllables (which are, consequently, compressed in function of the number of syllables contained in one inter-stress interval); conversely, in syllable-timed languages, syllable duration is more or less constant and, therefore, the duration of inter-stress intervals is proportional to the number of syllables. He mentioned English as an example of stress-timed language and Spanish as an example of syllable-timed language. However, in his book *The Intonation of American English*, the aim of which is to teach the American intonation to foreigners, he merely hints at this distinction and provides no empirical tests to support his claims[6].

Abercrombie (1967) drew on Pike's distinction and terminology. The influential yet controversial passage is entirely reported below:

> *It is the way in which the chest-pulses and the stress-pulses recur, their mode of succession and co-ordination, that determines the rhythm of a language. There are two basically different ways in which the chest-pulses and the stress-pulses can be combined, and these give rise to two main kinds of speech-rhythm. As far as is known, every language in the world is spoken with one kind of rhythm or with the other. In the one kind, known as syllable-timed rhythm, the periodic recurrence of movement is supplied by the syllable-producing process: the chest-pulses, and hence the syllables, recur at equal intervals of time – they are isochronous. French, Telugu, Yoruba illustrate this mode of co-ordinating the two pulse systems: they are syllable-timed languages. In the other kind, known as stress-timed rhythm, the periodic recurrence of movement is supplied by the stress-producing process: the stress-pulses, and hence the stressed syllables, are isochronous. English, Russian, Arabic illustrate this other mode: they are stress-timed languages.*
> *(Abercrombie, 1967:97)*

It can be said that he reformulated Pike's hypotheses, introducing the concept of isochrony and going slightly further in claiming that all languages of the world are either stress-timed or syllable-timed. The claim that a language can either be stress-timed or syllable-timed is supported by the observation that "when one of the two series of pulses is in isochronous succession, the other will not be"[7] (1967:97). This fact is illustrated by Abercrombie with two sentences, in English and French respectively:

Which is the | train for | Crewe, | please?

and

C'est ab*so*lu*ment* ridi*cule*

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[6] Eriksson (1991) states that Pike's book is written in the same traditional style as some normative grammars. He adds that "[r]eading his book today, one finds it surprising that his ideas got the attentions they did" (1991:19).

[7] To be precise, this observation only explains why a language cannot be both stress-timed and syllable-timed; it does not prove that all languages belong to one of the two rhythm classes.

In the English sentence, stressed syllables (although recurring at regular intervals) are separated by a different number of unstressed syllables (2 in the first unit, 1 in the second, 0 in the third). In contrast, in the French sentence (in which italics indicate stress), the syllable *ment* will supposedly be nearer to the preceding stressed syllable *so* than to the following stressed syllable *cule*, as only 1 unstressed syllable separates *so* and *ment*, while 2 unstressed syllables separate *ment* and *cule*. In fact, in compliance with what had already been stated by Pike (1945), the consequences of the two alleged types of isochrony are, on the one hand, that

> *there is considerable variation in syllable length in a language spoken with stress-timed rhythm whereas in a language spoken with a syllable timed rhythm the syllables tend to be equal in length*

and, on the other hand, that

> *[...] in French, a language with a syllable-timed rhythm, the constant rate of syllable-succession means that stresses separated by different numbers of unstressed syllables will be separated by different intervals of time.*
> *(Abercrombie 1967:98)*

2.2.3. Further studies on syllable-timing and stress-timing

As a consequence of Pike's and Abercrombie's claims, and despite the claims of stress-timing for English having already been disproved by Classe's (1939) experiment, many authors set out to verify the supposed stress-timing or syllable-timing of the languages mentioned by Pike and Abercrombie or to attempt a rhythmic categorisation of other languages[8]. Most of the experiments were carried out by measuring syllable durations (either in their phonological notion or as onset-to-onset) and/or inter-stress intervals (feet). Indeed, these studies are so numerous that some authors have even compiled reviews of the research in this subject (such as Bertinetto, 1989 – who introduces ironically labelled partitions between the studies according to their attitude towards isochrony –, Eriksson, 1991, and the most exhaustive and emblematically impressive 54-pages unpublished *Bibliography of Timing and Rhythm in Speech* by P. Roach[9]). I shall now report a selection of relevant studies in this field with no ambition of completeness whatsoever.

Bolinger (1965, reported by Eriksson, 1991:21, and Bertinetto, 1989:102) measures inter-stress intervals in 2 English sentences read by 6 speakers and finds that the number of syllables composing each interval seems to determine its length. Bertinetto (1989) classifies Bolinger (1965) together with Classe (1939), Allen (1975), Lehiste (1977) and others as "perceptual illusionists" since they suggest that isochrony might be evident perceptively, but seems to have no acoustic counterpart.

Allen (1975) stated that the impression of isochrony is given by the listeners' tendency to superimpose a rhythmic structure on the recurrent linguistic patterns (given by syllables and/or stresses). He also reformulated the classical dichotomy in

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[8] Abercrombie's statemets have been very influential, but scepticism about the stress-timed vs. syllable-timed dichotomy was fairly widespread at any rate: Mitchell writes that the classification of languages on the basis of this dichotomy is "something of an oversimplification" (1969:156).

[9] This document has been last updated in April 2003 but is currently still available online at the following address: http://www.personal.reading.ac.uk/~llsroach/timing.pdf

terms of rhythms of alternation (between heavy, fully articulated stressed syllables and reduced unstressed syllables) and rhythms of succession (of similar non reduced syllables). It is well-known that the verse of the supposed stress-timed languages is based on the foot as a metrical unit, while the verse of the supposed syllable-timed languages is based on the syllable. Starting from this observation, Allen states that:

> *The huge preponderance of English metrical verse has feet that are either two or three syllables long, with accent either beginning or ending the foot. Most of these metres will give rise to an alternating rhythm, since they have one or more unaccented syllables in each foot [...] Romance (and Japanese) poetry requires only a fixed number of syllables per line [...]. That is, since accentuation plays a weaker role in Romance phonology, the poetry of these languages makes little use of differences in syllabic accent, grouping the syllables instead into sequences of equals.*
> *Natural language rhythms thus appear to be largely either simple alternations or successions.*
> *(Allen, 1975:77).*

This claim is supported by the different status of unstressed syllables in the two categories of languages:

> *Unstressed syllables in English [...] are "reduced" in both quality and quantity to the extent that the resulting rhythmic pattern consists of the stressed syllables alternating with all of the intervening unstressed syllables, i.e. a sort of massive off-beat. When the unaccented syllables retain their phonetic shape, however, as in French or Japanese, the resulting rhythmic pattern remains tied as much to syllables as to accents. Stress rhythms are thus rhythms of alternation, whereas syllable rhythms are rhythms of succession.*
> *(Allen, 1975:80)*

The author states that listeners have a "centralizing tendency", a tendency to hear regularity where it does not necessarily exists. In other words, they tend to superimpose a kind of recurrent rhythmic structure on these two underlying rhythmic patterns. Hence the impression of isochrony: "we perceive speech as rhythmic because it is fairly regular in its sequential sound patterns often enough that we can impose upon it simple rhythmic structures" (Allen, 1975:78).

This view is shared by Lehiste (1977), who ran some experiments on the perception of timing and duration: she found that listeners obtained better scores when rating the duration of non-speech stimuli than of intervals of speech. So, she suggests that isochrony is language-bound, "rather than being a feature of the perception of rhythm. At least in terms of a gradient, it is slanted in favor of perception of spoken language" (1977:257). Like Allen (1975), she considers it "quite likely that the listener imposes a rhythmic structure on sequences of inter-stress intervals" (1977:258). However, she then presents a study of the interaction between syntax and isochrony[10] (for this reason she is classified among the “optimists” by Bertinetto, 1989).

Uldall (1971, reported by Eriksson, 1991:25, and by Lehiste, 1977:254) measured inter-stress durations in a speaker reading the narrative *The North Wind and the Sun* and claimed to have found a strong tendency to isochronism[11] as feet made up of less than 4 syllables tended to have durations between 385 and 520 ms. However, Eriksson (1991) wonders “by what standard of comparison Uldall is able to determine that a difference between 385 and 520 ms is ‘small’” and argues that “all one has to say to upset the whole ‘proof’ is that one finds the increase in foot duration as a function of the number of syllables ‘very striking’” (Eriksson, 1991:26).

A series of articles with emblematic titles (*Is Spanish really syllable-timed?, Is French really syllable-timed?,* etc.) appeared on the *Journal of Phonetics* in the early 80s. Authors verified the presence of isochrony at the syllable in supposedly syllable-timed languages: these studies include Pointon (1980), Wenk & Wioland (1982) and Borzone de Manrique & Signorini (1983) – the first two ones are classified as “label inventors” by Bertinetto (1989) as they proposed new terms to indicate the different (and often deviating) rhythm tendencies of the languages analysed: segment-timing (Pointon, 1980) as well as trailer-timed vs. leader-timed (Wenk & Wioland, 1982). In the former study, the author reviewed a number of previous studies on Spanish rhythm; the label segment-timing appears in Pointon’s conclusion and is supposed to refer to a language “in which the number and type of segments in each syllable […] determine the duration of a syllable” (Pointon, 1980:302). In the latter study, the two authors had 12 native French speakers read the following sentence (12 + 6 syllables):

Il a sollicité ma collaboration, car Pierre aime toujours l’art.

If hypotheses about the presence of isochrony at syllable level for French were correct, one would expect the first part (12 syllables) of the sentence to last approximately twice as long as the second part (6 syllables), but the results were far from confirming these hypotheses. Instead, the authors present a series of “phonetically[12] [sic] ambiguous, rhythmically distinct utterances” (such as /sɛdøpapa/, *c’est de papa* or *c’est deux, papa*) and argue that “in simplest terms, other things being equal, the greater the number of rhythmic groups[13] in an utterance, the greater the amount of time the utterance will be allotted” (Wenk & Wioland, 1982:194-195). Then, they carried out a perceptive test and found that “rhythm groups” are distinguishable by listeners, possibly thanks to the increase in duration and corresponding decrease in intensity of French final vowels. On the grounds of this explanation, Wenk & Wioland conclude that:

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[10] She probably refers to the “impression of isochrony” on the part of English speakers and listeners, rather than to “isochrony” proper.

[11] I have decided to include this study for, if one accepts its author’s conclusions, the finding is definitely counter-current.

[12] They possibly mean “phonologically”, since they use slashes for the transcriptions, which also look phonological.

[13] It seems that a definition of “rhythmic group” is not immediately provided by the authors, but their conclusion includes an indication on how to determine them (see below). Judging from their examples, their notion of “rhythm groups” seems to coincide with the interval between two minor prosodic breaks.

> *what serves to establish rhythmic groups in French is a lengthening of what is perceived as the final syllable in each group* [...]. *For this reason* [...] *it is proposed to characterize French as being trailer-timed.*
> *As English rhythmic groups, on the other hand, are delimited by the regular occurrence of stronger syllables at the beginning of each group, it is natural to regard English as being leader-timed*[14].
> *(1982:214)*

Borzone de Manrique & Signorini (1983) studied the durations of segments (both consonants and vowels, all divided in several different groups according to stress and positioning), syllables and inter-stress intervals in Argentine Spanish on sentences by 4 speakers. They found that neither segment (cf. Pointon, 1980) nor syllable duration was constant and, on the contrary, they were influenced by several factors, such as stressed or unstressed position. Surprisingly, instead, the measurements of inter-stress intervals seem to cluster around the same area: such findings bring the authors to the odd conclusion that “Spanish has a tendency toward stress-timed rhythm with differentiating characteristics in the way in which this is manifested” (1983:127).

Another “label inventor” (to use Bertinetto’s, 1989, classification) is Hoeqvist (1983a and b), who considered data of English (supposedly stress-timed), Spanish (supposedly syllable-timed) and Japanese (supposedly mora-timed). As for measurements at syllable level, results for Japanese “indicate that lengthening due to an added mora is considerably more than that found for non-phonemic lengthening” (1983b:222), which therefore seems to confirm at least a partial tendency towards mora-timing. Moreover, results for English reveal a “strong shortening effect due to an adjacent accented syllable” (1983b:223), which seems to be absent in data of Spanish[15] and Japanese. Hoeqvist argues that “perceptually, this shortening might serve to highlight the stressed syllable” or it may also be “a consequence of an attempt to maintain some overall durational structure” (1983b:223). On the basis of these observations, the author claims that Japanese could be defined as duration-controlling and English could be defined duration-compensating, while Spanish does not seem to belong to any of these two categories.

Major (1981) examined data involving both real and nonsense “citation” words as well as casual speech[16] of Brazilian Portuguese. The author concludes that Brazilian Portuguese shows a tendency towards stress-timing for several reasons, among others: “inter-stress durations are not directly proportional to the number of syllables; [...] syllable duration is inversely proportional to the number of syllables in a word; [...] in casual speech unstressed syllables delete, which has the effect of

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[14] This distinction definitely reminds of the distinction between trochee and iambs. Curiously, it can be noticed that French also shows a tendency towards post-modification, whereas English shows the opposite tendency towards pre-modification. However, this has to be taken merely as a remark: I am not implying any sort of correspondence between the two typological categories (leader vs. trailer-timing and pre- vs. post-modification) other than chance.

[15] Hoeqvist reports that this effect is actually visible in Spanish, but only in syllables preceding stress. However, he claims that “the differences between the amounts of shortening shown are so small that it is doubtful that any genuine cross-language difference is showing itself between Spanish and English” (1983b:225-226) The authors, therefore, considers only post-stress shortening (only visible in English) to be characteristic of stress-timing.

[16] By “casual speech” Major refers to speakers reading three sentences rapidly.

equalizing the number of syllables in each stress group" (1981:350). However, he finds differences as to these phenomena across the citation and casual speech styles (see also chapter 5).

Lehiste (1990, reported by Eriksson, 1991:22) did not find evidence of supposed stress-timing in Icelandic since the duration of feet turned out to be proportional to the number of syllables.

Finally, I shall hint at the numerous phonological contributions on rhythm that mainly attempt to analyse the distribution of stresses and accents[17]. In particular, much of the research in this field concentrated on the study of how languages solve stress clashes, the so-called Rhythm Rule, or stress lapses (see, among others, Liberman & Prince, 1977, Farnetani & Kori, 1990, Nespor, 1993, Arvaniti, 1994). Interestingly, Arvaniti (1994) suggests that languages belonging to different rhythm classes differ in the degree of toleration of these eurhythmic phenomena and in the way they try to solve them. In particular, English (stress-timed) tolerates neither stress clashes nor stress lapses and tends to correct both: the former are corrected with the insertion of an extra stress, whereas the latter are corrected with a stress shift. Instead, Italian and Greek are reported to be more tolerant to stress lapses and to correct stress clashes in a different way from English, namely by either de-stressing or by inserting extra duration between clashes. So, the behaviour of languages in relation to these phenomena might be indicative of their belonging to one of the two rhythm classes.

Before concluding this summary it is worth to point out the different problems in measuring inter-stress distances noticed by Eriksson (1991) in his review of previous research on stress-timing: apart from the intrinsic difficulties in identifying stresses, inter-stress intervals can be measured from vowel onset to vowel onset, or from syllable onset to syllable onset, or even from and to syllable centres. However, despite the different criteria used to identify inter-stress intervals, the result seems to be the same: inter-stress intervals are not isochronous in stress-timed languages, rather their duration seems to increase as a function of the number of syllables. Similar problems and parallel findings have been reported for syllables-timing: syllable boundaries are not always clear (some authors simply measured vowel-to-vowel distances, other used phonological criteria), but, at any rate, syllable durations do not seem to be constant in syllable-timed languages. As a coronation to the failure of research on isochrony, I shall report in the next paragraph the comparative study by Roach (1982).

2.2.4 A comparative study by Roach

Roach (1982) carried out an experimental test based on Abercrombie's assumption that syllable length tends to be greatly variable in stress-timed languages and equal in syllable-timed languages. His study involved the six languages quoted by Abercrombie (1967), three of which had been given as examples of stress-timing (English, Russian and Arabic), while the other three had been given as examples of syllable-timing (French, Telugu and Yoruba) – see above.

Firstly, Roach calculated the standard deviation of the durations of the syllables in the four languages assuming that if Abercrombie's hypothesis (the durations of syllables is constant in syllable-timed languages but greatly variable in

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[17] Many of these studies actually seem to even take the distinction between stress-timing and syllable-timing for granted.

stress-timed languages) was right, its value had to be higher for stress-timed languages and lower for syllable-timed languages. However, Abercrombie's hypotheses were not confirmed by the results: for some syllable-timed languages (French and Yoruba) the value of the standard deviation of syllable lengths was indeed lower than for English, but it was higher for Yoruba than for both Russian and Arabic, which is in contradiction with Abercrombie's statement. At any rate, Roach notes that the differences among the values obtained are too small (ranging from 66 milliseconds in Telugu to 86 in English) to justify the classification of a language as syllable-timed as opposed to stress-timed.

Secondly, he calculated the standard deviation of inter-stress intervals in order to test Abercrombie's second statement (*i.e.* that the length of inter-stress intervals should be constant in stress-timed languages and greatly variable in syllable-timed languages). One would expect the standard deviation of the duration of inter-stress intervals to be lower for stress-timed languages and higher for syllable-timed languages. But again, the results did not confirm expectations: surprisingly enough, the values given by syllable-timed languages (French, Yoruba and Telugu) are all higher than those given by stress-timed languages (English, Arabic and Russian).

However, as Roach says, the results of this experiment may have been influenced by the fact that only one speaker per language was recorded and by the difficulty in establishing which are the prominent stresses and, consequently, where the precise boundaries of inter-stress intervals fall. Yet, there seems to be no doubt about the fact that the differences are all too small to be able to draw any conclusions as to the classification of a language into a rhythmic category. Therefore, Roach suggests that Abercrombie's criteria for the distinction between the two rhythmic groups are inadequate and that stress-timing and syllable-timing may only be a matter of perception: "a language is syllable-timed if it *sounds* syllable-timed" (Roach, 1982:78).

2.3 Departing from isochrony

2.3.1 The "phonological illusionists"

In the 80s, many phoneticians abandoned Abercrombie's hypotheses as it was clear that the theory of isochrony was not supported by experimental data; at the very least, it had to be re-interpreted as a continuum spanning from a purely hypothetic stress-timing pole to a likewise hypothetic syllable-timing pole. And even so, acoustic measurements on syllables and inter-stress intervals did not always support these claims. Some authors proposed a set of phonological properties held to be responsible for the classification of a language as stress- or syllable-timed: for this reason, they have been labelled as "phonological illusionists" by Bertinetto (1989).

Bertinetto (1977, expanded in 1981 and 1983) measured syllable and foot durations in 15 sentences read by two native speakers of Italian. The durational increase of the foot seems to be a function of the number of syllables or phones that compose it, just like the durational increase of the syllable seems to be a function of the number of phones that compose it. These results support the interpretation of Italian as tending towards syllable-timing: in all the charts reported by Bertinetto (1983) "l'intercettamento dell'ordinata è sempre localizzato nei pressi dell'origine.

Ciò significa, senza possibilità di dubbio, che la tendenza verso l'isocronia sillabica dell'italiano si afferma in maniera constante, indipendentemente dal tipo di unità prescelta per la verifica" (1983:1081-2). Bertinetto (1977 and following) also proposes a list of phonological properties which characterise languages tending to one or the other pole of the rhythm continuum. These properties are then reported in his following publications dealing with this topic. I shall report below the version by Bertinetto (1989)[18] [19]:

> *a) Vowel reduction vs. full articulation in unstressed syllables;*
> *b) relative uncertainty vs. certainty in syllable counting, at least in some cases;*
> *c) tempo acceleration obtained (mainly) through compression of unstressed syllables vs. proportional compression;*
> *d) complex syllable structure, with relatively uncertain syllable boundaries, vs. simple structure and well-defined boundaries;*
> *e) tendency of stress to attract segmental material in order to build up heavy syllables vs. no such tendency;*
> *f) relative flexibility in stress placement […] vs. comparatively stronger rigidity of prominence.*
> *g) relative density of secondary stresses, with the corresponding tendency towards short ISI (inter-stress intervals, my insertion), and (conversely) relative tolerance for large discrepancies in the extent of the ISI. This feature seems to oppose languages like English or German on the one side, to languages like Italian or Spanish on the other.*
>
> *(Bertinetto, 1989:108-9)*

Bertinetto (1989) recognised a) and d) as the most important ones, a view which is essentially shared by Dauer (1983, see below). The phenomenon of vowel reduction is typically a phonological property of stress-timed languages and contributes to give prominence to stressed vowels (and, consequently, to stressed syllables) by shortening the length of unstressed vowels and making their quality less definite (which usually tends to be in the schwa area). On the contrary, in the languages where this phenomenon does not exist or is not consistent (e.g. syllable-timed languages), unstressed vowels tend to have a comparable length and a similar quality to stressed vowels, thus creating the impression that the duration of stressed and unstressed syllables is nearly alike. As for d), it is normally accepted that the syllabic inventory is larger in stress-timed languages than in syllable-timed languages. As a consequence, we can state that while syllable-timed languages have a simple syllabic structure[20] (*i.e.* only light consonantal clusters), stress-timed languages have a complex syllabic structure (*i.e.* they also have heavy consonantal clusters) particularly in stressed syllables, which are then given further prominence.

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[18] The reason for choosing the 1989 version is simply that it is in English. However, the first version dates to 1977 and Bertinetto (1981) also includes a similar list.

[19] For each pair of properties, the one on the left is typical of stress-timed languages, while the one on the right is typical of syllable-timed languages.

[20] This assumption relies on the fact that languages presenting complex syllables without possessing simple syllables are not known. So, only languages with a large syllabic inventory can have complex syllables. Indeed, the larger the inventory, the more complex syllables a language can afford.

Schmid (2004) added other phonological properties, such as the preference for closed syllables in stress-timed languages vs. the preference for open syllables in syllable-timed languages.

Another "phonological illusionist" is Dauer (1983), who measured the duration of inter-stress intervals on read passages of English, Thai, Greek, Spanish and Italian. She found no significant differences in variances of the values obtained for the five languages: in all cases, inter-stress intervals seemed to increase as a function of the number of syllables contained. Dauer suggested that the perceived difference between the two groups of languages might be an effect of differences in "language structure":

> *I would like to propose that the rhythmic differences we feel to exist between languages such as English and Spanish are more a result of phonological, phonetic, lexical, and syntactic facts about that language than any attempt on the part of the speaker to equalize interstress or intersyllable intervals.*
> *(1983:55)*

She stated that the areas in which languages differ (in respect to rhythm) are the following: syllable structure, vowel reduction and stress (this view is definitely in compliance with Bertinetto, 1977 and following, see above). On these grounds, she also proposed a change in terminology in favour of the term *stress-based*: furthermore, she claimed that it is not necessary to have a second term in opposition to stress-based (such as syllable-based) as the rhythmic distinction between languages has to be done along a continuum and therefore does not need two dimensions: "[l]anguages can be compared to each other along the dimension as having a more or less stress-based rhythm" (1983:59).

In conclusion, as resumed by Bertinetto (1989), "the original dichotomy has gradually lost much of its dichotomic character, and has more and more acquired the aspect of a scalar orientation" in terms of a continuum. The studies by Bertinetto (1977 and following) and Dauer (1983) suggest that the more phonological properties typical of stress-timing a language possesses, the more it can be placed near the stress-timing pole of the continuum; conversely, the more phonological properties typical of syllable-timing a language has, the more it can be placed near the syllable-timing pole of the continuum[21].

2.3.2 Compensation and coarticulation

The term "compensatory shortening" refers to the phonological phenomenon by which, in certain languages, the stressed syllable of a foot or word tends to be compressed according to the number of the following unstressed syllables in that foot or word. More precisely, this phenomenon is called *inter-syllabic compensation* in opposition to *intra-syllabic compensation*, which refers to the phenomenon by which the phonemes of a syllable tend to be compressed in function of the number

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[21] It has to be remarked that some languages possess properties typical of both rhythmic groups: Nespor (1990, quoted in Ramus et al., 1999) notes that Catalan has a simple syllabic structure but allows for vowel reduction, while, conversely, Polish has a complex syllabic structure but does not allow for vowel reduction. But this of course does not constitute a disproof of Bertinetto's and Dauer's hypotheses. It simply indicates that these languages are somewhere in an intermediate position of the continuum.

of the other phonemes present in that syllable. Intuitively, inter-syllabic compensation has been associated with stress-timing, whereas intra-syllabic compensation has been associated with syllable-timing. The tendency of readjusting the length of the syllables of each foot (inter-syllabic compensation) and the phonemes of each syllable (intra-syllabic compensation) are in fact interpreted as an attempt to standardise the length of the feet and the syllables, respectively. Studies of this type were initiated by Lindblom & Rapp (1973) and soon caught on.

Fowler (1981) makes an attempt to explain compensatory shortening and coarticulation as closely related phenomena, both due to co-production: in Fowler’s words shortening and coarticulation are “different measures of the same articulatory phenomena” (1981:128). This hypothesis is based on a model that sees consonantal segments superimposed on flanking vowels: according to this view, when a vowel is preceded or followed by one or more consonants, it “is measured to be shorter not necessarily because it is shorter in any articulatory sense, but because most of the durational extent over which it is coproduced with a consonant is conventionally assigned only to the consonants” (1981:128). The author also argues that if inter-syllabic compensatory shortening is explained as co-production, then also inter-syllabic compensation can be explained as the superimposition of unstressed vowels on stressed vowels. These hypotheses have been supported by an experiment which revealed the existence of bidirectional formant co-articulation between trans-consonantal vowels. More in particular, the influence of the stressed vowel seems to be more powerful on following than on preceding unstressed vowels, reproducing what Lindblom & Rapp (1973) found for intra-syllabic and inter-syllabic compensation. However, as stated by Fowler, “to demonstrate that coarticulation and shortening, both at the level of the segments in a syllable and at the level of stressed and unstressed syllables, are symmetric is not to confirm that they are in fact two different measures of the same phenomenon” (1981:131).

As for inter-syllabic compensation, it has been studied by various linguists (see Bertinetto, 1989 and 1990, for a summary of many of these studies) and the results seem to confirm that it is a characteristic of stress-timed languages. However, as for intra-syllabic compensation, the results of some studies did not confirm that it is a characteristic of syllable-timed languages. Vayra, Fowler & Avesani (1987, reported by Bertinetto, 1989) noticed more intra-syllabic compensation in English than in Italian and therefore suggested that English presents “intimations of syllable-timing”. This view is not shared by Bertinetto (1989), who claimed that “no (alleged) isosyllabic language examined so far exhibits strong inclinations towards intra-syllabic compensation” (Bertinetto, 1989:122). He argued, instead, that intra-syllabic and inter-syllabic compensation should be considered as the different facets of the same property, which is symptomatic of *duration compensating languages* (*i.e.* stress-timed languages, re-proposing the term introduced by Hoeqvist, 1983). He supports his claims by observing that it would be difficult for a language to obey two opposite tendencies, flexibility at the syllable level and compensation at the foot level (or vice versa): “it seems much more sensible to imagine that both levels obey the same tendency” (1989:123). He then argued that “the ultimate difference between iso-accentual and iso-syllabic languages might lie in the *different degrees of flexibility they exhibit at all relevant levels of structure*” (Bertinetto, 1989:123).

Finally, he proposed a new list of features that are supposed to characterise compensating languages[22]:

> i. *more intrasyllabic compensation;*
> ii. *more CS* [compensatory shortening] *at the foot (and word) level;*
> iii. *more vowel reduction in unstressed syllables;*
> iv. *more tolerance for extreme shortening of unstressed syllables;*
> v. *sharp contrast in the exploitation of prosodic features in stressed vs. unstressed syllables;*
> vi. *in general, less sensitivity to all linguistic and non-linguistic events localized on unstressed syllables.*
>
> *(Bertinetto, 1989:124)*

2.3.3 Linear regression studies and rhythm modelling[23]

An approach that seems to have yielded interesting perspectives consisted in defining the stress group (inter-stress interval, *I*) as a function of the number of syllables (*n*) according to the following formula:

$$I(n) = a + b * n$$

where a is a constant and b is a parameter describing the growing ratio of I versus n. With this formula, the two extreme ways of establishing the priority in rhythmic regulation of different languages are:

a) an absolute stress-timing, when b is naught and, therefore, the inter-stress interval is a constant ($b=0 \rightarrow I=a$; see figure 2.1);
b) an absolute syllable-timing, when a is naught and the inter-stress interval is directly proportional to the number of syllables ($a=0 \rightarrow I=bn$; see figure 2.1);
c) yet, languages usually tend to show an intermediate form (see figure 2.1).

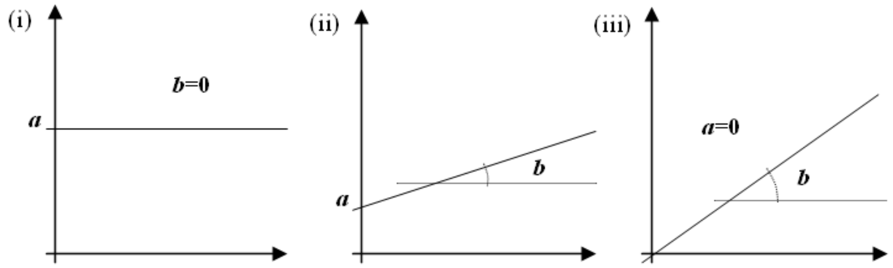

Figure 2.1 (from Romano & Mairano, 2010c). The growth of inter-stress intervals for (i) absolute stress-timed languages (on the left), (iii) for absolute syllable-timed languages (on the right) and (ii) for a mixed-timed language (in the mid).

This approach is fully explained by Eriksson (1991) and Barbosa (2006), but has been used earlier (with some variations) by other authors, such as Bertinetto (1983), Marotta (1985), Farnetani & Kori (1986 and 1990), and later by, for instance,

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[22] The author claims that this list has to be intended as an addition to (not a substitution of) the list of phonological features reported above.

[23] This paragraph has been extracted from Romano & Mairano (2010c) and partly re-manipulated.

Engstrand & Krull (2003). In particular, Bertinetto (1983) also applied this method to an intra-syllabic domain: in some of his charts he defined syllable duration as a function of the number of segments composing a syllable. Results for his data of Italian confirmed that the inter-stress interval increases as a function of the number of syllables composing it and, likewise, syllable duration increases as function of the number of segments composing it. As already reported, the author concluded then that Italian exhibits a tendency towards syllable-timing.

This approach is also the basis of the model that has been reproposed (see the relevant literature on previous studies, e.g. in Barbosa, 2006) and which predicts temporal patterns as the result of the coupling of two oscillators (see O'Dell & Nieminen 1999). The duration of the inter-stress interval is described as the function of the number of syllables and of two clocks whose contributions are regulated by a coupling strength (called *r*-parameter). So, *a*, *b* and *I* of the preceding equation are re-defined as in the following formula:

$$I(n) = \frac{r}{r\omega_1 + \omega_2} + \frac{1}{r\omega_1 + \omega_2} n$$

where ω1 is the oscillation velocity of the accentual oscillator, ω2 is the velocity of the syllabic oscillator and *r* is the coupling strength. When the value of the coupling strength (*r*) is 1, then *a* of the original equation is equal to *b* and both oscillators have the same influence; but when *r* is greater than 1 ($r > 1$) the overarching accentual-oscillator is dominant whereas when *r* is lesser than 1 ($r < 1$) it is the subordinated syllabic-oscillator which is dominant.

Studies of the '80s-'90s carried out for Swedish and English (Eriksson, 1991, and others quoted by Barbosa 2006) have evaluated *r* on different corpora with changing tempos and have assessed values around 2 against typical values obtained for Italian or Greek ($r \approx 0.9$). Barbosa (2006) tested the same mathematical model for different speech rates for Brazilian Portuguese finding values about 1.5. However, *r* did not systematically decrease for increasing speech rates, so that a shift towards syllable-timing for rapid tempos was not confirmed (see Dellwo & Wagner, 2003, for different results obtained with a different approach).

Romano & Mairano (2010) tested this model on a corpus of Italian sentences like the ones analysed by Marotta (1985): *Perciò pésa((me)lo) tùtto di nuovo... Perciò pesàte((me)lo) tùtto di nuovo...*[24]. They included similar sentences with different segmental structures (*sposta* instead of *pesa*) and even a nonsense word with growing number of inter-stress syllables as it happens in reiterant speech (*tàta*, *tàtata*, *tàtatata*). Sentences were pronounced by a male speaker with a mean syllable rate of 7.74 σ/s (with local minima down to 5.66 and maxima up to 10.25). The five series range from a mean syllable rate of 6.77 to 8.71 σ/s defining a fairly homogeneous corpus in terms of tempo. Measurements were taken from the stressed syllable of the word to the first following stressed syllable (*tùt*, excluded) thus obtaining σs-to-σs measures and from the stressed vowel (without the syllable onset) to the first following stressed vowel (*ùt*, excluded) thus obtaining V-to-V measures. The results are summarised in figure 2.2 together with the two regression lines

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[24] Similar sentences were measured and tested by other authors (Bertinetto, 1977, 1983; Vayra *et al.*, 1984, and Farnetani-Kori, 1986, 1990) bringing evidence on the reduced compression properties of Italian and discussing the discriminant role of stiffness parameters related to syllable and segment durations (similar outcomes are summarised for Spanish and French by Pamies, 1999).

giving estimates of a roughly linear growth in both cases: *a* has quite high values (slightly lower for *PV*: 148 *vs*. 145) whereas *b* is almost the same for the two measures (rounded to 85).

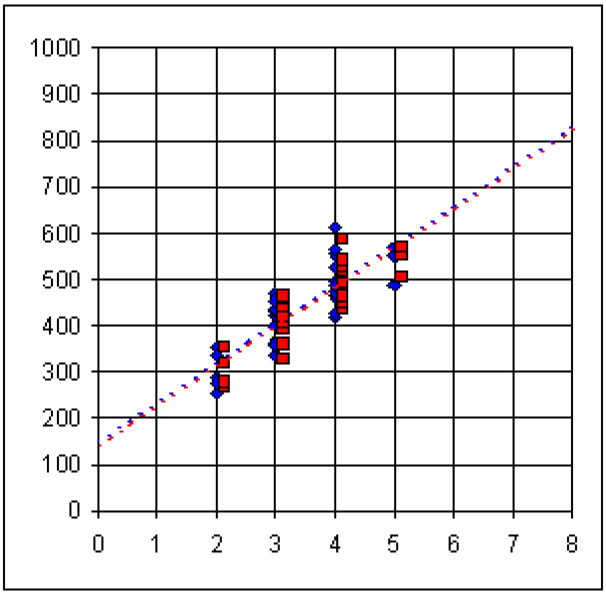

Figure 2.2. The growth of Interstress Intervals for a sample of 27 Italian sentences (◊ for measures at foot level vs. □ for PV measures). (Taken from Romano & Mairano, 2010)

This yields *r* values of 1.74 and 1.70, respectively, as if the accentual oscillator were dominant at phrase level (this is not very surprising according to Bertinetto, 1983, Vayra *et al.*, 1984, Marotta, 1985, and Farnetani-Kori, 1986 and 1990)[25].

2.3.4 Rhythm metrics

A recent approach to speech rhythm involves the so-called *rhythm metrics*. These are treated in detail in the next chapter, so I shall only provide a concise account of the topic. Rhythm metrics are formulae applied to measures of vocalic and consonantal durations giving a representation of the degree of variability of these measures. The rationale behind measuring the variability of consonantal and vocalic intervals rests on the observation by Bertinetto (1977 and following) and Dauer (1983) that the impression of stress-timing or syllable-timing may be given by specific structural properties of the languages (see the list reported above): the most relevant of these properties (mainly vowel reduction and syllable strcture) are arguably reflected by the variability of consonantal and vocalic durations.

The first and most used of these metrics include the deltas (see Ramus, Nespor & Mehler, 1999), their normalised versions called varcos (see Dellwo & Wagner, 2003) and the pairwise variability index (see Grabe & Low, 2002). Various authors set out to test the reliability of the metrics, while others used them to classify languages; many of these studies are reported in the next chapter.

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[25] The sensitivity of the measures to the segmental content of syllables is evident when analysing separately the fifth series: the low value of the coupling strength (0.14) accounts for very variable results (in contrast with e.g. r = 4.72 of the second series): these variations are greater than the ones induced by changes in speech rate.

A new and alternative method has recently been proposed by Bertinetto & Bertini (2008 ad following), which has its root in studies of compensation by Fowler (1977 and following) and in the idea expressed by Bertinetto (1989) that stress-timed (or compensatory) languages might be characterised by a higher compressibility at all levels (both intra- and inter-syllabic).

2.4 Back to syllable-timing and stress-timing?

2.4.1 A revisitation of stress-timing and syllable-timing

As has been outlined, the failure of the quest for isochrony at the syllable and foot level has discouraged research to persist on using the syllable and the foot as rhythm units: in fact, rhythm metrics are applied to vocalic and consonantal intervals. However, in recent years, some authors went back to look for a way of re-integrating these units into an account of speech rhythm, still of course keeping in mind the newer approaches. I shall report on a few studies in which rhythm metrics were applied to syllable and/or inter-stress durations.

Wagner & Dellwo (2004) proposed a new metric, ironically named YARD (Yet Another Rhytm Determination), which is actually constituted by the formula of the raw pairwise variability index but which is applied to z-transformed syllable durations. They tested it on samples of English, German, French and Italian from the BonnTempo corpus: the results were encouraging, with lower values (indicating lower syllable variability) for Italian and French than for English and German. The authors conclude that "future research should again concentrate on regarding rhythm as a sequence of – roughly – isochronous events within language specific internal structures" (2004:4/4).

Asu and Nolan (2006) applied the PVI to measures of consonantal and vocalic durations of Estonian (which is classified as a syllable-timed language), but also (more innovatively) to syllable and foot durations of Estonian and English. While consonantal and vocalic PVI values mainly reflected Grabe & Low's findings for Estonian, syllabic and foot PVI values showed interesting results: English, in compliance with the alleged tendency of stress-timed languages to control for the foot and not for the syllable, seems to have a greater variability at the syllable level than Estonian; instead, these two languages exhibit a nearly identical low-value foot PVI, thus indicating a low variability at the floot level. This seems to suggest that Estonian tends to control both at the syllable and at the foot level, thus proving that the results for the PVI calculated at the syllabic or intra-syllabic level are independent of the results for the PVI obtained at the stress level. The authors conclude that "a two-dimensional characterisation using syllable and foot PVIs [...] gives a more appropriate and subtle account of the rhythm of languages, and in the case of Estonian, examined here in detail, explains the intuition that it is both stress and syllable timed" (Asu & Nolan 2006:4/4).

I believe their results present extremely interesting consequences because they suggest a revision of the traditional stress-timed vs. syllabled-timed dichotomy into at least a quadriparted rhythmic classification. In other words, languages are no longer classified as either stress-timed or syllable-timed, or rather on a bi-polar continuum; instead, they can be spaced within a quadri-polar area which allows for languages being stress-timed (controlling for feet), syllable-timed (controlling for syllables), stress-and-syllable-timed (controlling for feet and syllables) and, perhaps, a-timed (controlling for neither syllables nor feet). These ideas have to be connected to what has been suggested by Bertinetto & Bertini (2010), who also suggest the possibility of classifying languages on a bi-dimensional paradigm.

2.4.2 An unplanned experiment

I shall now present an experiment which I had not planned, but which was inspired by the reading of the two studies reported above. I realised that I disposed of a segmented and CV-labelled multi-language corpus which I had prepared for other purposes (see chapter 3 for the details) but which could easily be exploited to compute rhythm metrics on syllable durations[26]. It has to be noted that by "syllable durations" I do not mean a phonological notion of syllable, rather an onset-to-onset distance (henceforth *inter-onset distance*): this is in compliance with many other authors, such as Farnetani & Kori, who view the rhythm syllable "as the temporal interval extending from the onset of a vowel to the onset of the following one" (1986:27). I shall also remark that vowels in hiatus have been considered as two intervals.

I shall not give details on the data, the segmentation and the methodology because all these aspects are detailed in chapter 3. I shall only briefly say that samples are constituted of read speech (the narrative *The North Wind and the Sun* translated in all the languages analysed – some versions were taken from the *Illustrations of IPA*, others recorded at *LFSAG*[27] or during fieldwork). Samples were segmented and labelled on *Praat* by two different phoneticians (AR and PM), but only data by PM has been used for this experiment[28]. In order to obtain the values of inter-onset distances, I wrote a *Praat* script that outputs the distances between each successive pair of vocalic labels. The values were finally analysed with a special function of *Correlatore* (see chapter 4).

It is important to note that this experiment is only presented here as a preliminary test, which may or may not bring to any relevant results. Although it exploits the formulae of the rhythm metrics and despite the data is described in detail in chapters 3 and 5, it was decided to present this test here because it is inspired by the studies quoted above and because it includes inter-onset measures: I thought that it would find its most natural collocation in this chapter, which deals more directly with syllable- and stress-timing. Moreover, it should be noticed that the test also recalls Roach (1982), who calculated the standard deviation (the delta) on inter-onset and inter-stress durations. As has been said above, his results were far from confirming Abercrombie's isochrony hypotheses, but the PVI might (or might not) yield better results (see chapter 3 for an account of the differences between the delta and the PVI).

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[26] Unfortunately not on inter-stress durations because stresses had not been marked.

[27] Laboratorio di Fonetica Sperimentale "Arturo Genre", University of Turin.

[28] I have also excluded the 10 Icelandic and the 6 Romanian for compatibility reasons. As explained in chapter 3, the 10 Icelandic samples had been labelled before the development of *Correlatore* and therefore using other criteria. The 6 Romanian samples, instead, have not been labelled with CV transcriptions, but as SAMPA transcriptions (which are also accepted by *Correlatore*); it would have not been difficult to convert SAMPA transcriptions into CV sequences, but for the moment I decided to stick with the data that was readily available.

2.4.3 The results

Figure 2.3 shows the results for the deltas and the PVIs on inter-onset durations for the data. All single values for each sample analysed can be consulted in appendix 1, while the charts only show the mean of samples of the same language. As it can be seen, Spanish, Italian and Greek (supposedly syllable-timed languages) show a lower variability of inter-onset distances, while German and, even more, Czech exhibit a high variability. However, one would not expect to find such high values for French (which sticks between Czech and German), Japanese[29] and Estonian. By checking the results obtained on each single sample (reported in appendix 1), it can be seen that variability between speakers of the same language is extremely high (this is clearly visible for the 15 Italian speakers) and, consequently, samples of languages belonging to different rhythm classes greatly overlap.

As for the hypothesis that the rPVI might provide a better discrimination, results do seem to improve with such a measure (see for example Dutch and Polish). However, on the whole, I would say that the discriminatory power of these measures applied to inter-onset distances looks dubious.

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[29] It has to be specified that the Japanese sample has been labeled in two different ways, phonologically (counting devoiced vowels as vocalic segments) and phonetically (counting devoiced vowels as consonantal segments). For practical reasons, in the present experiment I used only the phonetically labelled file (since the script also calculated f0 values for other experiments which are not included in this thesis). It is of course probable (and, indeed, logical) that a phonological labelling would have resulted in more congruent results: as is cleared in chapter 3, devoiced vowels have in fact a great impact on the variability of consonantal intervals, and consequently of inter-onset intervals as well.

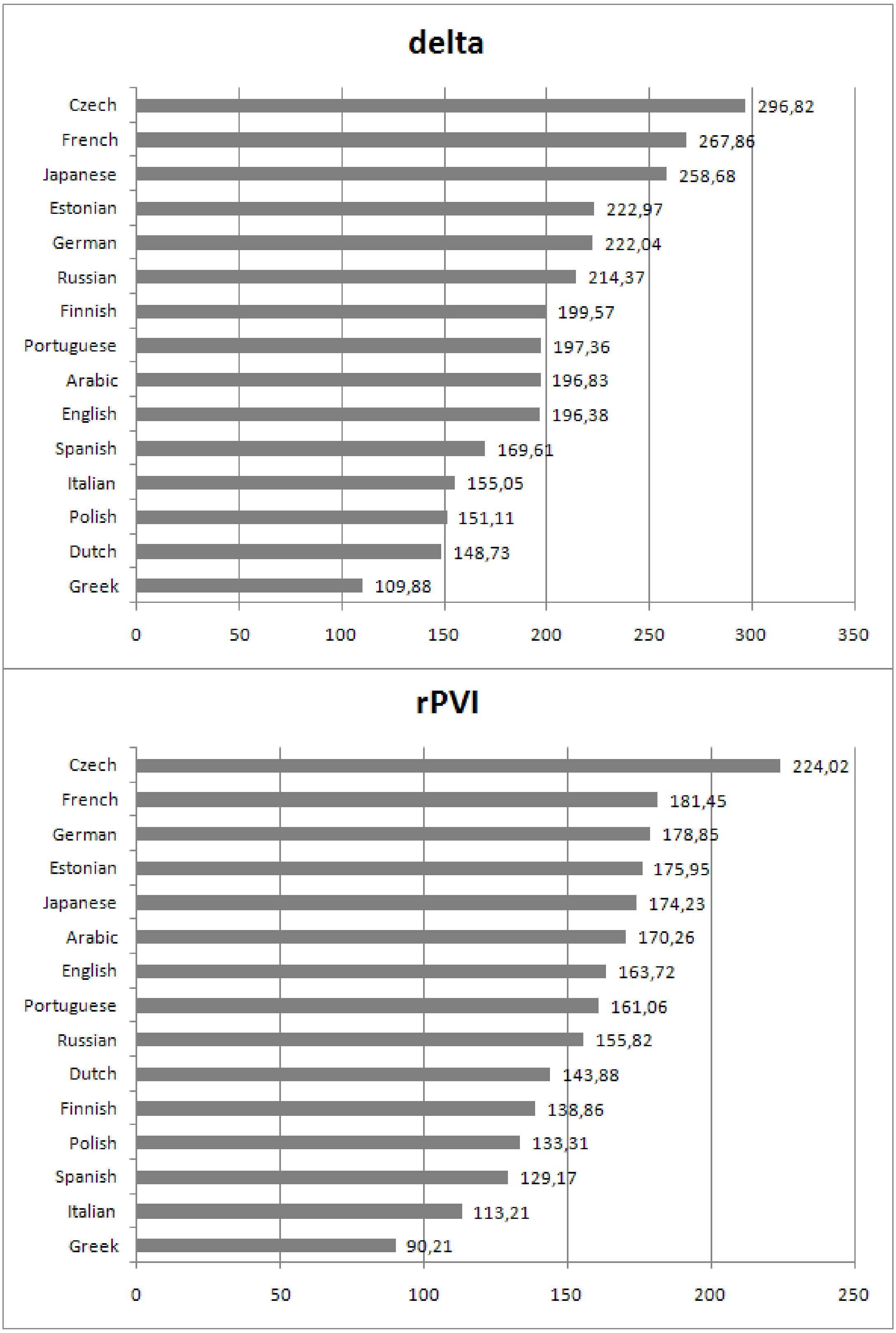
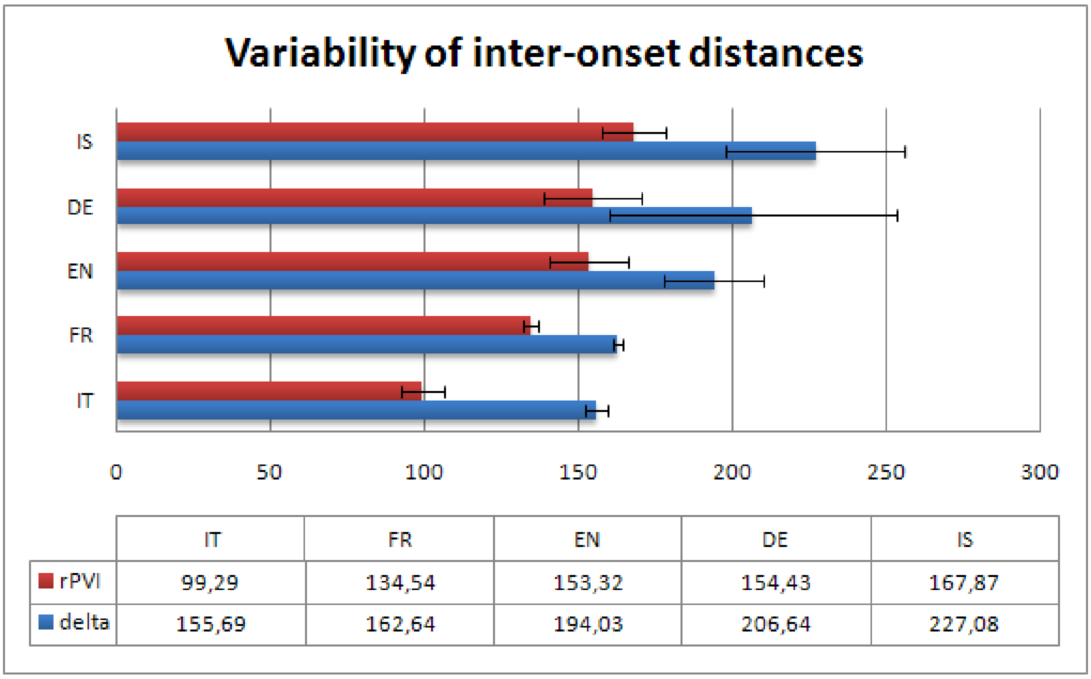


Figure 2.3. The delta (above) and the PVI (below) applied to inter-onset durations of samples of 15 languages (for more details on the data, see chapter 3 keeping in mind that only the files segmentated by PM have been considered for the present experiment).

In order to verify this approach on more controlled data, I also applied the metrics to 10 CV-labelled samples of one and the same speaker reading *The North Wind and the Sun* in 5 different languages (Italian, English, French, German and Icelandic, twice for each language). Data of this speaker are presented in more detail in chapter 5, it will suffice here to say that he is a native speaker of Italian and he is fairly fluent in English, French and, to a lesser degree, German. Results of the delta and the rPVI are shown in figure 2.4.



	IT	FR	EN	DE	IS
🟥 rPVI	99,29	134,54	153,32	154,43	167,87
🟦 delta	155,69	162,64	194,03	206,64	227,08

Figure 2.4. Values of the delta and the rPVI for inter-stress intervals calculated on a (native Italian) speaker in 5 languages. Results shown constitute the mean of the values obtained for two repetitions of *The North Wind and the Sun*. Standard deviations are shown as error bars.

Even though most of the data comes from an L2 speaker, the results seem to better meet expectations: samples of Italian and French (supposedly syllable-timed) show a low durational variability of inter-stress intervals both with the delta and with the PVI, whereas samples of English and German (supposedly stress-timed) show a high variability with both measures. Icelandic presents very high values even though the classification of this language is controversial (see chapter 3). Also, it has to be considered that the speaker is not proficient in this language, so conclusions are at best not drawn on this particular sample.

2.4.4 A brief discussion of the results

In summary, it can be said that these measures (in the particular the PVI) applied to inter-onset intervals do seem to have something to say about speech rhythm. It might be interesting to calculate them on inter-onset intervals as well and put the results on bi-dimensional charts. This would also allow for a unified representation of the two levels of speech rhythm, allowing for an ideally quadriparted rhythm space in the chart (for instance, the syllable level on x axis and the stress level on the y axis). However, the idea is very hazardous and there are no results at the moment that can confirm the reliability of the PVI at higher levels. As put forward by Bertinetto &

Bertini (2010), in fact, variability at the second level is more difficult to capture as it might be realised in different ways in different languages.

2.5 Conclusion

In these pages I have provided a sketch of the history of research on stress-timing and syllable-timing. Many ‘sceptic’ authors have wondered why a distinction based on no empirical data (actually, often contradicted by empirical data) has had such a fortune. Barry & Andreeva write:

> *One of the intriguing and, at the same time frustrating things about the instrumental analysis of spoken-language rhythm is that it has stubbornly survived, without empirical justification it would seem, for a human life-span. In dynastic terms, we should be well into the third generation, traditionally a guarantee of the approaching demise.*
> *(2010:27)*

However, judging from the present vitality of the studies in this field, one would not say that the demise is getting closer. On the contrary, it seems that the flourishing of new methods and models (be they successful or not) is convincing more and more people to invest in the research of speech rhythm. This is clearly illustrated in the next chapter, which focuses on the studies that have used rhythm metrics.

3.

1999-2010: rhythm metrics

3.1 Introduction

In the last decade, research in speech rhythm has focused on rhythm metrics (initially called rhythm correlates), that is to say in variables derived from durational measurements of consonantal and vocalic intervals. Studies following this new approach have at least two things in common, which I shall illustrate by quoting the two initiators:

> *We depart […] from the search for isochrony.*
> *(Grabe & Low, 2002:516)*
>
> *Instead, […] we measured the duration of vocalic and consonantal intervals. A vocalic interval is located between the onset and the offset of a vowel, or of a cluster of vowels. Similarly, a consonantal interval is located between the onset and the offset of a consonant, or of a cluster of consonants.*
> *(Ramus, Nespor & Mehler, 1999:272)*

Research on rhythm has gained new vitality after the publication by Ramus, *et al.* (1999), which has been the turn of the screw in the studies of linguistic rhythm. They proposed a set of three phonetic correlates and claimed that the results managed to discriminate languages belonging to the three traditional rhythm categories (stress-timed, syllable-timed and mora-timed[30]). More or less at the same time, a similar approach had been independently developed by Low and co-workers, started by Low & Grabe (1995, quoted by Grabe & Low, 2002): they proposed another index which differs from the one suggested by Ramus *et al.* (1999) in that it takes in consideration the temporal succession of segments.

Further studies by various authors have been aimed at testing these rhythm metrics on different data and many have shown their instability in relation to some factors (particularly speech rate). Controversial results have been obtained for the same languages across different studies or in different speech styles. For these reasons, some authors have taken their distance from rhythm metrics (e.g. Barry & Russo, 2003), while others have proposed a modification of some metrics in order to reduce their sensitivity to speech rate (e.g. Dellwo & Wagner 2003). More recently, Bertinetto & Bertini (2008) have proposed a new index which is based on a different rationale from the others and which has its roots in previous studies on compensation.

In this chapter, I shall give a detailed account of the research dealing with rhythm metrics from the publications of Ramus *et al.* (1999) to the present day (2010). In 3.2 the most frequently used rhythm metrics will be explained and illustrated one by one in an effort to try and follow the linear development of research in this topic. In 3.3 I shall present the results obtained by calculating the metrics on the corpus which was introduced in chapter 2. Finally, in 3.4 I shall hint at the possibility of applying the metrics on parameters other than duration for the study of speech rhythm. An important remark concerns the terminology: in an attempt to respect the preferences of each author, I shall use the terms *rhythm*

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[30] Mora-timing is the rhythm class to which Japanese is said to belong.

correlates, *rhythm metrics* and *rhythm measures* as synonyms to refer to these variables calculated from consonantal and vocalic measurements.

3.2 An account of rhythm metrics

3.2.1 The deltas

Ramus, Nespor & Mehler (1999) proposed three phonetic correlates of rhythm relying on the list elaborated by Dauer (1983) and which contains the phonological properties which are believed to be responsible for the perception of a language as either stress-timed or as syllable-timed. As already mentioned in chapter 2, the most important of these phonological properties are: a) the presence vs. absence of vowel reduction and b) a complex vs. simple syllabic structure. The acoustic correlates they proposed are supposed to account for these properties by applying specific mathematical formulae to the durations of vocalic and consonantal intervals.

The authors derive three variables from these measurements, namely ΔV, ΔC and %V. They consider the standard deviation of vocalic intervals (ΔV) to be indicative of the presence/absence of a high degree of vowel reduction in unstressed syllables: stress-timed languages, allowing for a high degree of vowel reduction, are supposed to present a higher variability between the length of stressed, fully articulated vowels and unstressed, short, reduced vowels. Therefore, these languages were expected to result in a higher value of ΔV.

The standard deviation of consonantal intervals (ΔC)[31] was instead supposed to be indicative of syllable complexity: the higher its value, the more complex the syllabic structure. This claim relies on the observation that, as has been previously mentioned, languages with a simple syllabic structure (syllable-timed languages) presumably only allow for simple consonantal clusters, whereas languages with a complex syllabic structure (stress-timed languages) allow for both simple and complex consonantal clusters resulting in a higher value of ΔC. The standard deviation measures the degree of variability on a list of values by comparing every possible pair according to the following formula:

$$\sigma_{\mathrm{x}} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n-1}}$$

The vocalic percentage (from now on %V) is meant to be an acoustic correlate of both the complexity of the syllabic structure and the presence/absence of a high degree of vowel reduction[32]. The fact that %V will be lower for languages presenting a high degree of vowel reduction (stress-timed languages) is intuitive enough not to need further clarification, while the assumption that %V will also be lower for languages allowing for more complex syllables can be accounted for by

---

[31] Ramus et al. (1999) refer to ΔC as to “standard deviation of inter-vocalic intervals”. I have decided to use the term “standard deviation of consonantal intervals” for its straightforwardness and in order to be consistent with its abbreviated form ΔC.

[32] It has to be noted that, as Ramus et al. (1999) point out, the consonantal percentage is isometric to the vocalic percentage and thus needs not be calculated.

saying that a complex structure implies a higher consonantal percentage, that is to say a lower vocalic percentage.

The author's expectations are illustrated in figure 3.1 (taken from Barry & Russo, 2003), where the A circle represents languages traditionally classified as syllable-timed (expected to result in lower values of ΔV and ΔC), whereas the B circle represents languages traditionally classified as stress-timed (expected to result in higher values of ΔC and ΔV).

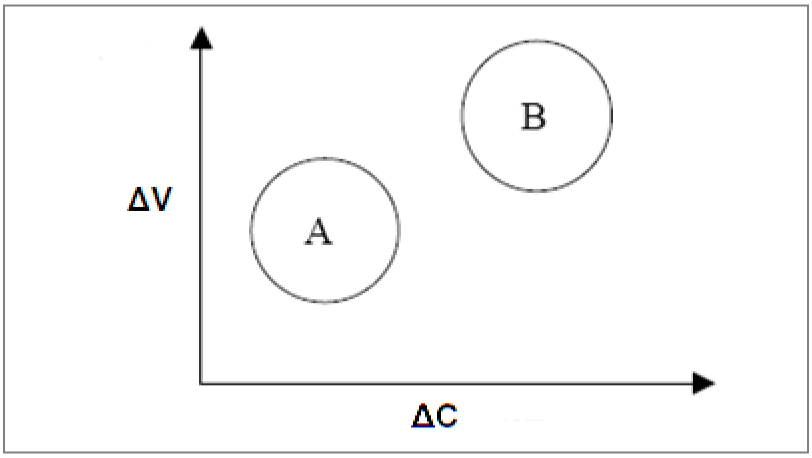

Figure 3.1. Chart showing the alleged difference in the values of ΔV and ΔC for syllable-timed (A) and stress-timed (B) languages. (From Barry & Russo, 2003).

Ramus *et al.* carried out an experiment based on eight languages (three supposedly stress-timed – English, Dutch and Polish – , four supposedly syllable-timed – Italian, French, Catalan and Spanish – and one supposedly mora-timed – Japanese) with 5 sentences uttered by four native speakers per language. The authors describe their data as follows:

> *Sentences were short news-like declarative statements, initially written in French, and loosely translated into the target language by one of the speakers. They were matched across languages for the number of syllables (from 15 to 19), and roughly matched for average duration (about 3 s).*
> *(Ramus et al., 1999:271)*

They calculated the three acoustic correlates for their data and put the results on three charts combining the values obtained for the correlates in each language. These charts seem to confirm their hypotheses: English and Dutch cluster in a group with high values of ΔC and ΔV and lower values for %V, whereas Catalan, French, Italian and Spanish cluster in a group with opposite values; Japanese occupies an isolated position, presenting even lower values of ΔC and ΔV than syllable-timed languages and a higher value of %V (thus looking more syllable-timed than languages traditionally considered as such); Polish, however, sticks with English and Dutch as for %V and ΔC, but it exhibits very low values of ΔV.

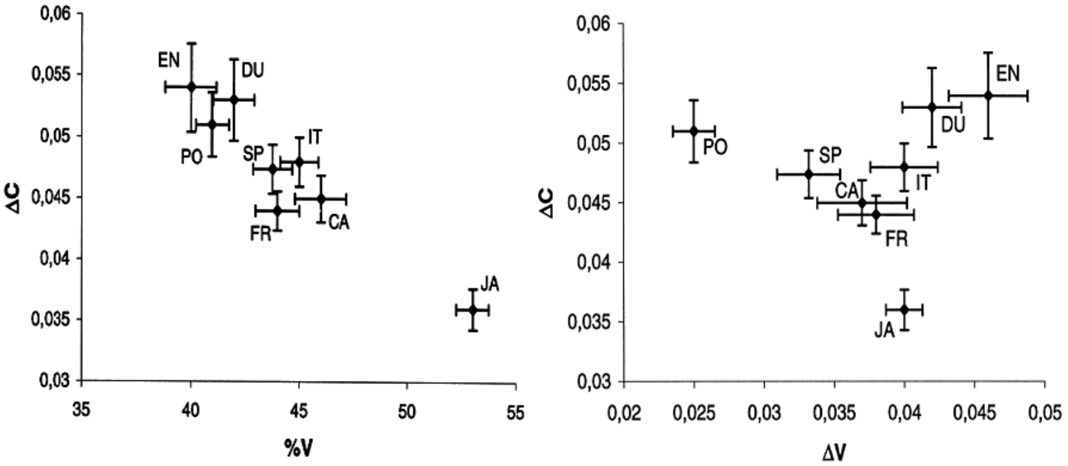

Figure 3.2. %V/ΔC and ΔC/ΔV charts, from Ramus *et al.* 1999:273.

In the second part of their article, the authors described a set of experiments about the perception of rhythm which seemed to suggest that both adults and infants can discriminate languages belonging to different rhythm classes. These experiments are dealt with in more detail in chapter 6. The authors conclude that the %V/ΔC chart (see figure 3.2) has the best discriminatory power for languages belonging to different rhythm classes, as ΔV is too heavily influenced by other factors.

Finally, I would like to stress something that seems to pass unnoticed in most modern studies on speech rhythm: *the deltas in se have nothing new*, they are simply the standard deviation, which had already been used in previous studies looking for isochrony in the ’70s and ‘80s (e.g. Roach, 1982). Rather, what is innovative is the fact that they are not applied to syllable or to inter-stress durations, but to other linguistic entities, *i.e.* to vocalic and consonantal durations. This implies that the phonetic reality corresponding to the perceptive distinction between stress-timing and syllable-timing is no longer sought in terms of syllable or foot isochrony, but by measuring acoustic correlates of the phonetic properties associated to stress-timing or syllable-timing.

3.2.2 The PVI

Low and co-workers developed a slightly different approach based on the Pairwise Variability Index (PVI), which is meant to give an indication of the variability of vocalic and consonantal intervals.

The PVI, just as the deltas, is applied to the duration of vocalic and consonantal intervals, but its advantage consists in considering the segments in their temporal succession (m is the number of intervals, while d_k is the duration of the k^{th} interval):

$$rPVI = \left[\sum_{k-1}^{m-1} |d_k - d_{k+1}| \,/\, (m-1) \right]$$

In other words, the formula of the raw PVI (rPVI) calculates the difference in duration of all pairs of successive intervals and finally calculates the mean of all differences. This is in contrast with the rationale of the standard deviation, whose formula considers all possible pairs (successive and non successive). The normalised

PVI (nPVI) is basically the same formula, but it adds a normalisation by dividing the duration of each interval by the mean duration of pairs:

$$nPVI = 100 \times \left[\sum_{k=1}^{m-1} \left| \frac{d_k - d_{k+1}}{(d_k + d_{k+1})/2} \right| / (m-1) \right]$$

The different rationales of the standard deviation and the PVI are illustrated in figure 3.3 with an example: a purely hypothetic and extremely artificial sequence of vocalic durations in decreasing tempo, in which each vowel increases by 10 ms would yield very different results of Δ and rPVI: the standard deviation formula considers the differences of all possible pairs, while the rPVI exclusively considers the differences between successive pairs (which in this case is always 10). This example is, of course, absurdly artificial, but it clearly illustrates the difference between the two formulae.

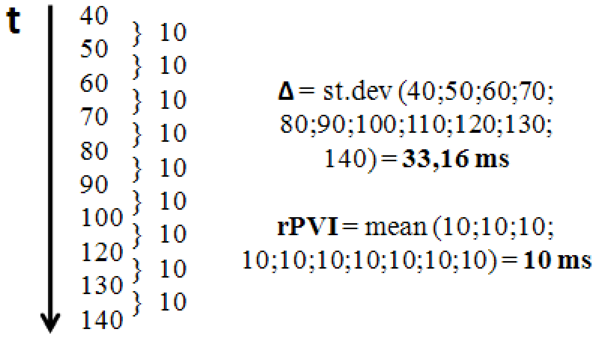

Figure 3.3. A comparison of the Δ and the rPVI.

Work on the PVI started with Low & Grabe (1995, quoted by Grabe & Low, 2002) and Low, Grabe & Nolan (2000, quoted by Grabe & Low, 2002), who applied the nPVI to vocalic measures and found a higher variability for British English (supposedly stressed-timed) than for Singapore English (supposedly syllable-timed). They also claimed that the nPVI of vocalic interval is a better indication of rhythmicity than ΔC and ΔV. These ideas were further developed in Grabe & Low (2002), an article which has now become the reference for all researchers using the PVI for the study of linguistic rhythm.

Grabe & Low (2002) conducted an experiment in order to test the deltas against the PVI. They included all the languages studies by Ramus *et al.* (1999) apart from Italian – thus Catalan, Dutch, British English, French, Japanese, Polish, Spanish – and added many more – Estonian, German, Greek, Luxembourgish, Malay, Mandarin Chinese, Rumanian, Singapore English, Tamil, Thai and Welsh. They ended up with four stress-timed languages (English, German, Dutch and Thai), four syllable-timed languages (French, Spanish, Tamil and Singapore English), one mora-timed language (Japanese) and 9 mixed or uncategorised languages. Instead of “news-like declarative statements”, they used translations of the *North Wind and the Sun* and only one speaker per language.

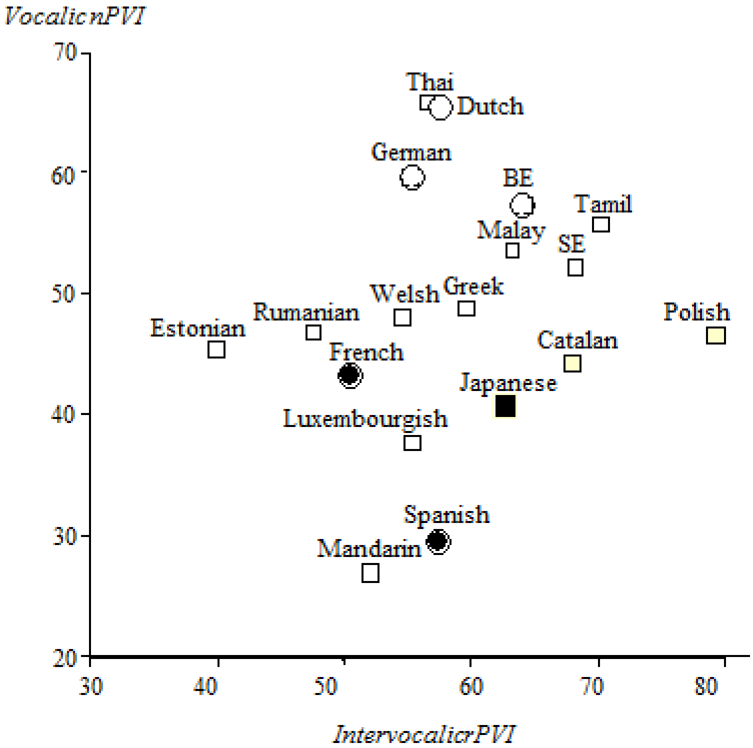

Figure 3.4. Vocalic nPVI/Consonantal rPVI chart, taken from Grabe & Low (2002:7/16).

Their results of the PVIs (see figure 3.4) confirmed expectations fairly well, with stress-timed languages exhibiting high values of vocalic nPVI. Consonantal rPVI, instead, seemed to have a lower discriminatory power, with comparable values for both stress-timed and syllable-timed languages. The chart seems to work well also for mixed languages such as Polish, whose high rPVI value reflects its complex syllable structure (with long consonant clusters, up to 5 segments) and whose low nPVI value reflects the fact that it does not have phonological vowel reduction (these findings are similar to the ones obtained by Ramus *et al.* 1999).

The authors also calculated %V and ΔC for the same data in order to compare results with the PVI. They found that the disposition of languages was in some cases similar, but then some languages moved to a different area of the chart, less in compliance with expectations. The authors explained this by claiming that the three correlates proposed by Ramus *et al.* (1999) do not work when some variables come to play a role, especially speech rate.

Grabe & Low's conclusion is that the disposition of languages in rPVI/nPVI chart proves that "a categorical distinction between stress-timing and syllable-timing cannot be defended" (2002:525) as languages tend to scatter within the chart and many of them occupy intermediate positions even with some overlap between the two traditional classes.

3.2.3 Considerations on speech rate and the varcos

Ramus (2002) is a response to Grabe & Low (2002) in which the author comments on their results and calculates the PVIs on his own corpus. He finds that the results given by the PVIs are similar to those given by the deltas (though nPVI actually provides a clearer differentiation than ΔV) and stresses the fact that, since Grabe &

Low used just one speaker per language, their results could reflect speaker's idiosyncrasies. Ramus advocates for a higher number of speakers being studied and admits that the validity of ΔC and ΔV as correlates of rhythm can easily be influenced by speech rate. He claims:

> *It is essential to have a variety of speakers for each language;*
> *It is essential to control for speech rate, either by constraining the corpus, or by using a normalisation procedure;*
> *The usefulness of variables such as ΔV and ΔC may well be limited to corpora where speech rate is strictly controlled.*
> *(Ramus, 2002:117)*

He then proceeds to a survey of several problems which arise when attempting to control speech rate and, in conclusion, states: "Salvation lies in larger data sets. [...] Automatic speech processing carries hopes of effortless constitution of unlimited corpora, as well as the spectres of imprecision and meaninglessness." (Ramus, 2002:119).

Barry & Russo (2003) calculated both the deltas and the PVIs on semi-spontaneous dialogues from the AVIP corpus for 13 Italian speakers (6 from Naples and 7 from Pisa) and from the Kiel corpus for 4 speakers (the dialogues are longer than in the AVIP). The results they obtained seem to confirm neither the validity of ΔV and ΔC, nor that of the PVIs as correlates of rhythm since their values, contrary to expectations, are on average higher for speakers from Naples and Pisa than for German speakers. The authors argue that speech rate heavily influences the values of these correlates: they presented a chart suggesting that an increase in speech rate takes the languages towards a position associated with syllable-timing according to the methods proposed by Ramus *et al.* (1999). Russo & Barry (2008) include further considerations from the observation of the same data. In particular, the authors notice that %V is "by far the most tempo-resistant and the most language-distinguishing measure" while the "[...] Ramus delta values and the Grabe and Low PVI values are to a considerable part a function of articulation rate" (Russo & Barry, 2008:4/4).

Dellwo & Wagner (2003) conducted an experiment on English, French and German in order to examine the influence of speech rate on %V and ΔC. Their results reflect the language groups found by Ramus *et al.* (1999). Speech rate is found to affect the values of the correlates (above all ΔC), but its influence does not seem to be strong enough to prevent the clustering of stress-timed and syllable-timed languages into separate areas. In order to correct the sensitivity shown by ΔC, the authors propose to divide this variable by the mean value of consonantal intervals, thus obtaining varcoΔC[33]:

$$\text{varco}\Delta C = \Delta C \,/\, \text{meanC} * 100$$

This idea follows the same rationale as the normalisation found in the formula of the nPVI, where interval durations are divided by the mean duration. VarcoΔC is then tested in Dellwo (2006), where the author calculates this parameter on data drawn from the BonnTempo corpus[34]. The results can be seen in figures 3.5.

---

[33] Varco stands for variation coefficient.

[34] The Bonntempo corpus is a corpus devised by the V. Dellwo for the combined study of peech rhythm and rate (see Dellwo et al., 2004). The data presented in Dellwo (2006) includes tha same

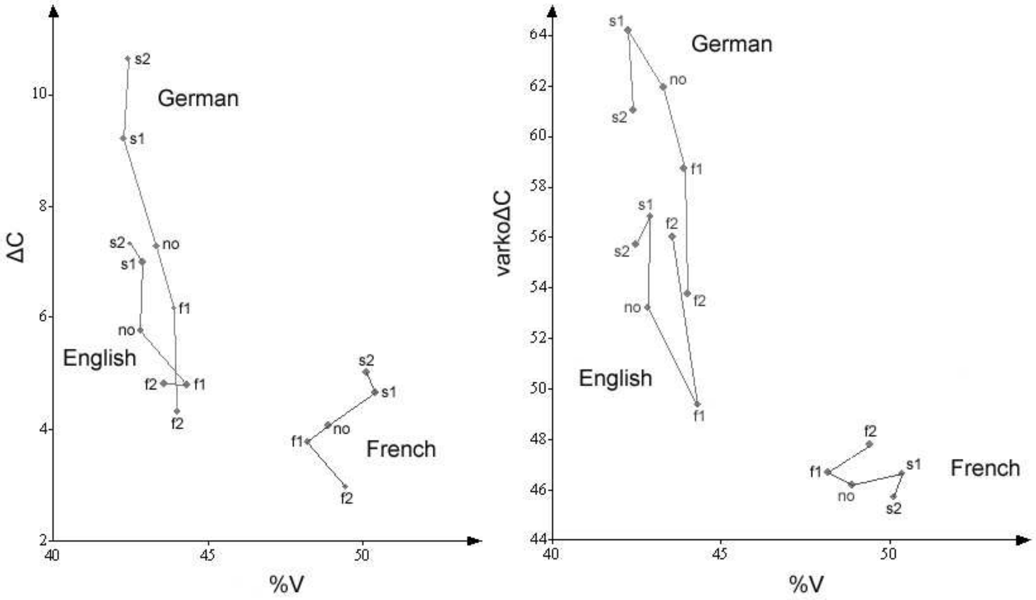

Figure 3.5. ΔC/%V chart, taken from Dellwo (2006).

The figures show that the results are encouraging, as

> *general cluster patterns of stress-timed and syllable-timed languages are clearer with varcoΔC than with ΔC since all F* [French] *versions lie well below E* [English] *and G* [German] *on the varcoΔC scale which is not the case for ΔC* [...]. *In other words: the use of a variation coefficient for ΔC enhances differenciability of rhythm classes for the data presented.*
> *(Dellwo, 2006:5/8)*

More recently, Benton (2010) proposes a slight modification of the normalisation applied by VarcoΔC and by the nPVI. As for VarcoΔC, the author proposes to divide ΔC for the local mean of consonantal durations, instead of the overall mean. However, this approach is not entirely new and a similar remark had already been put foward by Mairano & Romano (2007a and b) referring to the deltas: the two authors calculated the deltas both “globally” (the A method) and “locally” (the B method)[35]. As for the modification of the nPVI, the author suggests that the formula should not only normalise an interval in relation to the preceding interval, rather the “Reverse-normalized PVI would then attempt to normalize the utterance over all past durations from that particular utterance”. The formula he proposes is the following:

$$Rev\_nPVI_i = 100 \times \left[\sum_{k=1}^{m-1} \frac{|d_k - d_{k+1}|}{\left(\sum_{i=0}^{n} d_{k-i} + d_{k+1} \right) /(2+i)} /(m-1) \right]$$

---

data used in Dellwo & Wagner (2003) plus more (in total, 12 German speakers, 7 English speakers and 7 French speakers).

[35] The two methods are also available in the *Correlatore* software, see chapter 4 and Mairano & Romano (2009).

3.2.4 Deltas and varcos versus the PVI, the debate goes on

The studies of Ramus, Nespor & Mehler (1999) and Grabe & Low (2002) have given new impulse to the research in the field of rhythm and several authors have attempted to enlarge the perspectives with the aim of including as many different variables as possible. I shall now report on some of the numerous authors who set out to test the validity of these correlates. However, I shall concentrate here on authors who have dealt with general problems of the rhythm categorisation of languages or who studied characteristics of a specific language. Those who focused on the issue of variation and/or variability in speech rhythm using the rhythm metrics are reported in chapter 5[36].

Schmid (2001) conducted an experiment on English, German, Swiss German (stress-timed languages), Italian, French, Spanish (syllable-timed languages) and calculated the values of the three parameters proposed by Ramus *et al.* (1999). His results seemed to confirm the validity of ΔC and ΔV as correlates of rhythm, but not of %V, which was surprisingly high for English and very low for French. He concluded that the results may have been influenced by the fact that only a small corpus was used and he puts forward the need of wider studies including more speakers and more data.

Galves *et al.* (2002) drew on this quest (also stressed by Ramus, 2002, and by most authors who worked on rhythm metrics). They argue that hand labelling is very time-consuming and, furthermore, brings about several inconsistencies in relation to, for example, phonological choices: most emblematically, the decision on whether or not a certain vocalic segment is present has huge implications as it affects greatly the value of ΔC (because the surrouning consonants will be considered as one long or two short segments according to the choice). On the basis of the perceptive tests carried by Mehler *et al.* (1996), in which new-borns are found to discriminate between languages belonging to rhythmic classes with a signal filtered at 400Hz, Galves *et al.* argue that

> *at this level it is hard to distinguish nasals from vowels and glides from consonants. This strongly suggests that the discrimination of rhythm classes by babies relies not on fine-grained distinctions between vowels and consonants, but on a coarse-grained perception of sonority in opposition to obstruency.*
> *Therefore a natural conjecture is that the identification of rhythm classes must be possible using a rough measure of sonority.*
> *(Galves et al., 2002:2/4)*

The authors manage to capture the variability of voiced and devoiced intervals by applying some autosegmentation procedures on the same corpus used by Ramus *et al.* (1999). Results mainly reflect those obtained on vocalic and consonantal intervals.

A similar idea was applied by Dellwo, Fourcin & Abberton (2007) who calculated VarcoΔUnvoiced and %Voiced on English, German, French and Italian: results suggest that it is possible to discriminate between rhythm classes by using

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[36] The distinction between the two approach is of course not always neat, as some authors deal with both. Still, I have tried to draw a line in order to shape the two chapters along these two different themes.

these measures as the classification is very similar to the one obtained with ΔC and %V.

Lijan (2004) computed the nPVI on vocalic durations (separately for full and reduced vowels) of American English (considered as stress-timed) and Taiwan English (supposedly syllable-timed). The results confirm author's expectations as they show higher nPVI values for American English than for Taiwan English both for full and reduced vowels[37].

Rouas & Farinas (2004) conducted an experiment on English, German, Mandarin Chinese (stress-timed languages), French, Italian, Spanish (syllable-timed languages) and Japanese. They included a large number of speakers by using an autosegmentation procedure. They calculated both the three correlates proposed by Ramus *et al.* (1999) and those proposed by Grabe & Low (2002) and concluded that the results were not thoroughly satisfactory. So, they proposed new correlates based on the automatic segmentation of the speech signal into "pseudo-syllabes"[38]. For each "pseudo-syllabe", the authors calculated: a) the total duration of the consonantal segments, b) the total duration of the vocalic segment and c) the number of consonantal segments. Their correlates are shown in charts where stress-timed and syllable-timed languages seem to form two fairly separated groups (though Italian tends to stick in the neighbourhood of stress-timed languages). Nevertheless, no other author seems to have taken their hint and their parameters have not been tested by anyone else.

Dankovicova and Dellwo (2007) added Czech to the data already investigated by Dellwo (2006) expecting that it should fall half-way between the two rhythm classes because (a) it does not have phonological vowel reduction but does have vowel length opposition (b) its syllable structure is fairly complex, but not as complex as in stress-timed languages. The authors, however, found that only %V managed to reflect this, while both VarcoΔC and consonantal rPVI classified Czech as stress-timed, while vocalic nPVI classified it as syllable-timed.

Benton *et al.* (2007) applied the deltas and the PVIs to large corpora of non-laboratory speech of American English and Mandarin Chinese. They used news broadcasts with more than 50 speakers per language totalling more than 100 minutes of speech that was analysed with the help of automatic natural language processing and other scripts. Mean results for both the deltas and the PVIs confirm the classification of Mandarin Chinese as syllable-timed and of American English as stress-timed, though values for single speakers are reported to vary greatly.

White & Mattys (2007) tested the various correlates on first and second language speakers of English, Dutch, Spanish and French. In particular, they tested native English speakers, native Dutch speakers, native French speakers, native

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[37] I find these results slightly controversial: the values of vocalic nPVI are meant to be higher in stress-timed languages because of the remarkable difference in these languages between, on the one hand, fully-articulated vowels and, on the other hand, reduced vowels. Obviously, calculating the nPVI separately for fully articulated and reduced vowels fails to capture this difference and one may well wonder what the rationale behind this choice is and on what grounds this particular application of the nPVI was expected to yield higher values in stress-timed than in syllable-timed languages.

[38] Their automatic system is said to recognise vocalic intervals (V) and non-vocalic intervals (C). The segments are consequently grouped into "pseudo-syllabes" according to the scheme C…CV. This is to say that any sequence of C segment will be put together with the following V segment in order to form a "pseudo-syllabe". In other words, the duration of a "pseudo-syllable" coincides with the inter-onset distance (the distance between two successive vocalic onsets).

Spanish speakers, non-native English speakers (Spanish natives), non-native English speakers (Dutch natives), non-native Dutch speakers (English natives) and non-native Spanish speakers (English natives). As expected, the metrics classified Dutch speaker of English and English speakers of Dutch in the stress-timed area (both Dutch and English are stress-timed languages), while Spanish speakers of English and English speakers of Spanish resulted in an intermediate area, a fact that presumably reflects a certain degree of adaptation on the part of L2 speakers to the rhythm of the target language. According to the two authors, VarcoV/%V seems to be the combination that best reflects their hypotheses.

Tortel & Hirst (2008) used the PVI in order to discriminate the rhythmical properties of French learners of English. They carried out an experiment in which three groups of French learners (FR1 non specialist English speakers, FR2 first-year university students of English, FR3 fourth and fifth-year university students of English) and one group of British English native speakers had to listen to some sentences pronounced by a "model" and then repeat it as closely as possible. The vocalic nPVI is found to better reflect the language competence of speakers than the consonantal rPVI. In effect the nPVI values increase from FR1 through FR2 and FR3 and up to BR, whereas the rPVI values are less consistent. Tortel & Hirst (2010) add the deltas and the varcos (which they questionably call cv – standing for coefficient of variation), finding that these measures allow three types of discrimination: (a) learners vs. natives (b) FR1 vs. FR2 (c) a graduation from FR1 to BR (which they call GB in their study in their study in 2010).

Loukina *et al.* (2009) calculated a plethora of rhythm measures (15 different indices, each computed in 3 different ways[39], which gives a total of 45) on voiced and devoiced intervals retrieved by a procedure of automatic segmentation. The authors then built classifiers[40] and tested how often they could correctly predict the language, based on a combination of one or more rhythm metrics. Results show that some rhythm measures calculated on automatic segmentation are better than others at separating languages, but on the whole "there exists substantial variation within languages which makes it impossible to reliably separate languages based on the rhythm of a single paragraph". The authors argue that such results reflect human identification of delexicalised speech. They also claim that rhythm seems to be a two or three-dimensional phenomenon as classifiers based on more than 2 rhythm measures do not significantly improve the success rate.

More authors who used the metrics are listed in chapter 5 as their attention was concentrated in showing rhythm variation and variability across different dialectal or regional varieties, or across different speech rates.

3.2.5 Bertinetto & Bertini (2008): the CCI.

A new proposal, the Compensation and Control Index (CCI) was put forward by Bertinetto & Bertini (2008). Its formula is inspired by the rPVI and, like the other

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[39] (a) calculating them for each sentence and then averaging partial results (cf. the B method in Mairano & Romano, 2009);
(b) calculating them for each sentence leaving out segments preceding pauses (as they are often lengthened) and then averaging partial results;
(c) calculating them on the entire text (cf. the A method in Mairano & Romano, 2009).

[40] A classifier is defined by the authors as "an algorhythm that will optimally predict which language was most likely to have produced the observed RMs [rhythm measures]" (Loukina et al. 2009:1932).

metrics, is applied to vocalic and consonantal measures (though with important differences), but it has a different rationale and draws on previous works by Fowler and colleagues (1977 and following) on compensation (see also Farnetani & Kori, 1986 and following). Details about these works are given in chapter 1, I shall therefore only briefly resume the conclusions: data on compensation did not confirm the hypothesis that stress-timed languages should exhibit more inter-syllabic compensation (to equalise feet durations) and syllable-timed languages more intra-syllabic compensation (to equalise syllable durations); instead, stress-timed languages were found to exhibit both intra- and inter-syllabic compensation. In the light of these observations, Bertinetto (1989) revisited the traditional dichotomy of stress-timing vs. syllable-timing in terms of control vs. compensation (although the terms were drawn from Hoeqvist, 1983): controlling languages (corresponding to syllable-timed languages) are supposed to show low levels of compensation at all levels, whereas compensating languages are supposed to show higher levels of compensation at all levels (intra and inter-syllabic). As stated by Bertinetto & Bertini, “[t]he CC view aims at describing the intra-syllabic behaviour, which in turn affects (or is possibly affected by) the overarching accentual alternation” (2008:1/4) and will possibly integrate in the future a model for this second level (like the one proposed by O’Dell and Nieminen, 1999).

In order to account for the intra-syllabic behaviour, then, the CCI needs to consider the segments composing each vocalic and consonantal interval: its formula is in fact a modification of the rPVI that divides interval durations by the number of segments[41] that compose it:

$$CCI = \frac{100}{m-1} \sum_{k-1}^{m-1} \left| \frac{d_k}{n_k} - \frac{d_{k+1}}{n_{k+1}} \right|$$

The authors’ prediction was that controlling languages should be located along the bisecting line as vocalic and consonantal fluctuations should tend to be more or less the same in these languages. Instead, compensating languages should tend to be placed below the bisecting line as vocalic fluctuations should be higher in these languages than consonantal fluctuations due to the difference between fully articulated stressed vowels and reduced unstressed vowels. The two authors expected no language to be collocated in the zone far above the bisecting line as this would imply a higher level of consonantal compensation than of vocalic compensation. They provided the results of the CCI computed on dialogues by 10 Italian speakers and compared them with the values obtained with other metrics (%V, deltas and PVIs): results for Italian seemed to reflect expectations for controlling languages, with the ten speakers clustering along the bisecting line (see figure 3.6). Then, the authors divided speakers into three tempo groups and, in line with expectations, they found that with decreasing speech rate, consonants and vowels are compressed more or less at the same level up to a threshold (which is sooner reached for consonants than for vowels).

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[41] As noted by the authors, the idea of introducing the number of segments composing each interval is not entirely new, as it had already been experimented by Rouas & Farinas (2004), who used the number of consonants composing a C interval as one of many indices.

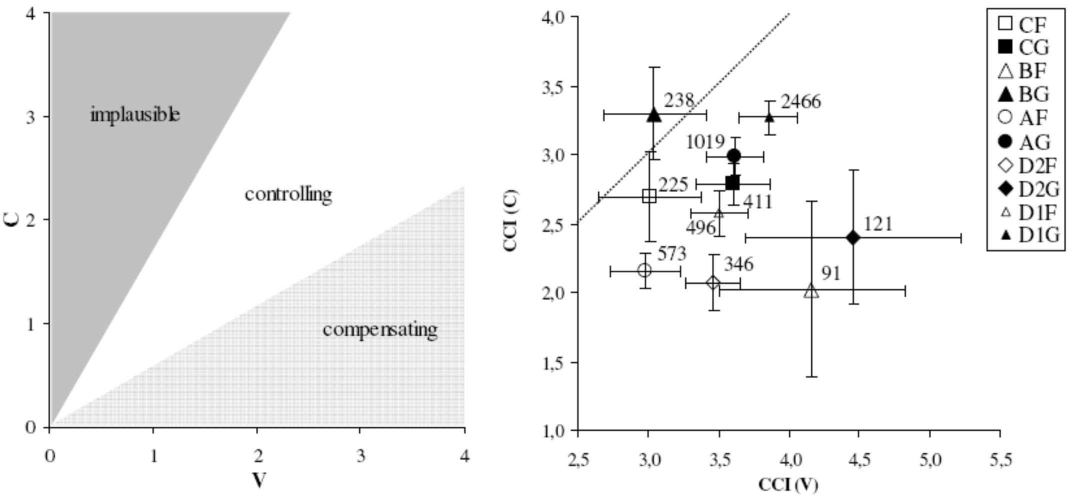

Figure 3.6. Results of the CCI for semi-spontaneous productions of 10 Italian speakers (taken from Bertinetto & Bertini, 2008).

Bertini & Bertinetto (2009) gave detailed information on how they computed the CCI: as has been said, each interval has to be divided by the number of phonological segments composing it, but this has the drawback of creating ambiguities as for the phonological interpretation of some segments. For example, the two authors considered both on- and off-glides as consonantal: while considering on-glides as consonantal is a common feature of most other studies on rhythm metrics[42], the fact of considering off-glides as consonants is at odds with most other authors' choices[43]. Italian geminated consonants were considered as intervals composed by 2 phonological segments and it was prescribed that phonologically long vowels (in languages like Finnish) should also be considered as double intervals. Vocalic intervals were mostly composed of one segment, apart from cases of synaloepha, which were treated as double intervals in contrast to cases if hiatus, which were assigned to two different nuclei. Furthermore, the two authors decided on the following criteria to select utterances for inclusion in the study:

> *I) sono stati scelti enunciati privi di esitazioni, pause, forme di assenso, esclamazioni, false partenze, fenomeni vocali non verbali, sequenze inintelligibili, routines discorsive (come le frasi fatte ricorrenti);*
> *II) sono state ulteriormente eliminate le parti terminali di enunciato di tipo asseverativo (ad esempio: ..., no?), così come quelle introduttive (ad esempio: cioè,...);*
> *III) sono state selezionate sequenze che, in trascrizione ortografica, avessero almeno 9 sillabe (> 9 sillabe) e, foneticamente, almeno 8 sillabe (> 8 sillabe). La differenza è motivata dal fatto che non tutte le sillabe potenziali si realizzano effettivamente nel parlato, a causa*

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[42] Actually, Grabe & Low (2002) considered even on-glides as vocalic when it was not possible to distinguish them on the spectrogram: "[w]e excluded initial glides from vocalic portions if their presence was indicated by clearly observable changes in formant structure or in the amplitude of the signal. Otherwise, glides were included in the vocalic portion." (Grabe & Low 2002:5)

[43] The estimate applies to those authors who have declared the criteria followed in the segmentation.

> *di possibili fenomeni di fusione tra vocali adiacenti, riduzione di iato, ipoarticolazione etc.*
> *(Bertini & Bertinetto, 2009:4/17)*

The two authors also state that they "discarded the final portion of each utterance, from the last stressed syllable (inclusive) onward. This portion has an entirely different rhythmic behavior, that should best be analyzed on its own" (2008:2/4).

The CCI is youger than the other rhythm metrics and, for this reason, it has not yet been applied to many data; so far, apart of course from its authors, it has only been used by Mairano & Romano (2008 and following) as far as I am aware. Results of the CCI for various languages are also reported below.

3.3 Applying the metrics to the corpus

3.3.1 Reasons for setting out to compute rhythm measures

The brief description sketched above has shown that many authors have tested the metrics in a fair amount of conditions, checking their (in)stability over different speech styles and speech rates. In most cases, while the hypothesis of two (or three if we include mora-timing) clear-cut rhythm classes does not seem to be plausible, rhythm measures do seem to yield a more or less approximate scalar characterisation of the rhythm typology of languages. However, with a few exceptions, most studies on the field of rhythm metrics have included limited data sets (which is understandable as the computing of these measures is a long a time-consuming procedure). Furthermore, data from different studies are often not directly comparable because of different choices in the segmentation or in the interpretation of some specific phonological segments. For example, as has been stressed by Mairano & Romano (2007a and b) and Loukina *et al.* (2009), there does not seem to be a general agreement as to the procedure with which rhythm metrics should be calculated: some authors compute them on all vocalic and consonantal (or voiced and unvoiced) interval durations, while others exclude the last segments, and others compute the measures separately for each sentence or inter-pausal unit finally averaging results.

As a consequence, what was claimed nearly 10 years ago (e.g. Schmid, 2001, and Ramus, 2002) is still relevant: these studies have proven the necessity of enlarging the perspectives and conducting experiments on a wider range of data including more languages, more speakers, more sentences per speaker, different registers and speech styles. In particular, the number of languages for which correlates have been calculated is still fairly small, the wider spectrum probably still being the one presented by Grabe & Low (2002)[44].

So, around 2007 I set out to gradually gather data, which has already been described in chapter 2. At first, the corpus was very limited, but the number of languages and speakers grew gradually and currently totals 21 national languages and 61 speakers. For these data, the most commonly used rhythm metrics were calculated with *Correlatore* 2.2 (see chapter 4) in two different ways, namely globally (the A method) and locally (the B method). Loukina & al. (2009) have reported that such different methods do not yield significant differences, yet at the

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[44] Alhtough it was corroborated by only one speaker per language.

beginning of my research in this field (cf. Mairano & Romano, 2007a and b), I found that the B method provided a slightly better classification of rhythm classes. The results are presented below.

3.3.2 The data

I shall now introduce the data, which are the same throughout all tests on rhythm presented in this chapter. I have been gathering recordings of the narrative *The North Wind and the Sun* by different speakers in different languages for some years as a constantly growing corpus. At the time of writing, the corpus was composed of 61 speakers of 21 national languages (in alphabetical order: Arabic, Chinese, Czech, Danish, Dutch, English, Estonian, Finnish, French, German, Greek, Icelandic, Italian, Japanese, Polish, Portuguese, Romanian, Russian, Spanish, Swedish and Turkish).

The corpus is thus homogeneous as for text type (a narrative), speech style (read speech), text length (translations of the same text, ranging from 23.30s to 49.78s and averaging at 32.50s ±5.29s) and number of segments uttered by speakers; speech rate, unfortunately, varies a little according to speakers, ranging from 4.13 sylls/s to 6.84 syll/s and averaging at 5.84 syll/s (±0.72). All recordings involved native speakers of the languages analysed[45].

The main drawbacks of the corpus at its present state are (a) its strong bias towards the Indo-European family and (b) the under-representation of some languages in comparison to others, with only 1 speaker for Czech, Danish, Estonian, Greek, Japanese, Polish, Swedish and Turkish as opposed to the 15 speakers of Italian. Furthermore, the samples have different provenances as some were recorded in a sound-proof booth at LFSAG (*Laboratorio di Fonetica Sperimentale 'Arturo Genre'*, University of Turin), whereas a few others were recorded during fieldwork and others were taken from the *Illustrations of the International Phonetic Association* either published in the *Handbook of the IPA* (1999) or in various issues of the *Journal of the IPA*. Still, the corpus is fairly wide and certainly includes a higher number of languages than most other comparative studies on rhythm. A list of all samples (and their source) in alphabetical order by national language follows.

- Arabic - 2 speakers: 1 male speaker of Standard Arabic taken from Thelwall & Akram Sa'adeddin (1999) and 1 female speaker of Lebanese Arabic recorded at LFSAG (*CELI*, 2009).
- Chinese - 2 speakers: 1 male speaker of Mandarin Chinese from the province of Chao Yang and 1 female speaker of Mandarin Chinese from Hongkong. Both samples were recorded at LFSAG (S. Pittoni, 2008).
- Czech - 1 speaker: a male speaker of standard Czech recorded at LFSAG (D. Brdička, 2007).
- Danish - 1 speaker: a female speaker of standard Danish taken from Grønnum (1999).
- Dutch - 1 speaker: a male speaker of standard Dutch, taken from Gussenhoven (1999).

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[45] With the possible exception of the Indian English speaker: even though this speaker might have learnt English in the family and have been educated in English, there are clear auditive cues that suggest that he might be assimilated to a speaker of English as an L2. At any rate, the issue seems to be questionable.

- English - 5 speakers: a female RP speaker (taken from Roach, 2004), a female GA speaker taken from Ladefoged (1999), a male speaker of Australian English (recorded at LFSAG, *CELI* 2009), a female speaker of New Zealand English (taken from Bauer *et al.*, 2007) and a male speaker of Indian English (recorded at LFSAG).
- Estonian - 1 speaker: a female speaker of standard Estonian, taken from Asu & Teras (2009).
- Finnish - 2 speakers: 2 female speakers of standard Finnish recorded at LFSAG (L. Capovilla, 2007).
- French - 2 speakers: 1 female speaker of standard French (tajen from Fougeron & Smith, 1999) and 1 female speaker of Canadian French recorded by P.L. Salza (2006), *Loquendo*, (who kindly granted me permission to use the recording for research purposes).
- German - 2 speakers: 2 female speakers of Standard German recorded at LFSAG (L. Capovilla, 2007).
- Greek - 1 speaker: 1 female speaker of standard Greek taken from Arvaniti (1999).
- Icelandic - 10 speakers: 8 speakers (7 M and 1 F) of Icelandic recorded in 2007 by me in Reykjavik during fieldwork and 2 (1 M and 1 F) more speakers recorded at LFSAG.
- Italian - 15 speakers: 4 speakers of supposedly Standard Italian: Italian01 and Italian04 are males and were recorded at LFSAG in 2009 respectively by A. Romano and L. Calabrò, Italian02 is a male speaker taken from Canepari (2004), Italian05 is a female speaker taken from Rogers & D’Arcangeli (2004); one female speaker of Rome regional Italian (Italian03, taken from Costamagna, 2000), 4 (2 M and 2 F) speakers of Piedmontese regional Italian (Italian06, Italian07, Italian08, Italian15, all from Turin and recorded at LFSAG), 1 female speaker of Sicilian regional Italian (Italian09 from Mazara del Vallo, recorded at LFSAG), 1 female speaker of Northern Apulias regional Italian (Italian10 from Bitonto recorded at LFSAG), one male speaker of Calabrian regional Italian (Italian11, from Vazzano, recorded at LFSAG), 1 female speaker of Sardinian regional Italian (Italian12, from Nuragus, recorded at LFSAG), 1 female speaker of Neapolitan regional Italian (Italian 13, from Tramonti, recorded at LFSAG) and 1 female speaker of Venetian regional Italian (Italian14, from Treviso, recorded at LFSAG). Note that all 15 recordings are samples of standard or regional varieties, no dialectal varieties of Italy were included in the corpus[46].
- Japanese - 1 speaker: 1 female speaker of standard Japanese recorded at LFSAG.
- Polish - 1 speaker: 1 female speaker of Standard Polish taken from Jassem (2003).
- Portuguese - 3 speakers: 1 female speaker of Standard European Portuguese taken from Cruz-Ferreira (1999), 2 female speakers of Brazilian Portuguese (1 from Manaus recorded at LFSAG and 1 from Sao Paulo taken from Barbosa & Albano, 2004).

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[46] I did record 6 samples of Piedmontese, but they have been kept separated from the rest of the corpus and are presented further on (see chapter 5).

- Romanian - 6 speakers: 1 female speaker from Bucharest, 1 female speaker from Brasov, 1 male speaker from Bucovina, 1 male speaker from Moldavia, 1 male speaker from Muntenia and 1 male speaker from Oltenia. The first 3 speakers were recorded at LFSAG, while the last thee speakers were recorded, respectively, by H. Bendea, D. Jitaru and G. Stan during fieldwork.
- Russian - 2 speakers: 1 male and 1 female speaker both recorded at LFSAG (Romano, 2010).
- Spanish - 5 speakers: 1 female speaker of Castilian Spanish taken from Martinéz Celdrán *et al.* (2003), 1 female speaker from Granada (Spain, recorded by I. Giacoletto), 1 female speaker from Bogotà, 1 male speaker from Caracas and 1 male speaker from Lima (all three recorded by S. Amorosini).
- Swedish - 1 speaker: 1 female speaker of Standard Swedish taken from IPA (1999).
- Turkish - 1 speaker: 1 speaker of standard Turkish recorded at LFSAG.

3.3.3 Labelling the data

Initially, all samples were analysed with *Praat* and the durations of each vowel and consonant were saved in a spreadsheet for analysis. This procedure was very time-consuming and so, when *Correlatore* became available (see chapter 4), all data were labelled as CV (consonantal and vocalic intervals) following the conventions outlined in chapter 4 (or, in very few cases, as SAMPA transcriptions) and were saved as *TextGrids*[47]. However, the transition was long as all old recordings had to be re-labelled and sometimes the results were slightly different[48]. This is also the reason why the values of the correlates presented here are not exactly the same as in old publications by Mairano & Romano (e.g. 2007).

As a rule, all samples were labelled manually by two trained phoneticians (PM and AR) in order to minimise fluctuations in the results due to the author's choices or bias. However, this does not apply to the 10 Icelandic speakers and to 8 of the 15 Italian speakers (who were labelled exclusively by PM) and to the Danish, Swedish, Turkish and the 2 Chinese speakers (who were labelled exclusively by AR). Unless otherwise specified, the results presented in the charts of this thesis represent the average of the results obtained by each phonetician and errors bars illustrate (unless otherwise specified) the standard error of the mean[49] of the values obtained by PM and AR.

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[47] *TextGrids* are *Praat* annotation files in text format.

[48] The 10 Icelandic speakers still have not been relabelled. Results presented for these samples are still the ones obtained with a spreadsheet. Yet, they have been inserted in Correlatore's reports using an extra functionality and this is why some metrics are missing in the report (such as vocalic rPVI and consonantal nPVI, which are usually not used and which therefore were not calculated).

[49] Please note that error bars in this thesis differ sensibly from errors bars published in preceding works by Mairano & Romano and Romano & Mairano. This is because in previous publications, we did not use the standard error of the mean, but the standard deviation (which is also used here in some cases but for other purposes, see chapter 5). In fact, the standard error of the mean is the standard deviation divided by the square root of the number of samples (in this case 2 - PM and AR). The standard error of an estimation is defined as the standard deviation of the sampling distribution associated with the estimation method. I am aware that the standard error (as well as the standard deviation) tends to underestimate the real population variability, still it was impossible to have the data labelled by more than 2 phoneticians for evident practical reasons. At any rate,

Of course, both phoneticians were not familiar with all the 21 languages taken in consideration. In particular PM is fluent in Italian (native speaker), English, French, German and has some knowledge of Icelandic, Spanish and Portuguese, while AR is fluent in Italian (native speaker), English, French and has some knowledge of Greek, Spanish and Portuguese. For the languages which both PM and AR are familiar with (Italian, English, French, Spanish, Portuguese), the segmentation was carried out by the two phoneticians in a completely independent way and relying on no external resource. For the languages which neither was familiar with, both authors made use of the phonetic transcriptions provided by the authors of the illustrations of the IPA (either in IPA, 1999, or in different contributions in the *Journal of the International Phonetic Association*, see the bibliography) if available. If no such transcription was available and for languages which either phonetician was familiar with, PM or AR set out to provide a transcription of the narrative for the language in question with the help of handbooks or other phonetics manuals: this transcription was then used by both phoneticians for help in the segmentation and in order to fulfill the conditions set by the *CCI*, which requires the specification of the number of phonological segments for each vocalic or consonantal interval (see chapter 3 and 4). More details about the work done by the two phoneticians will be given in chapter 5.

3.3.4 The segmentation

As has been said, audio data needs to be segmented into consonantal and vocalic intervals for a computation of rhythm metrics. As has already been stated in chapter 2, the segmentation of data has been carried out manually. Automatic segmentation has not been taken in consideration because its results are sometimes questionable[50] and I preferred to have control over decisions on segments' classification. The drawbacks noted by Galves *et al.* (2002) and Loukina *et al.* (2009) concerning the intrinsic subjectivity of manual segmentation have been mitigated by a double segmentation and labelling, carried out independently by two trained phoneticians, PM and AR, using *Praat*. The segmentation was then saved in text files containing interval durations called *TextGrids* and analysed with *Correlatore* (see chapter 4).

As already mentioned, work by PM and AR has been carried out completely independently for languages which both authors were familiar with (Italian, English, French, Spanish, Portuguese) and semi-independently for languages which neither or only either of the two authors was familiar with (see chapter 2 for further clarifications). The variability of rhythm metrics according to the measurements by each phonetician will be dealt with in more detail in chapter 5.

In many cases, above all for languages in which the segmentation was carried out in a completely independent way, authors' choices diverged either for segmentation criteria, or for the phonological interpretation of specific segments. I have compiled an explanatory and absolutely non-exhaustive list of ambiguous or potentially problematic segments or phenomena found in the languages taken in consideration.

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most comparable studies rely on one only segmentator, so the fact of using 2 segmentators already places these results at a higher level of objectivity.

[50] This, is particularly true for heavily co-articulated passages or anomalous phonetic realisations, such as voiceless vowels and approximants.

Semi-consonants ([j] and [w])

They are classified as approximants by the IPA because they have some vocalic characteristics but they are intrinsically dynamic (formants move) and are distinguished from corresponding fricatives. They are present in most languages (e.g. Italian *viaggiatore* [vjaddʒaˈtoːre], *più* [pju]) and it is very difficult to delimit them from the following vowel precisely because of their dynamicity. Furthermore, in some languages (including English) they tend to be at least partially devoiced after voiceless plosives (e.g. *disputing* [dɪsˈpj̊uːtɪŋ]).

In compliance with most studies in which segmentation choices are explicitly declared, on-glides have been considered as consonantal segments by both PM and AR. In some cases, high unstressed vowels in particular contexts are realised as approximants by some speakers (e.g. in Italian *innanzi avvolto* pronounced as [inːantsjaˈvːɔlto] by one of the speakers from Turin): in such cases, the two phoneticians adopted different solutions, following their impressions. Clearly, differences are also found in many specific cases as to where each phonetician set their boundaries.

It has to be noted that Finnish has raising diphthongs (which are perhaps best described as vowel clusters like *ie* in *pieni* ‘piccolo’, *ia* in *pian* ‘presto’), which were considered totally as vocalic intervals since, from a phonetic point of view, they are not approximants[51].

Off-glides

The final part of falling diphthongs was considered as vocalic in accordance with the bibliography (see Ramus *et al.*, 1999, among others) and with real/observed phonetic realisations.

Postvocalic r in many languages

Postvocalic r was indeed fairly difficult to categorise as C or V in many languages. PM and AR’s choices diverged, for instance, in American English for words such as *stronger*, which could be interpreted as either [ˈstɻ̊ɑːŋgɚ] or as [ˈstɻ̊ɑːŋgəɻ] or even as [ˈstɻ̊ɑːŋgɻ̩]. The cases of American English are perhaps the most emblematic, but similar problems are found in German (e.g. *Nordwind*, with pronunciations oscillating between [ˈnɔɐtvɪnt] and [ˈnɔʁ̞tvɪnt]), Swedish and Danish.

Syllabic consonants

Syllabic consonants were found in many languages. Phonologically, they are present in English but do not occur in the English version of *The North Wind and the Sun*. The German version had several occurrences of syllabic n and l (e.g. *stritten sich* [ˈʃtʁɪtn̩ zɪç] and *Mantel* [mantl̩]), sometimes making segmentation choices extremely challenging (e.g. *einen Mantel*: [zaɪnən ˈmantl̩] vs. [zaɪnn̩ ˈmantl̩] vs. [zaɪnː ˈmantl̩], see figure 3.7).

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[51] Yet, they were classified as consonants in those cases in which phonetic cues suggested that they were consonantal. Choices of PM and AR sometimes diverged in this respect.

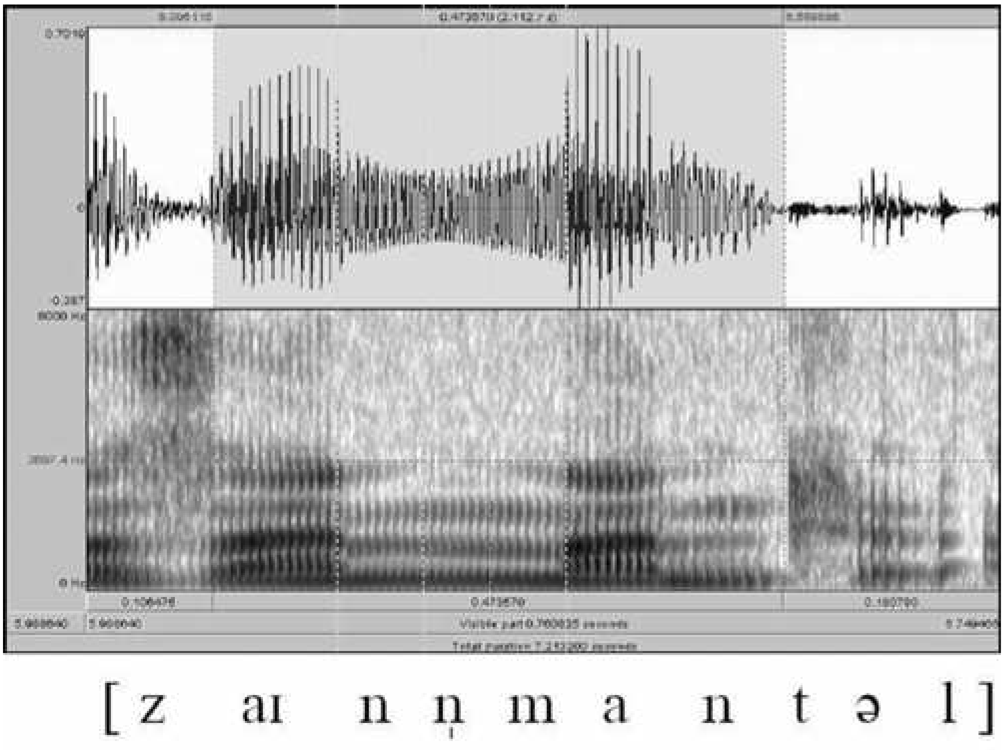

Figure 3.7. Spectrogram for German *seinen Mantel*.

Syllabic consonants were also found in other languages, in some cases even at a purely phonetic level, as realisations of an unstressed vowel followed by a nasal or a lateral. In all cases, syllabic consonants were considered as vocalic segments (again, in agreement with the bibliography) on the grounds that they occupy a syllabic nucleus, and therefore constitute a prominence peak within the syllable and within surrounding consonants. However, some doubts arose about this choice because syllabic consonants, in spite of occupying a nucleus, maintain the acoustic characteristics of consonants; further considerations will be discussed when analysing the results.

Sentence-initial voiceless plosives

Sentence-initial voiceless plosives are of course only partially visible in the spectrogram: only the outburst can be observed, as the hold phase is of course represented by silence. So, it is impossible to determine the exact moment in which the plosive begins, and consequently its duration cannot be measured exactly. Both phoneticians, however, agreed to arbitrarily attribute a duration of 70 ms to all sentence-initial plosives[52].

Sentence-final vowels

Sentence final vowels are hard to delimit as well, because they are usually lengthened and, furthermore, echo might make it impossible to take a decision. Following widespread conventions, both PM and AR considered the end of the second formant as the end of the vowel.

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[52] In compliance with CLIPS annotation criteria.

Devoiced or voiceless vowels

Devoiced or voiceless vowels systematically occur in Japanese (see figure 3.8) and in Romanian (although the Romanian speakers recorded for the corpus often pronounced voiceless vowels as only partially devoiced), but also sporadically in certain speakers of other languages, including Italian. It is hard to decide whether devoiced and voiceless vowels have to be classified as vocalic or consonantal segments: acoustically, they are consonants (see figure 3.8); phonologically, they are vowels.

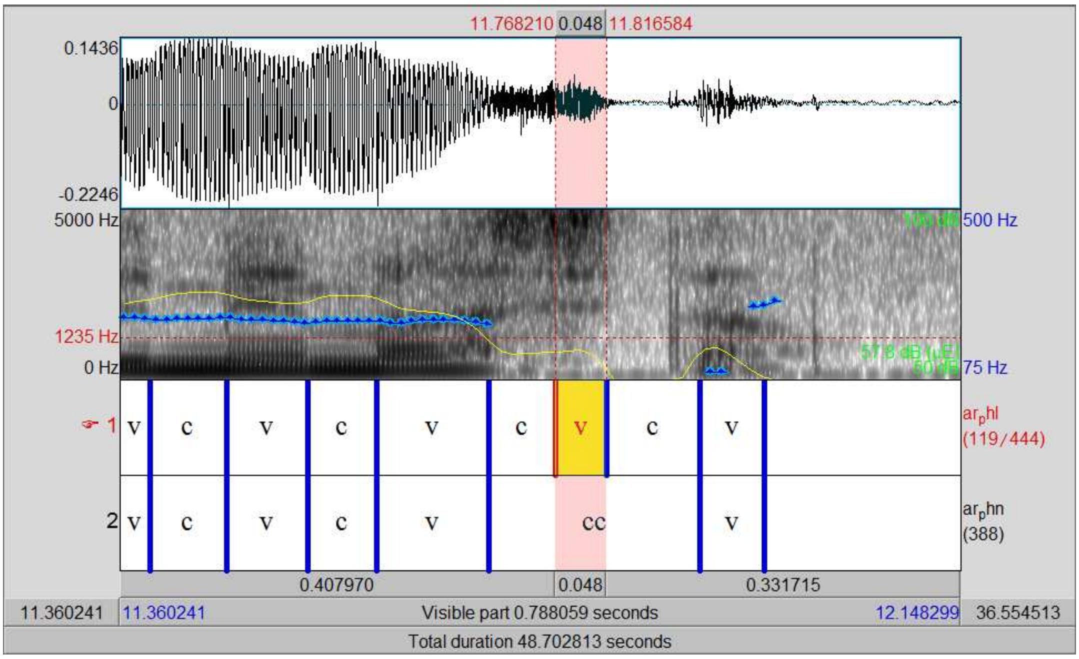

Figure 3.8. Spectrogram for a voiced Japanese vowel (in the selection): as it can be seen, the /i/ can hardly be distinguished from the preceding fricative (perceptively, the result is [ʃ]). The two transcription tiers show the possible interpretations as a consonantal or as a vocalic segment.

PM and AR sometimes adopted different solutions as to their classification. In Japanese, the consonantal aspect of this type of segments was so strong and so clear that both authors considered them as consonants. However, the results yielded by the metrics were quite in disagreement with those of other studies, so we tried to classify them as vowels and got results comparable to the ones found in the literature. More details will be discussed in the analysis.

Glottal stops

Phonological glottal stops were considered as consonantal segments if they were visible in the spectrogram (e.g. German *wurden sie einig* [ˈvʊɐdn̩ zi ˈʔaɪnɪç]), otherwise they were ignored as, in such a case, accounting for them would imply measuring silence. Glottal stops in languages for which they are not described or are described as extralinguistic or paralinguistic sounds were ignored (e.g. in Italian, Spanish, French etc.).

Epentheses

Various cases of epenthesis (both vocalic and consonantal) were found in many languages. Perhaps the most common one was schwa epenthesis within complex consonantal clusters, which was usually considered as an independent vocalic interval by both PM and AR. In Italian, some schwa epentheses were also found in word-final position at the end of a sentence in words ending in a consonant (e.g. *nord* pronounced by some speakers as [ˈnɔrdə]).

Other conventions

In some studies (e.g. Bertinetto & Bertini, 2008, Grabe & Low 2002), the final parts of each sentence have been excluded as they are considered to contain spurious data that does not contribute and is not beneficial to speech rhythm. In previous trials, Mairano & Romano (unpublished poster) tried adopting this approach and got no significant differences in the results[53]. So, for sake of simplicity, all segments uttered by the speakers were labelled and classified as either consonantal or vocalic.

Unlike Grabe & Low (2002), PM and AR did not include consonantal spikes as part of the vowel.

3.3.5 The deltas and the varcos

I shall now discuss the values of the deltas and the varcos obtained for the 61 samples in the corpus. These results were obtained by saving the segmentations as text files in *TextGrid* format and by using *Correlatore* for computing the metrics and building the charts (see chapter 4).

Numerical results and other information (number of consonantal intervals, number of vocalic intervals, number of pauses, mean duration of vocalic intervals, mean duration of consonantal intervals) for all data in the corpus can be consulted in appendix 2, which contains *Correlatore*'s entire report for the corpus. However, only the charts will be used in the discussion, as they provide a clearer visualisation (although they are of course merely a graphic representation of numerical data). Samples of different languages were averaged altogether even in those cases in which speakers came from different areas (e.g. GA English, RP English, AUS English and so no)[54]. I am aware that this is risky, but it responds to the practical need of not loading too many samples on the charts, which are already overcrowded. Moreover, the variation and variability of rhythm metrics are treated in detail in chapter 5, while appendix 2 contains the results for each single speaker.

Figure 3.9 shows data for the rhythm metrics proposed by Ramus *et al.* (1999), that is to say ΔC/ΔV and ΔC/%V. Expectations[55] seem to be confirmed for

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[53] The validity of this observation may well be limited to the speech style considered, *i.e.* read speech.

[54] It has to be noticed that the two samples of Mandarin Chinese (one from the province of Chao Yang, the other from Hong Kong – I shall specify that the speaker of the sample from Hong Kong really spoke Mandarin, not Cantonese) have been kept separated as the results yielded by most metrics placed those two varieties fairly apart, often in different rhythm groups (also cf. the discussion in Romano, 2010:51).

[55] I am aware of the problems concerning expectations for rhythm metrics stressed by Bertinetto & Bertini (2010) and discussed in various parts of the thesis. Rhythm metrics do not constitute a fully predictive model and expectations are based on perceptive impressions (which most of the times are not even verified with perceptive tests) and/or on an estimate based on the phonological properties of the language(s) analysed. Using either criterion, it is not possible to quantify exactly the values of the metrics and thus the position they will occupy in the chart, so that only relative distances can be commented.

most languages traditionally considered as stress-timed or as syllable-timed; English, German and Arabic (usually considered as stress-timed) show high values of both vocalic and consonantal deltas and are therefore situated in the north-east corner of the first chart; they also show low values of %V and thus occupy the north-west corner of the second chart. Conversely, Italian, Spanish and Greek (traditionally considered as syllable-timed languages) exhibit low values of both vocalic and consonantal deltas and therefore occupy the south-west corner of the first chart; however, their values of %V are not extremely low, which accounts for their southern position in the second chart (not far from the expected south-eastern position, occupied instead by French, also usually classified as syllable-timed, Chinese_CY and to a lesser extent Greek and Finnish).

Indeed, ΔC values are in general more consistent with expectations than %V and ΔV values; in effect, languages traditionally considered as syllable-timed, instead of showing low values of ΔV and low values %V tend to exhibit either low or high values of both metrics: French, Finnish, Chinese_CY and Romanian have fairly high %V and ΔV, whereas Italian and Spanish, as already mentioned, have low values of ΔV and medium values for %V. In the same way, Russian (traditionally considered as stress-timed) exhibits low values of both %V and ΔV (the latter was expected to be greater as Russian has phonological vocalic reduction). ΔV shows several inconsistencies as to expectations, such as English and Russian having lower values than French. The case of Portuguese is also worth mentioning: even if it has been controversially classified as syllable-timed by others (Fikkert *et al.*, 2004) or as stress-timed (e.g. Major, 1981, and more recently Mairano & Romano, 2010a), it certainly shows those phonological features typical of stress-timed languages and is thus expected to cluster with other stress-timed languages: in effect, it does exhibit high values of ΔC and ΔV, but it also bizarrely shows high values of %V, which do not seem to account for its evident phenomena of vocalic reduction (which can go as far as vowel deletion).

On the whole, ΔC values seem to better separate supposedly stress-timed languages from supposedly syllable-timed languages. However, one very noticeable exception is represented by Dutch, which shows very low ΔC values and which consequently clusters amid syllable-timed languages. Also, Turkish and Estonian values for ΔC are fairly high and place these two languages in the stress-timed area, although perceptively they rather sound syllable-timed. Danish and Swedish have not so far been included in any other studies using rhythm metrics as far as I know, so no particular expectation or reference was available, apart from the observation that they both allow for a fairly complex syllable structure (though not as complex as the German one) and that vocalic reduction is present but not particularly evident in these languages (similar considerations can be made for Icelandic, vocalic reduction being in this case even more limited). The second chart (and the first one to a lesser extent) seems to suggest that these languages are mildly stress-timed.

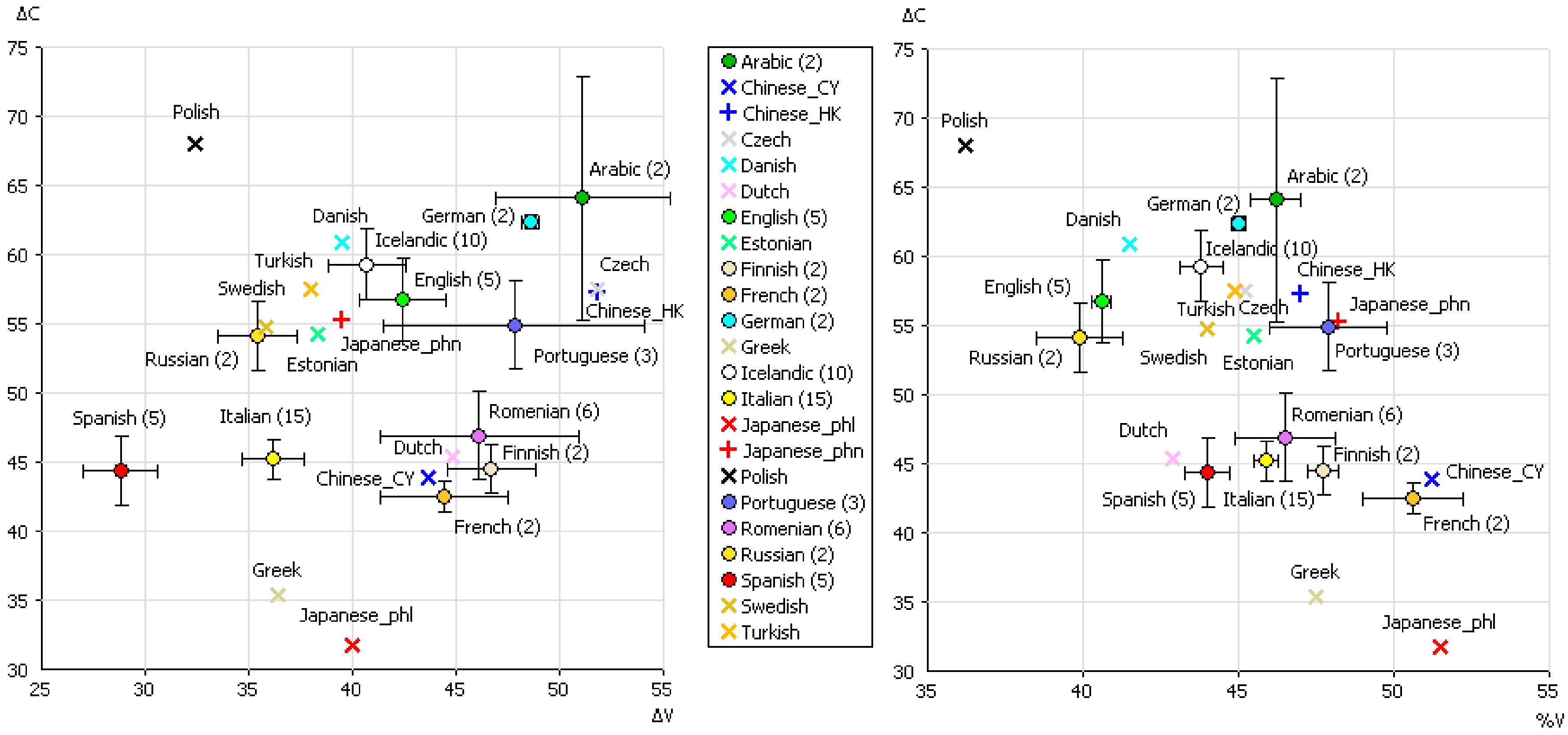

Figure 3.9. ΔC/ΔV and ΔC/%V chart with calculated globally (cp. the A method, chapter 4) for all data in the corpus. Dots represent mean values for different speakers of the same language, error bars indicate the standard error. Numbers in parentheses indicate on how many samples the mean was calculated.

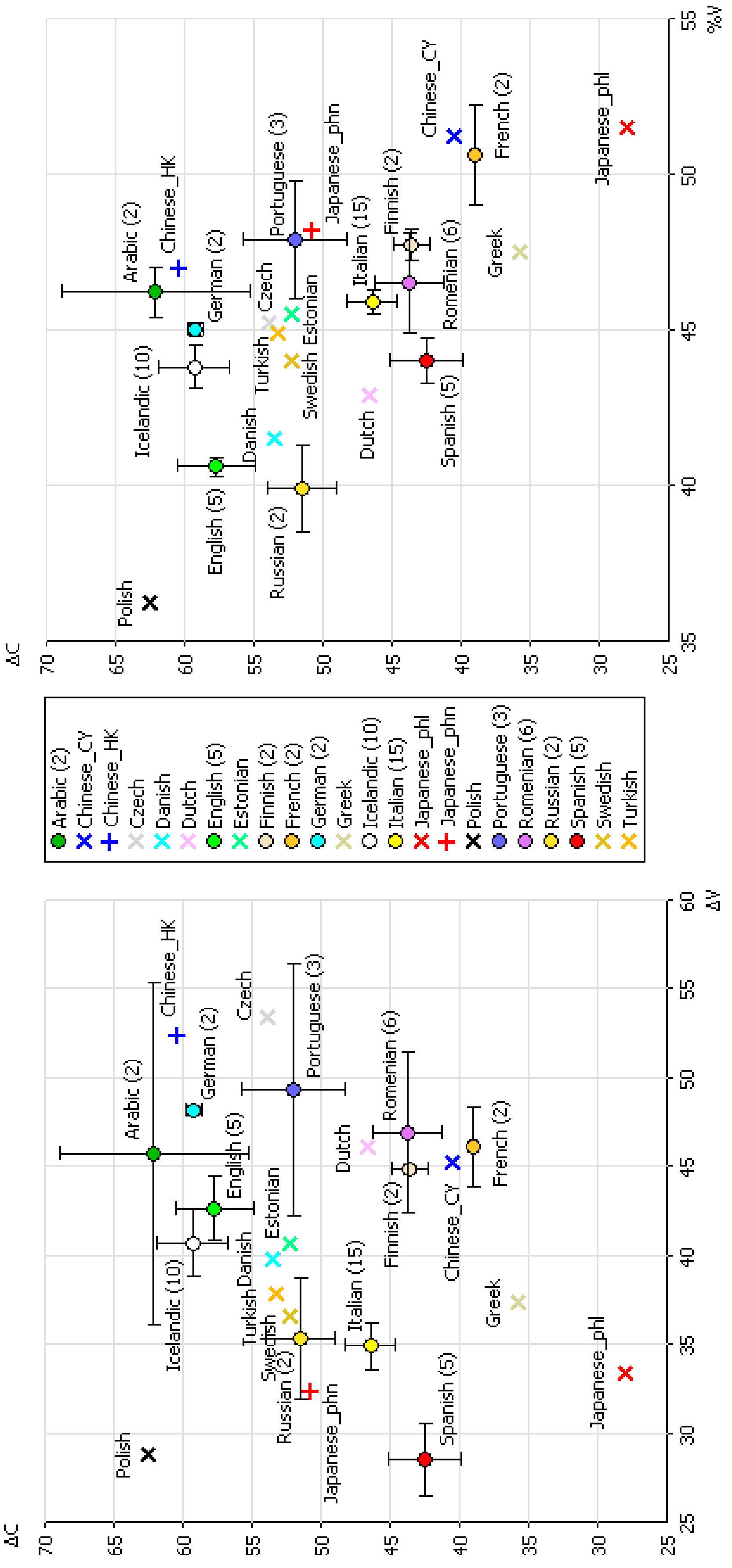

Figure 3.10. ΔC/ΔV and ΔC/%V chart with calculated locally (at sentence level, cp. the B method, chapter 4) for all data in the corpus, finally averaging local results. Dots represent mean values of different speakers for the same language, error bars indicate the standard error. Numbers in parentheses indicate on how many samples the mean was calculated.

One thing that strikes out is the departing of Polish and Japanese from the other languages, though in opposite directions: Polish has the highest ΔC and the lowest %V and ΔV of all languages (apart from the Spanish ΔV value), whereas Japanese_phl has the lowest ΔC value and the highest %V value, ΔV values being medium. Visibly, Polish is confined to the far north-western corner of both charts, whereas Japanese_phl is confined to the far south or south-western corner. This is in compliance with previous studies (cf. Ramus *et al.*, 1999) and with expectations, since Polish allows for complex consonant clusters (hence a high ΔC) but does not have macroscopic phenomena of vowel reduction (hence a low ΔV); Japanese, conversely, has a very simple syllable structure (hence a low ΔC and a high %V) and does not have evident vowel reduction (but it has mono and bi-moraic vowels – hence perhaps a medium ΔV). However, as it can be seen in the legend, two Japanese values have been included in the chart, Japanese_phl and Japanese_phn; both correspond to the same language sample, but the former has been segmented phonologically (*i.e.* considering voiceless vowels as vocalic segments), while the latter has been segmented phonetically (*i.e.* considering voiceless vowels as consonantal segments). The results are immensely different, as Japanese_phn comes to be placed in the stress-timed area: this confirms the hypothesis that segmentation choices have an influence on the results and, in particular, that the phonological interpretation of voiceless vowels has a huge and direct effect on ΔC (the effect on %V is of course present but far less evident, while ΔV is virtually the same for Japanese_phn and Japanese_phl). Finally, one should remark that these charts seem to classify Chinese_CY as syllable-timed and Chinese_HK as stress-timed (most previous studies of these varieties classified them as syllable-timed, see Grabe & Low, 2002, and Mok & Dellwo, 2008).

Results presented so far have been calculated globally, that is to say by applying the formulae to all consonantal and vocalic intervals in the narrative for each speaker (obviously separately for consonants and vowels). I shall now present the values of the deltas calculated locally for each inter-pausal unit and finally averaged, which are shown in figure 3.10. As it can be seen in the two charts, differences are minimal. The only remarkable discrepancy concerns the Arabic ΔV value, which moves to a less peripheral region and which shows an even greater error bar. To a minor extent, Chinese_HK is also affected (its ΔC rises slightly, but it remains next to languages traditionally classified as stress-timed) and Japanese_phl exhibits a lower vocalic variability (more in compliance with Ramus *et alia*'s results). Since the two methods of computing rhythm metrics do not seem to cause significant differences, the two approaches will not be reviewed for the other metrics and the analysis will only[56] include results computed globally, which seems to be the most used approach in the literature (although many authors do not clarify this aspect).

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[56] The results of the B method can still be consuled in appendix 2, with results for each language sample of the corpus.

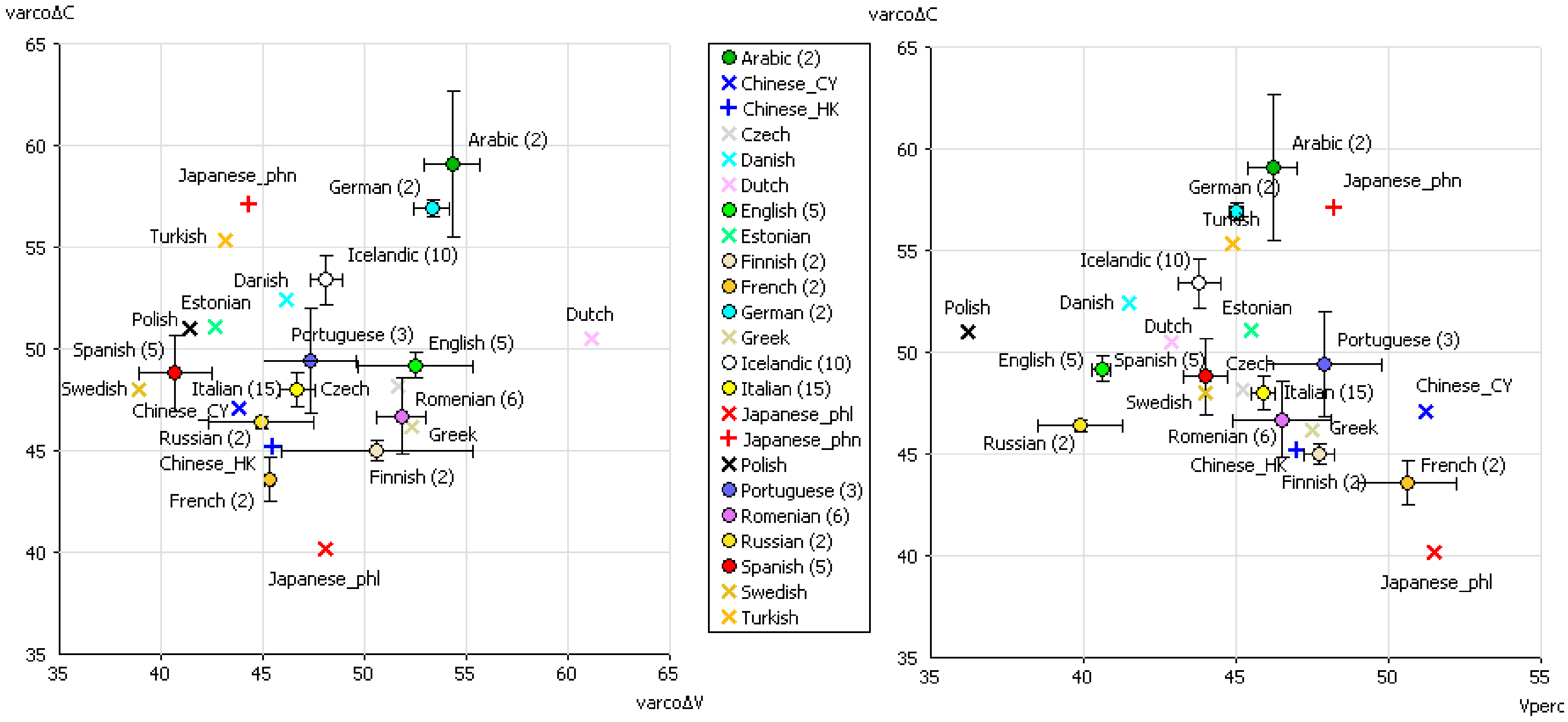

Figure 3.11. VarcoΔC/VarcoΔV and VarcoΔC/%V chart for all data in the corpus. Dots represent mean values of different speakers for the same language, error bars indicate the standard error. Numbers in parentheses indicate on how many samples the mean was calculated.

Figure 3.11 presents the results obtained with the varcos for the same data. As has been said above, the idea behind the varco is to introduce a variation coefficient with the aim to normalise in respect to speech rate (see Dellwo & Wagner, 2003 for reference). Again, it is possible to recognise a group of languages traditionally classified as stress-timed (such as German and Arabic[57]) in the north-eastern corner of the first chart and in the north of the second chart; conversely, a group of languages traditionally classified as syllable-timed (such as French and Italian) is situated in the south-western corner of the first chart and the south-eastern corner of the second chart. However, some differences distinguish the results of the varcos from those of the deltas.

Firstly, it catches the eye that error bars are far slighter: the ΔC/ΔV chart shows that these two metrics have great fluctuations within different samples of some languages (noticeably in Arabic and Portuguese), which is notably reduced by the use of varcoΔC and varcoΔV. Therefore, the variation coefficient seems to effectively neutralise between different characteristics of speakers of the same language. These characteristics may well include speech rate, which varies remarkably between the two Arabic speakers, but could also include other parameters (the two Arabic speakers and the three Portuguese speakers have a different geographical provenance).

Moreover, it should be noted that the varcos place Dutch and French in a position that is more consistent with expectations, French exhibiting a low varcoΔV (which was not the case with ΔV) and Dutch exhibiting an extremely high varcoΔV and a high varcoΔC (while it had a fairly low ΔC and merely medium ΔV). On the other hand, Russian has moved to an even less comfortable position, amid syllable-timed languages with low values of varcoΔC, which is difficult to account for (given its phonological features). Spanish and Greek lose a bit of their marked characterisation as syllable-timed, moving towards more central regions, varcoΔC being greater than ΔC for these languages. Polish lowers slightly, suggesting a less exceptional consonantal variability, still conserving low levels of varcoΔV which indicates a very limited vocalic variability. Interestingly, varcoΔC values for Chinese_HK drop dramatically and move this language from the stress-timed group to the syllable-timed group, while Japanese_phl conserves its confinement to the south (first chart) and south-east (second chart) corners.

So, applying a variation coefficient seems to be a better solution for ΔV than for ΔC, as is shown by the chart in figure 3.12, with ΔC on the y axis and varcoΔV on the x axis. This solution seems to yield a better scenario for a rhythmic categorisation of languages than with only the deltas or only the varcos. Moreover, it reflects the usual visualisation of the PVI, which, following Grabe & Low (2002), applies a normalisation to vocalic measures (using the formula of the nPVI), but not to consonantal measures (for which the rPVI formula is used).

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[57] For the classification of Arabic as stress-timed, see for instance Miller (1984) and Ghazali et al. (2002, although ΔC shows sometimes aberrant values).

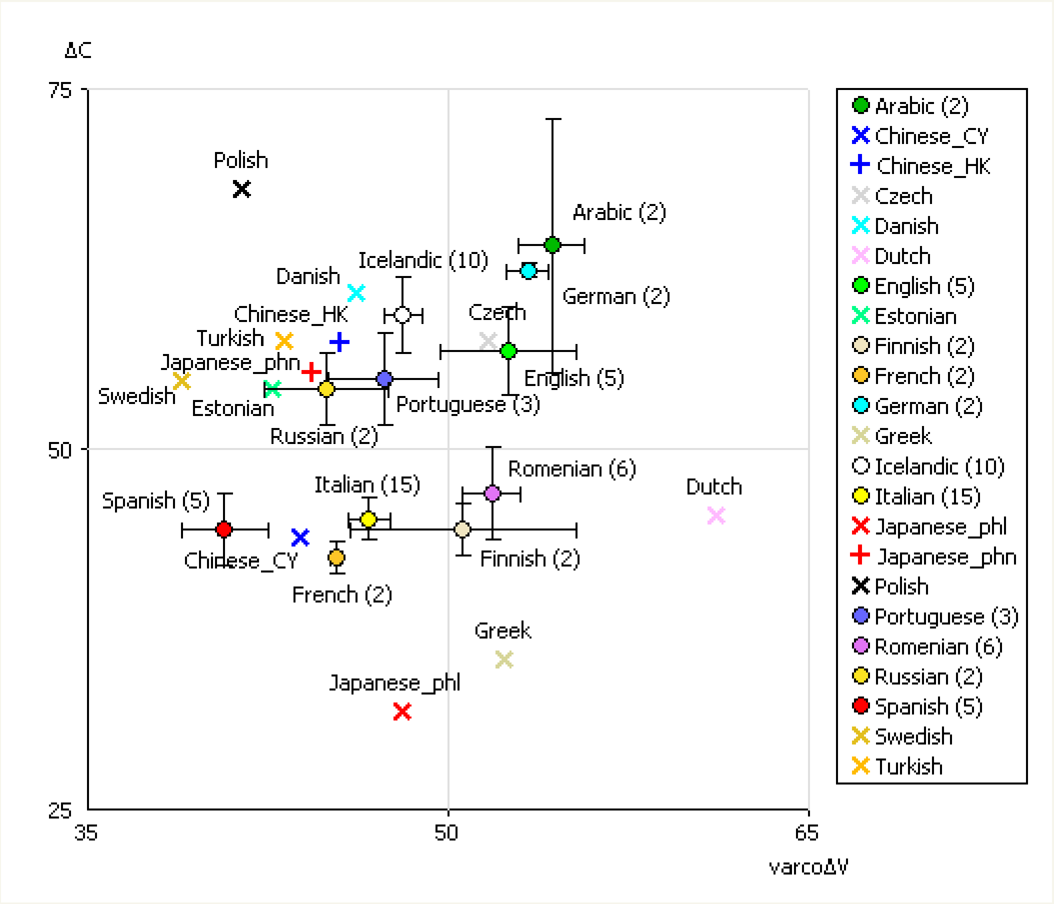

Figure 3.12. ΔC/VarcoΔV chart for all data in the corpus. Dots represent mean values of different speakers for the same language, error bars indicate the standard error. Numbers in parentheses indicate on how many samples the mean was calculated.

The chart in figure 3.12 offers an interesting scenario: ΔC clearly separates two groups of languages. Languages traditionally classified as syllable-timed (Italian, French and Spanish) are situated below 50ms, while languages traditionally classified as stress-timed (English, German, Arabic, Russian and Portuguese) as situated above this line. However, the chart also presents a vertical partition at roughly 50ms on the x axis (values for varcoΔV), which again separates French, Spanish and Italian from English, German and Arabic. Interestingly, the two lines create a quadripartition with four zones in the chart, none of which is empty. Actually, each of the four zones seems to have a cluster of languages: French, Italian, Spanish and Chinese_CY occupy the south-western slot, traditionally allocated to syllable-timed languages; English, German, Arabic and Czech occupy the north-eastern slot, traditionally allocated to stress-timed languages; Finnish and Romanian occupy the south-eastern slot, indicating a simple syllabic structure combined with high durational variability at the vocalic level (explained in Finnish with the phonological opposition of vowel length, in Romanian with devoiced vowels); Danish, Swedish, Icelandic, Estonian, Turkish, Chinese_HK, and rather surprisingly, Russian and Portuguese occupy the north-western slot, indicating limited vocalic variability (only explainable for Danish, Swedish, Icelandic and to a lesser extent for Estonian, Turkish and Mandarin) combined with a complex syllabic structure (fairly unexpected for Estonian and Turkish).

Furthermore, it is interesting to remark that languages tend to cluster in a focal area extending from north-east to south-west (see the red lines). Only four languages are scattered away from the focal area: Polish to the far north-west (as expected), Japanese_phl to the far south-south-west (again, as expected), Greek to the far south-south-west, Dutch to the far south-east-east. However, these four languages are all represented by only one speaker and it may well be possible that, averaging results from more speakers, their isolation would be less or not at all remarkable.

3.3.6 The PVI

As has been previously mentioned, the PVI differs from the deltas in that it takes in consideration the sequential order of the segments by calculating the difference between successive vocalic or consonantal intervals (see above). Figure 3.13 shows the results of the consonantal rPVI and the vocalic nPVI calculated on the corpus.

Probably, this chart provides the best representation for a rhythmic categorisation of languages according to expectations coming from perceptual evidence and phonological properties. English, German, Arabic, Danish, Swedish and to a lesser extent Russian, Icelandic, Czech and Portuguese (supposedly stress-timed languages) cluster in the north-eastern area, exhibiting high values of both rPVI and nPVI, indicating great durational variability both at the vocalic and at the consonantal level. On the contrary, Italian, Spanish, French, Romanian, Greek, Finnish and Estonian (supposedly syllable-timed languages) cluster in the south-west area, with low values of both rPVI and nPVI, which in turn indicate a limited consonantal and vocalic durational variability. Again, the two Chinese samples occupy different portions of the chart: Chinese_HK amid stress-timed languages, Chinese_CY not far from syllable-timed languages.

Similarly to what happened with the deltas and the varcos, Japanese_phl (segmented phonologically) and Polish occupy isolated positions: both exhibit a limited vocalic variability (neither of them has evident phenomena of vowel reduction) though the values for Japanese_phl (which does have mono and bi-moraic vowels) are slightly higher. Polish has the highest value for the consonantal rPVI, while Japanese_phl has by far the lowest: as already said, this is in compliance with expectations based on the syllabic structure of these two languages and it reflects results obtained by other authors. Dutch, as well, occupies an isolated position with very high values of vocalic nPVI and medium values of consonantal rPVI.

Results for consonantal rPVI and vocalic nPVI roughly reflect those for ΔC and varcoΔV. Still, the PVIs provide a scalar characterisation of languages that is more in line with expectations coming from perceptual evidence and structural properties (e.g. for Greek as syllable-timed and for Portuguese as stress-timed). A quadripartition is in this case far less evident and, as expected, only Polish, Japanese and to a lesser extent Dutch are isolated from the central area. Remarkably, the diamond-shaped focal area confirms the scenario found by Grabe & Low, 2002, for a similar though smaller sample of languages. This may suggest that languages showing a very high variability on one axis and a very low variability on the other axis, should be considered as marked.

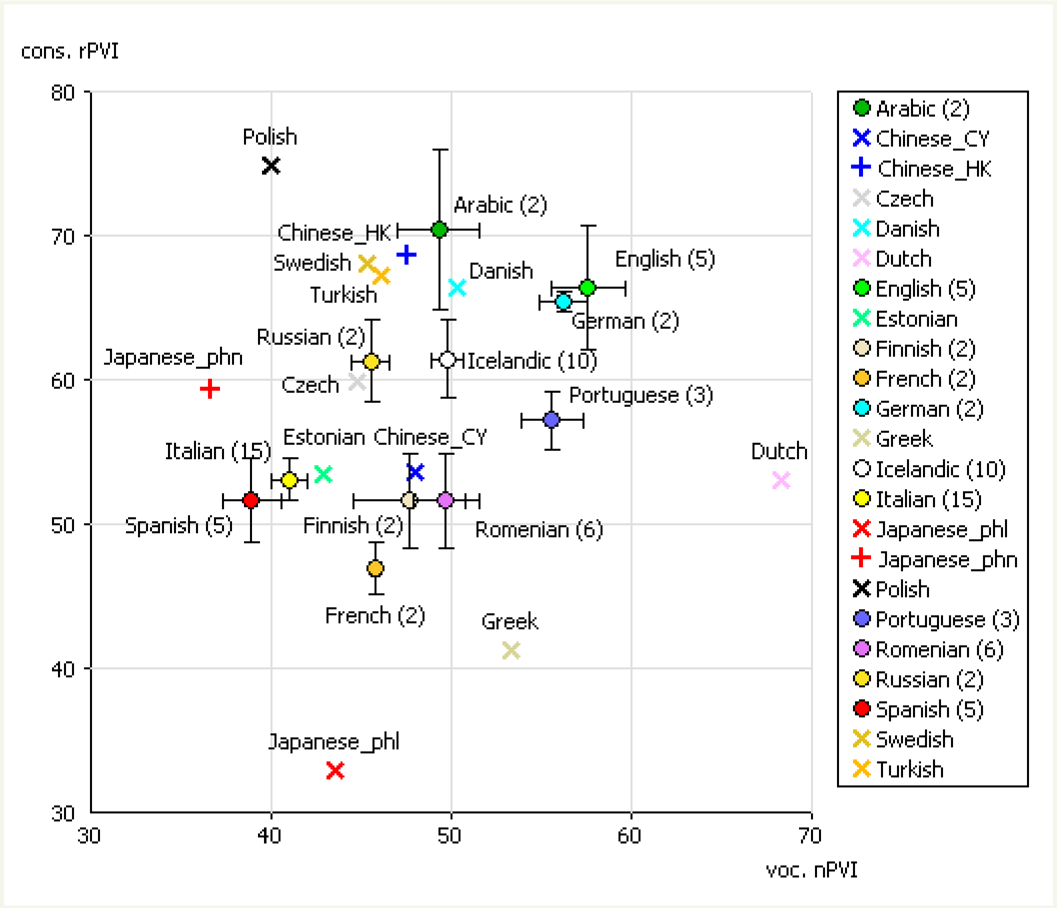

Figure 3.13. Consonantal rPVI / vocalic nPVI computed for all data in the corpus. Dots represent mean values of different speakers for the same language, error bars indicate the standard error. Numbers in parentheses indicate on how many samples the mean was calculated.

3.3.7 The CCI

As has been said above, the Control and Compensation Index (CCI, devised by Bertinetto & Bertini, 2008) is a modification of the rPVI formula by which the duration of each vocalic and consonantal interval is divided by the number of phonological segments that compose it and aims at measuring the level of segmental compensation allowed by different languages. This of course implies that the segmentation cannot simply be carried out as C-V, but requires a more sophisticated analysis. Determining the number of phonological segments of vocalic and consonantal intervals might seem a trivial task, but it has brought about several interpretation dilemmas. I shall review the most relevant ones below.

Gemination

As suggested by Bertinetto & Bertini (2009), Italian, Icelandic, Finnish and Estonian geminate consonants were considered as one interval composed of two segments: this included Italian intrinsically geminate consonants ʃ ʎ ɲ ts dz in inter-vocalic position (e.g. Italian *riuscito*). However, for speakers of Northern regional varieties of Italian, intervocalic ʃ was considered as having only one segment as its short realisation does not depend on compensation, but on the fact that this consonant is not intrinsically geminated in these varieties. Moreover, Icelandic preaspirated consonants were also considered as intervals composed of two segments as they are the phonetic realisation of phonologically geminated voiceless plosives (see Thrainsson, 1978, and Helgason, 2002, for reference).

Diphthongs

In line with most other studies on linguistic rhythm, on-glides were considered as consonantal, off-glides were considered as vocalic (in contrast to Bertinetto & Bertini, 2008 and following, who considered both as consonantal), so rising diphthongs were labelled as |c|v|, while falling diphthongs were labelled as |vv| (a vocalic interval consisting of two segments). This is valid for most languages included in the corpus, but with some exceptions: for example, Finnish and Estonian diphthongs (rising and falling) were always considered as vocalic segments with two intervals |vv| on the grounds of their acoustic characteristics. German diphthongs resulting from postvocalic r were considered as |vv| if the r segment presented evident vocalic properties as shown in the spectrogram.

Insertions

Realised but non expected segments (epentheses) were included in the segments count if they were clearly visible in the spectrogram and perceptively evident; that is to say that Italian *nord* pronounced as [ˈnɔrdə] was labelled as |c|v|cc|v| and measured accordingly.

Deletions

Expected but non realised segments were counted in the total amount of segments composing one interval: for instance, German *einst stritten* expected as [aɪnst ˈʃtʀɪtn̩] but realised as [aɪn ˈʃtʀɪtn̩] or as [aɪns ˈʃtʀɪtn̩] was labelled as |vv|cccccc|v|c|v|; similarly French *reconnaitre que* theoretically expected as [ʀəkonɛtʀ(ə) kə] was labelled as |c|v|c|v|ccc|v| even when it was realised as [ʀəkonɛt kə]. The same applies to nasals realised only through nasalisation of the preceding vowel, for example, Italian *un mantello* realised as [ũ mãnˈtɛllo] was labelled as |v|cc|v|cc|v|cc|v| (in which the second interval – cc – also includes the last third of the [ũ] in order to account for the cancelled nasal). The reason for including cancelled segments in the count is that the cancellation of a segment corresponds to the highest possible level of compensation and, therefore, they have to be accounted for in a measure that aims at describing compensation. Some particular cases of deletion were excluded from this reasoning as they were not caused by compensation, for example, h-droppings in English weak forms (e.g. *his* pronounced as [ɪs] or [ɪz] in unstressed position) and others (such as *and* pronounced as [ən]).

Hiati and synaloephae

According to the indications given by Bertinetto & Bertini (2009), synaloephae were considered as one vocalic interval composed of one segment |vv|, while hiati were considered as two separate vocalic intervals |v|v|. Cases such as Italian *tolse il mantello*, <se il> was considered as |c|v|v|c| if it was realised as a hiatus [se.il] (rarely), as |c|vv|c| if it was realised as a diphthong [seil] (still rather rarely), as |c|v|c| if the second part was deleted [sel] (most often). In this case, the cancelled segment was not accounted for in the segmentation because its deletion is not due to a compensation phenomenon. The same considerations applied in cases in which the first and the second vowel had the same quality, e.g. in Italian *togliersi il*, in which realisations as [si.il] were labelled as |c|v|v|c|, realisations as [siːl] were labelled as |c|vv|c|, realisations as [sil] were labelled as |c|v|c|.

Other
Sentence-final parts were not excluded from the segmentation both for practical reasons and because previous trials showed little difference in the results.

The values of vocalic and consonantal CCI obtained for all samples in the corpus are reported in figure 3.15. As it can be seen, some compensating languages such as German, Czech and Portuguese are collocated below the bisecting line, while some controlling languages are collocated along the bisecting line, such as French, Chinese_CY, Finnish, Spanish and Japanese. On the one hand, the disposition of some languages given by the CCI is more convincing than for others, such as Turkish (which is classified as a controlling language by the CCI but as a stress-timed language by the deltas and PVIs against perceptive impressions).

On the other hand, some supposedly compensating languages (namely Arabic and Polish) occupy the position above the bisecting line: this was thought to be impossible (or at least improbable) by Bertinetto & Bertini (2008) as such a result suggests that these languages compensate more for consonants than for vowels. However, it is possible that this prediction failed to take in consideration languages like Polish, which do have very complex consonantal clusters (and thus presumably need a certain amount of consonantal compensation), but which do not exhibit evident phenomena of vowel reduction (and thus do not compensate much at the vocalic level).

As claimed by Bertinetto & Bertini (2010), the CCI is a “phonologically-driven” index, as it needs a careful phonological evaluation of each segment as, for instance, deleted segments have to be accounted for (but only if their deletion has to do with compensation) and numerous other decisions have to be made. This task, as stated by their authors, requires a deep knowledge of the phonetic and phonological characteristics of the language(s) analysed. However, this is of course difficult to achieve for 21 languages and, as has been stated in the presentation of the data, the two phoneticians have mostly relied on transcriptions and descriptions published as illustrations of the IPA[58]. Problems often arise when choices have to be made for ambiguous segments, such as on- and off-glides, syllabic consonants, etc. As can be seen from the segmentation criteria specified above, PM and AR made some different choices from Bertini & Bertinetto (2009). PM and AR generally explicitly adopted a more phonetically-oriented segmentation, such as the interpretation of off-glides as consonantal segments (despite their phonological consonantal value, as stressed by Bertini & Bertinetto, 2009). Indeed, it is well possible that changing criteria even just for these very frequent segments would yield completely different

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[58] PM gave up the segmentation of the Chinese samples discouraged by the difficulties he encountered.

results and would perhaps fix the incoherencies presented by the CCI chart, such as the placement of Arabic and Russian.

Still, these results clearly ask for further analysis and interpretation of the disposition of languages on the CCI chart, which can only be done with more data for each speaker. Other considerations on these new metrics follow in the next lines.

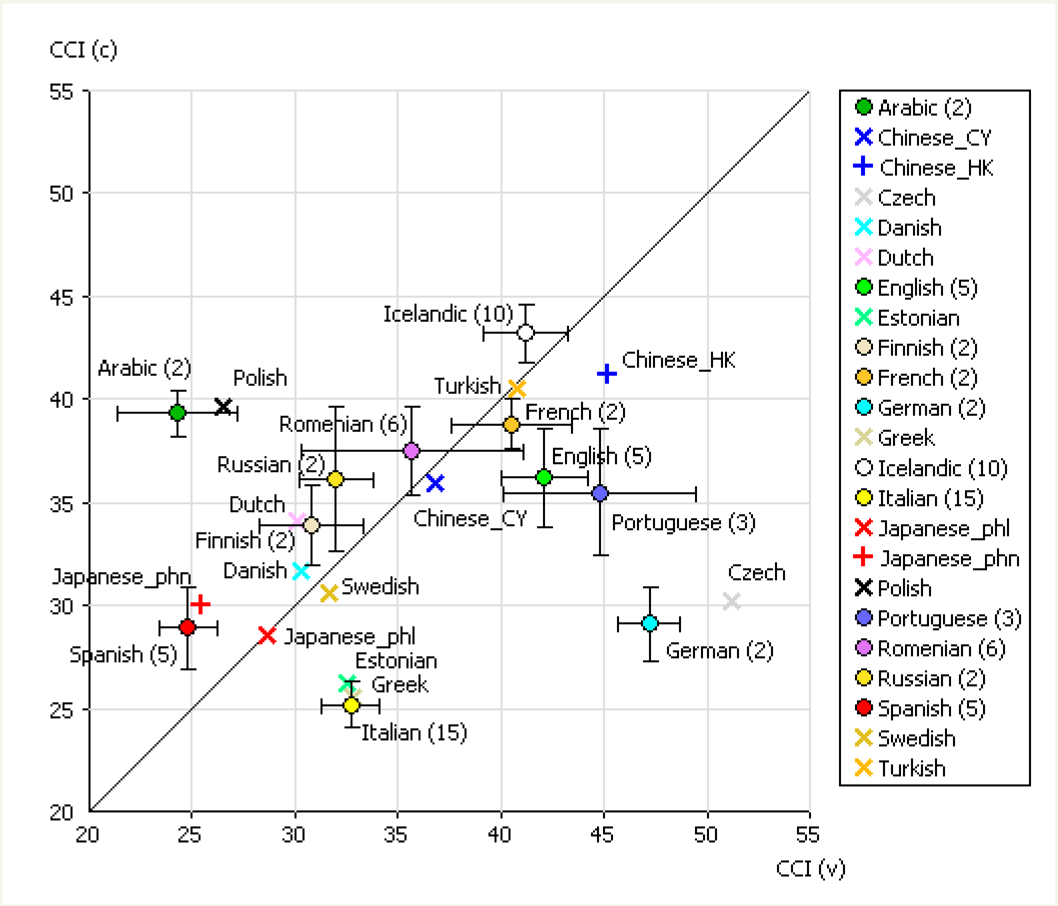

Figure 3.14. Consonantal CCI / Vocalic CCI computed for all data in the corpus. Dots represent mean values of different speakers for the same language, error bars indicate the standard error. Numbers in parentheses indicate on how many samples the mean was calculated.

The formula of the CCI tries to capture segments' variability which is supposed to be higher in compensating languages (precisely as an effect of compensation) than in controlling languages. In order to do this, intervals are divided by the number of segments that compose them. In practice, similar results could presumably be obtained by directly applying the PVI formula to segments' durations[59]. The comparison of the CCI and this approach would certainly be of

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[59] I shall explain myself more clearly. Grabe & Low (2002) apply the PVI formula to vocalic and consonantal intervals in order to capture fluctuations in intervals' duration. Bertinetto & Bertini (2008) change the focus from intervals to segments and aim at measuring segments' variability (which is thought to be greater in compensating languages as they have fewer constraints and are freer as to fluctuations at all levels). So, if we want to capture fluctuations in segments' length, the most straight-forward way of doing it is to apply the same formula to segments durations. Predictions would of course be unchanged, that is to say that controlling languages should tend to align along the bisecting line, while compensating languages should tend to cluster below it.

some interest; however, I suppose that such a choice would probably bring to biased results as the final value would be heavily influenced by the intrinsic length of different categories of sounds (e.g. voiceless fricatives being far longer than taps and so no). Indeed, the CCI does have the same problem, although it is somehow mitigated by considering each vocalic or consonantal interval and dividing it by the number of segments that compose it: this way, for intervals of more than one segment, the value obtained does not correspond to any actual duration, but is rather an abstract representation of the level of compensation within that interval. Yet, for mono-segmental intervals, the problem is not solved.

Another consideration regards the fact that the CCI does not preserve each segment's weight on the final value: in fact, each segment's weight on the final value is inversely proportional to the number of segments composing the interval[60]. I shall not deal with this matter in any further detail now, except for stating that if ever this is found to be a problem, a possible solution would perhaps simply imply the introduction of a coefficient for increasing the weight of each segment in plurisegmental intervals.

More importantly, compensation should become more evident in a language at increasing speech rate. Therefore, the CCI ought to be computed at different speech rates for each language, like its authors did (see Bertinetto & Bertini, 2008). This is even more true given the fact that the CCI does not normalise for speech rate (as a specific choice by its authors on the basis of the tight relationship between rhythm and speech tempo): such a choice certainly has rooted grounds, but it implies that for cross-language comparative studies the CCI must be applied to samples rigorously comparable as for speech rate. Otherwise, the results might reflect the effects of speech tempo as well as of compensation properties and other rhythmic cues. And, of course, it would be difficult to identify those characteristics that have to be attributed to speech tempo and those that that can be attributed to real cross-language differences.

At the light of these considerations and also keeping in mind that the CCI is younger than the other rhythm metrics, it can be claimed that it still needs to be tested across a combination of different languages and, crucially, different speech rates. Unfortunately, my corpus is not adequate (at least at the moment) for testing both different languages and different speech rates and, so, results present some incoherencies that might otherwise be fixed: the disposition of the samples within the CCI chart meets expectations for some languages, while others occupy an area which was predicted to be empty. For the time being, the interpretation is unclear and represents a challenging perspective for future studies in this field.

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[60] As it has already been said and repeated, the CCI divides each interval by the number of segments composing it. Consequently, each interval issues one value, whether it is composed of one, two or more segments. So, a segment included in an interval with 3 segments will weight as 1/3 of segment on the final value, while a segment composing an interval in itself will weight as 1 segment. Furthermore, since it is usually stressed syllables that tend to attract segmental material and thus present consonantal clusters, and that stressed syllables are less numerous than unstressed syllables, it is well possible that reduced (compensated) segments will be underrepresented in the final computation.

3.4 On the possibility of including pitch and intensity

3.4.1 Why on earth?

Even though only few studies on speech rhythm have attempted to include parameters other than duration, the importance of pitch and intensity for an account of speech rhythm has been stressed by several authors, mainly on perceptive grounds. In the 70s, some experiments were conducted by different authors, among which Lehiste and Allen (some of them are reported by Allen, 1975, and, Lehiste, 1977). They have shown that sequences of stimuli can be perceived as having an alternating[61] rhythmic structure by manipulating not only durations, but also intensity or pitch alone. So, a difference in pitch and/or intensity is enough for our mind to create rhythm: this seems to me a fairly good reason to try and integrate these two parameters into a speech rhythm account.

More recently, other authors have stressed the importance of pitch and intensity on the perception of rhythm and some of them have put forward some proposals. Lee & Todd (2004, but see also Lee, 2010) hypothesised that stress-timed languages displayed a higher variability in the prominence of syllable nuclei than syllable-timed languages. Since prominence is not only given by duration, they measured the delta and the rPVI on values of intensity and pitch on 2 different sets of data (one made up of English and French sentences, the other containing samples of Dutch, English, French and Italian drawn the corpus used by Ramus *et al.*, 1999). All measures proposed in their study seemed to reflect a rhythm categorisation of languages.

Cumming (2009) carried out a perceptive experiment on French and Swiss German speakers on the spur of the ones made by Lehiste (see above). She found that f_o has an impact on the perceived duration of speech stimuli ([si] syllables in this case) for both groups of listeners:

> *Since length judgments do not differ significantly between the two (prosodically different) language groups, this tends to suggest that the perceived lengthening effect of dynamic f0 is not dependent on language background […].*
> *If f0 changes affect the subjective duration of successive intervals in several languages, the rhythm of a language which tends to use f0 dynamism within the syllable may be perceived differently from that of one in which f0 changes minimally within the syllable. However, durational rhythm metrics may not accurately reflect this difference; therefore, in answer to the title, rhythm metrics should take account of f0. Finding a suitable means of integrating duration and f0 change into metrics such as the PVI could be the next challenge.*
> *(Cumming, 2009:14)*

On the basis of informal tests carried out by manipulating the prosodic parameters of the incipit of *The North Wind and the Sun* in English and French, Romano (2010) suggested that much rhythm information is lost by equalising the

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[61] Allen (1975) makes a distinction between rhythms of alternations rhythm of successions. An alternating rhythm is given by an alternation of more prominent and less prominent beats. See 2.2.3 for further details.

pitch contour and, similarly, that some rhythm information is kept when equalising vocalic durations and leaving the original pitch values. The author concludes as follows:

> *A simple experiment like this allowed us to start thinking in a different way with regard to speech rhythm:*
> *(1) it demonstrates the inadequacy of metrics based on durations only;*
> *(2) the reduced importance of vocalic durations* […] *suggests the possibility that the distance in time between f0 peaks or specific movements could be one of the main cues in listening discrimination of different rhythmic types.*
> *(Romano, 2010:66)*

3.4.2 An attempt

I made an attempt to introduce pitch and intensity in an account of speech rhythm. It was merely a preliminary test, whose results did not confirm expectations and which was therefore discontinued. However, since I have not yet found any other solution for the integration of prosodic parameters in the study of speech rhythm, I shall briefly present the experiment.

The test was based on the very simple idea already attempted by Lee & Todd (2004) of applying rhythm metrics to measures not only of duration, but also of pitch and intensity. This may seem weird, but there is a rationale: as noted by Bertinetto, in stress-timed languages, there is a “tendency of stress to attract segmental material in order to build up heavy syllables” (1989:108). This certainly is one of the reasons[62] why stressed syllables are more salient in some languages (such as English) than in others, but prominence is usually achieved through other prosodic parameters as well, such as pitch and intensity. So, it may be that the higher degree of prominence showed by stressed syllables in stress-timed languages (if compared to stressed syllables in syllable-timed languages) is contributed by a bigger difference between the pitch and intensity values of stressed and unstressed syllables in stress-timed languages than one would find in syllable-timed languages. A way to test this difference in pitch and intensity variability consists then in applying the metrics to these measures.

However, I should stress two important problems concerning the comparison of intensity and pitch values. First of all, raw f_0 values (in Hz) are obviously of no use as it is nonsense to calculate variability on values distributed on a non-linear scale: I therefore need to use semitones. Secondly, it is extremely risky to compare intensity values of different recordings as they are heavily influenced by several factors (such as, most importantly, the distance of the speaker from the microphone). For this reason, it was not possible to use the same as for the experiments presented above (some of the samples were recorded at LFSAG, but many others were drawn from the *Illustrations of the IPA*, each produced by different authors). So, I used the most uniform and comparable data I had, the same that have been used in chapter 2: 10 samples by the same speaker, recorded the same day and in the same conditions,

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[62] The other being that unstressed vowels are often reduced and centralised.

reading *The North Wind and the Sun* twice in 5 languages (English, French, German, Icelandic and his mother tongue Italian).

As for the methodology, I prepared a *Praat* script that saved in a text file the mean values of intensity and f_0 (the latter were converted in semitones) for each vocalic interval (meaning that the values of the metrics would then be calculated with *Correlatore* – see chapter 4). Then, the 10 recordings were labelled manually according to the criteria already specified. I shall linger no longer on the description of the data and the segmentation in detail, as they are presented, respectively, in chapter 5 and above. Instead, I shall pass directly to the results

3.4.3 The results

I computed the delta and rPVI on semitones and intensity values (obtained through the *Praat* script) with a special function of *Correlatore* and put the results on the charts shown in figure 3.15 (each dot represents the mean obtained for each pair of samples of the same language).

As it can be seen, the delta and the rPVI reflect basically the same scenario, with low variability of pitch and intensity values for the Italian samples and high values for English, French, German and Icelandic. The results do not seem to reflect a standard rhythm representation of languages, since French sticks next to English (on the left) and German (on the right), with high values of variability for both intensity and semitones. Instead, for some reason, they seem to distinguish between the speaker's L1 (Italian) and all L2s, so that the interpretation is challenging. These values may result from insecurity on the part of the speaker as regards the L2s, but this should somehow be reflected by speech rate, as well (which does not seem to be the case, see chapter 5).

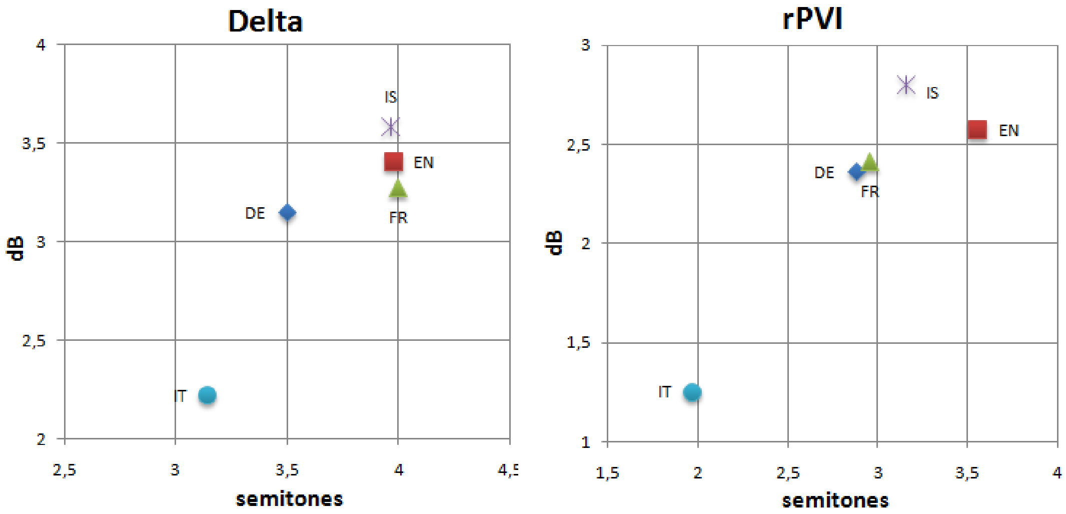

Figure 3.15. Charts showing the values obtained by computing the deltas (on the left) and the rPVI (on the right) on semitones and intensity values of vocalic intervals. Data consist of 10 recordings of *The North Wind and the Sun* in 5 languages (twice per language) by a native speaker of Italian.

3.4.4 So...

Whatever the interpretation of these results, the integration of pitch and intensity is certainly no easy task and has to be pondered more. Besides, this method does not appear to be suitable for a direct integration in a speech rhythm account for a number of reasons. Firstly, it is very problematic to acquire comparable data (as has been said, intensity values differ across studies according to recording methods and conditions). Furthermore, results run the risk of being influenced by various phenomena and are not easily interpretable. Arguably, the integration of prosodic parameters could more sensibly integrate a speech rhythm account at a higher level.

3.5 Conclusion

By applying the formulae of various rhythm metrics on the corpus, it has been shown that all of them provide an acceptable representation of speech rhythm that is mainly consistent with expectations based on perceptive impressions. Moreover, other studies have shown that it is possible to obtain a rhythm categorisation even by applying the deltas and the PVIs to voiced and devoiced intervals. This somehow suggests that the different formulae are interesting and challenging more for the theoretical perspectives and the rationales standing at their base, than for the practice. It has also been shown that each of them has advantages and drawbacks, both at the theoretical and at the practical level. For example, metrics that normalise for speech rate run the risk of ignoring relevant phenomena; yet, they usually provide a more solid representation of different language samples precisely because they neutralise differences in speech rate.

One thing to keep in mind when observing the results for rhythm metrics is that they reflect exclusively the first level of rhythmicity, that is to say the segmental one. They do not measure anything at the second level. Therefore, researchers should be careful at classifying languages on the basis of what they see on these charts. It can be inferred that low deltas, varcos or PVIs characterise languages tending towards syllable-timing or segmental control. However, languages that show high values of deltas, varcos or PVIs cannot be said to tend towards stress-timing, because nothing has been measured at that level: simply, these languages do not tend to syllable-timing, but there is no proof at all that they tend towards stress-timing. In fact, in line with other studies (see the scheme presented in Bertinetto & Bertini, 2010), I suggest that the two levels allow for a quadripartition of languages based on control/compensation at each level.

It also has to be noted that the four slots of the quadripartition need not necessarily be all represented by languages: time will tell. The CCI are clearer as the other metrics as for this, as they only intend to describe the intra-syllabic behaviour of languages; therefore, languages aligning along the bisecting line are only said to show segmental control, while languages clustering below the bisecting line are only considered to compensate at the segmental level.

As for the inclusion of prosodic parameters (namely pitch and intensity), the preliminary test has not provided a clear representation of language groups. This may well be because the values have been computed on a non-native speaker, but procedural caveats make it difficult to obtain comparable data by several speakers. However, it is desirable that intensity and pitch be somehow integrated in a fulfilled speech rhythm account.

4.

Correlatore

4.1 Introduction

This chapter is the most technical one of the thesis as it introduces *Correlatore*, a programme that I have developed in Tcl/Tk in order to automatically compute the most commonly used rhythm metrics (%V, ΔC, ΔV, Varcos, PVIs, CCIs) from *Praat*'s annotation files. Initially, *Correlatore* was merely conceived as Perl script applying the formulae of rhythm metrics to raw data, but it then developed into a full framework that can be used for the study of linguistic rhythm with the metrics. It includes a tool for saving and organizing data into multiple reports, a module for building customizable charts, and various extras, such as the visualisation of the segmentation (into vocalic and inter-vocalic segments), the consultation of the formulae for each rhythm metric, the customisation of how SAMPA transcriptions should be treated and the creation of simple *SASASA* files for perceptive tests.

The version of *Correlatore* that will be presented here is 2.2[63]. At first, I shall briefly review the reasons for setting out to develop such a programme, and then I shall illustrate how it works and how it has been implemented.

4.1.1 The reasons for developing *Correlatore*

Since the computing of rhythm correlates is an extremely time-consuming task, most authors have used (above all at first) a restricted corpus for their research. Some authors (e.g. Rouas & Farinas, 2004) have thus used automatic segmentation tools in order to speed up the procedure and be able to use greater amounts of data. However, the results are marred by the fact that the tools that are presently available are not yet able to produce a high-quality segmentation. Most authors assume though that the drawback of low-quality segmentation is somehow compensated by the use of great amounts of data.

On the other side, instead of automating speech segmentation, it is possible to speed up the processing of formulae on data. Everyone working with rhythm metrics has experienced that computing them in spreadsheets is not only time-consuming, but also fairly uncomfortable and complicated. This is even more so when one sets out to enlarge their corpus and/or decides to use other metrics.

So, after annotating speech samples of English, French, German, Italian, Icelandic and Finnish with *Praat* and computing the deltas, the varcos, the PVIs and the CCI, I experienced growing difficulties in the organisation and maintenance of data on spreadsheets. Furthermore, since I had used different spreadsheets for different metrics, making modifications and/or corrections on data was extremely complicated and redundant, which, in turn, made it difficult to make cross-comparisons between specific sets of data and metrics.

For these reasons, I decided that I needed at least a faster and simpler way of calculating rhythm metrics, so at first I wrote a Perl script which processed the formulae on *Praat*’s annotation files (*TextGrids*). Then, I thought I might make it publicly available and built a rudimentary graphic user interface with Perl/Tk. At that point, I realised that I could develop a more sophisticated program, so I turned to Tcl/Tk and gradually added extra features, which finally merged into *Correlatore*

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[63] At the moment of writing, the last version downloadable from the website was 2.1, but the 2.2 version should be soon available. It can be retrieved at the following Internet address http://www.lfsag.unito.it/correlatore/index_en.html (it has a GPL license).

1.0. A series of bug fixes and modifications in the interface and report system were then integrated in Correlatore 2.0.

So, if one wishes to carry on research on rhythm metrics, one only needs to annotate wave files with *Praat* and, then, to open the *TextGrids* in *Correlatore*: one will obtain the values for the correlates quoted above and will be able to build charts with the results displaying all possible combinations of metrics.

Finally I shall explain the name *Correlatore*: it refers to how the metrics were first called by Ramus, Nespor & Mehler (1999), that is to say *rhythmic correlates*, *correlati del ritmo* in Italian. I added the Italian suffix *-tore* (which can be compared to the English suffix *-er* and which denotes the agent or the instrument) to the stem *correlato* to form *Correlatore* (that is to say, "somebody or something that produces correlates"); but it is also a pun, as the word *correlatore* actually exists in Italian and indicates the co-director of a thesis.

4.2 How to use Correlatore

4.2.1 The annotation of *Praat*'s *TextGrids*

Correlatore works on *Praat*'s *TextGrid* files, so the first step is of course to annotate sound files in *Praat*. As of version 2.2, annotations with two types of transcriptions are supported: in CV and SAMPA (CV transcriptions are implemented with a higher degree of correction). However, whatever the choice of using CV or SAMPA, one should carefully follow the conventions reported below in order to avoid the risk of *Correlatore* interpreting the transcriptions badly. Although these conventions may seem odd and unnecessary, there are reasons why I had to introduce them: they are explained in chapter 3 with the illustration of how the segmentation is carried out.

For CV transcriptions, every label should correspond to a vocalic/consonantal interval and be annotated with as many "c"' or "v" as the number of segments composing the interval. For instance, <campus> should be annotated as |c|v|cc|v|c| and Italian <palla>' as |c|v|cc|v|. Pauses should be left empty or labelled as |#|. This leaves the user free to decide how to treat segments whose phonological status is debated (such as syllabic consonants) and to be in full control of the subdivision of intervals; so, it is possible to follow the instructions set by Bertini & Bertinetto (2009) for the calculation of the CCI: for example, hyati can be labelled as 2 distinct intervals: e.g. Italian 'suo' |c|v|v|.

Alternately, it is also possible to use a simpler segmentation that does not take into consideration the number of segments composing each interval, ex. <campus> |c|v|c|v|, Italian 'palla' |c|v|c|v|, but keep in mind that this will result in faulty CCI values (their formula requires each interval to be divided by the number of phonological segments composing it, which in this case would be interpreted as 1, thus giving the same results as the rPVIs).

For SAMPA transcriptions:

a) every label should correspond to one and only one phone (that is to say a vowel or a consonant, not a vocalic or consonantal interval);
b) phonologically long phonemes (like long vowels in Finnish and geminate consonants in Italian) should be annotated with two distinct labels (even though the boundary between the two is of course ficticious); for instance,

the Finnish word 'saami' should be annotated as: |s|a|a|m|i|, not as |s|a:|m|i| and nor as |s|aa|m|i|;

c) it is normally possible to use standard SAMPA diacritics, but if you use any non standard diacritic or annotation convention, this may interfere with the substitution variable (see below). For instance, if you use t_u (instead of t_w) to indicate a labialised voiceless alveolar plosive, this label will be interpreted as a vowel because of the 'u'.

d) Pauses should be labelled as '#' or left empty.

e) *Correlatore* uses a substitution variable to transform SAMPA transcription into CV sequences that contains all the symbols that should be considered as vocalic: if a label contains one of these symbols, it will count as a vowel, otherwise as a consonant (except for '#', which indicates pauses). The variable's value is shown in the statusbar in the main window and it is possible to change it by clicking on it.

f) During the process of segmentation of a tier labelled as SAMPA, Correlatore builds vocalic and consonantal intervals by summing the duration of adjacent consonants/vowels. This means that hyati will be considered as one interval: although, this does not have any effects on the results of the deltas, varcos and PVIs, it does have some consequences on the values of CCI. So, if one wishes to obtain more precise results for the CCI, it is advisable to opt for a CV segmentation.

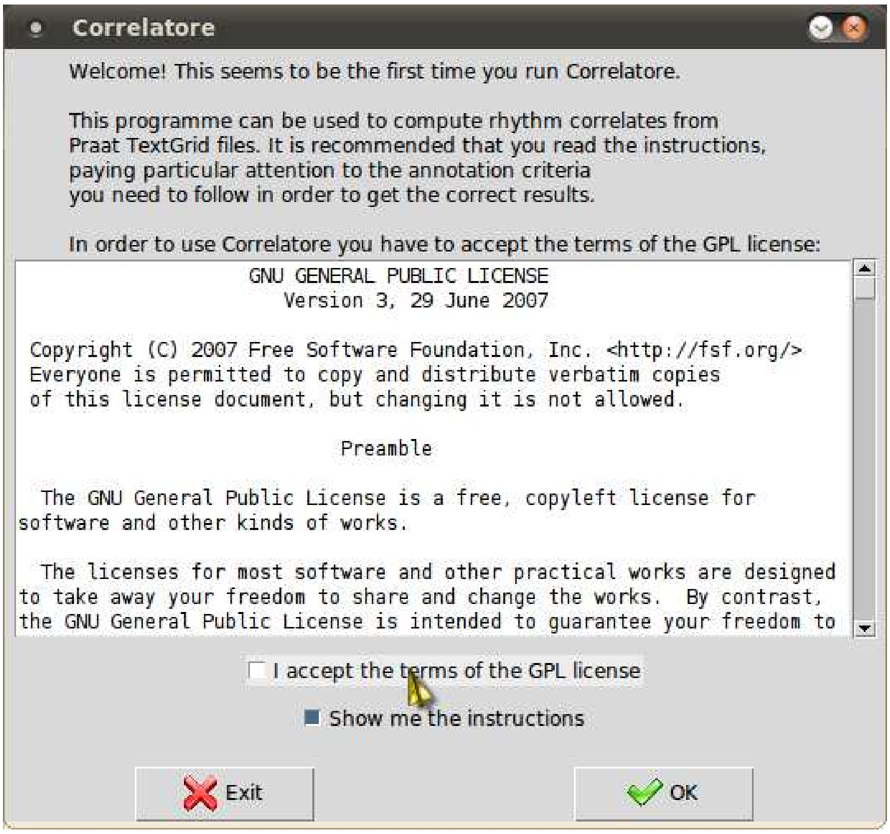
4.2.2 Computing rhythm metrics

Once the *TextGrids* have been annotated, it is possible to open them in *Correlatore*. As already mentioned, *Correlatore* does not need installation, it is started by simply double-clicking on the executable. The first time it is run, the user will be prompted with a window asking to specify the language (English or Italian, see figure 4.1), and then to accept the terms of the GPL license and whether he/she would rather see the instructions (see figure 4.2).

Correlatore 2.2 - 2009-2011
Paolo Mairano
Laboratorio di Fonetica Sperimentale
Universita' di Torino

Welcome! Please choose your language.
Benvenuti! Per favore scegliere la lingua.

Figure 4.1. *Correlatore*'s window asking to choose the language. This window is only shown the first time the executable is run.



Welcome! This seems to be the first time you run Correlatore.

This programme can be used to compute rhythm correlates from
Praat TextGrid files. It is recommended that you read the instructions,
paying particular attention to the annotation criteria
you need to follow in order to get the correct results.

In order to use Correlatore you have to accept the terms of the GPL license:

```
                    GNU GENERAL PUBLIC LICENSE
                       Version 3, 29 June 2007

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 Everyone is permitted to copy and distribute verbatim copies
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                            Preamble

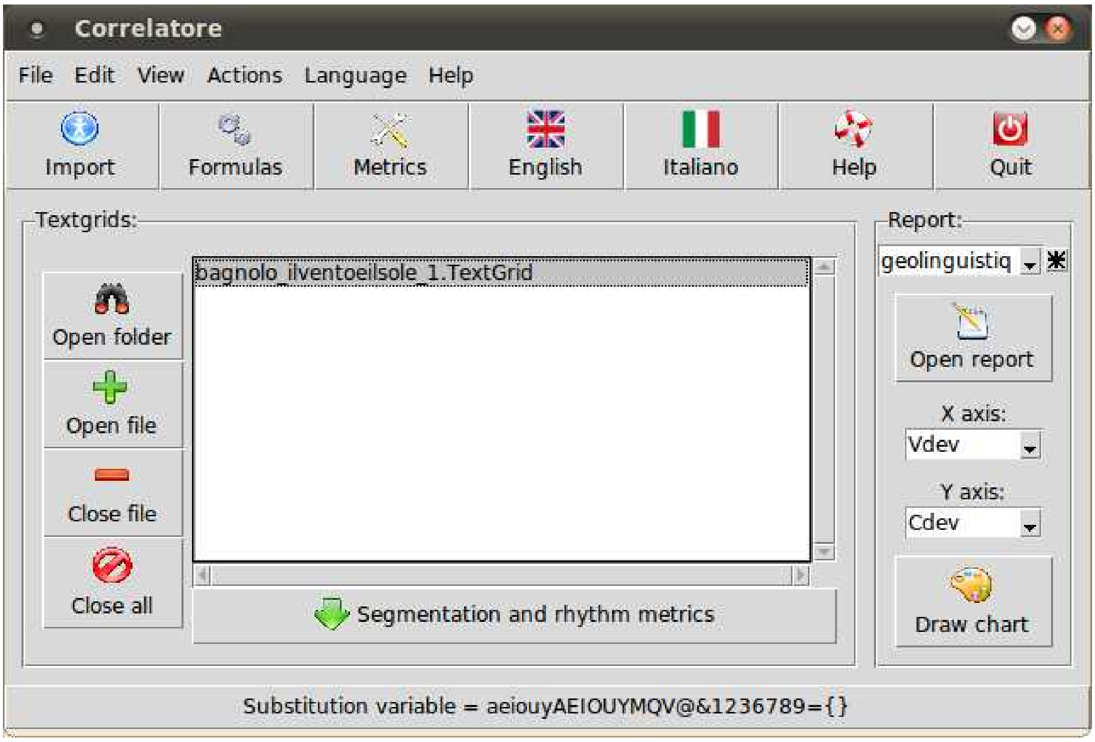
  The GNU General Public License is a free, copyleft license for
software and other kinds of works.

  The licenses for most software and other practical works are designed
to take away your freedom to share and change the works.  By contrast,
the GNU General Public License is intended to guarantee your freedom to
```

☐ I accept the terms of the GPL license

☑ Show me the instructions

Figure 4.2. *Correlatore*'s window asking to accept the GPL license. This window is only shown the first time the executable is run.



bagnolo_ilventoeilsole_1.TextGrid

Report: geolinguistiq

X axis: Vdev

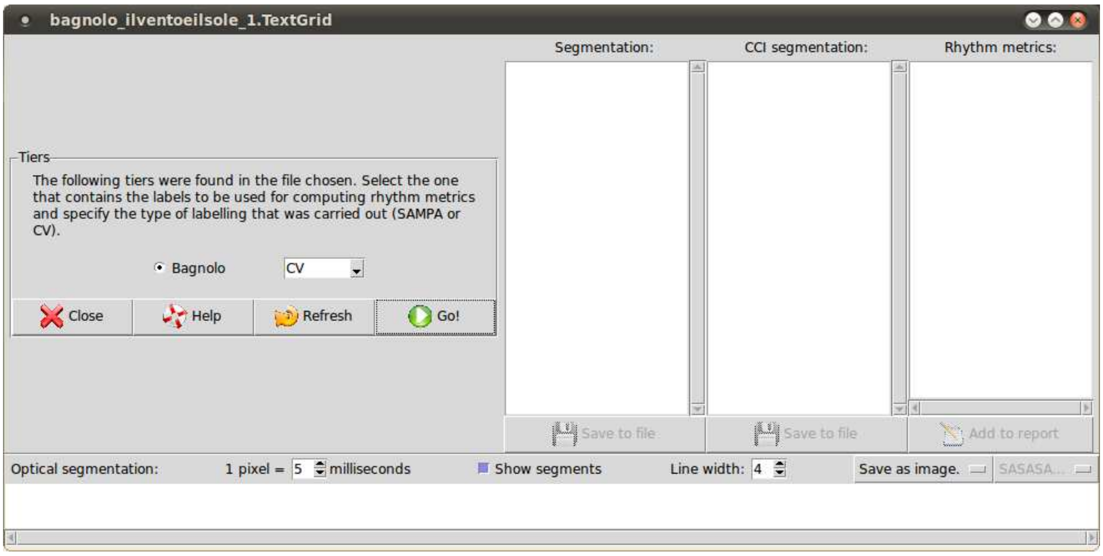
Y axis: Cdev

Substitution variable = aeiouyAEIOUYMQV@&1236789={}

Figure 4.3. *Correlatore*'s main window.

After making these choices, the user will be presented with *Correlatore*'s main window (figure 4.3), which includes a menu, a toolbar, some buttons and an empty box. The left part of the window deals with *TextGrids*, while the right part deals with reports and charts. The statusbar indicates the current value of the SAMPA substitution variable. Once *Correlatore* starts, it automatically scans in its folder for files with a *.TextGrid* extension; if it finds any, they will appear in the box of the main window; otherwise, it will be possible to click "Open file" or "Open folder" and browse to the folder containing the *TextGrid*(s). Once open, its/their name(s) will be shown in the box. They can be closed by clicking "Close file" and "Close all".

In order to compute the rhythm metrics, one has to select one and only one *TextGrid* and click on "Segmentation and rhythm correlates". A new window will pop up (see figure 4.4) showing on the left the names of the tier(s) found in the *TextGrid*. The user is asked to select the tier (if there is more than one) he/she intends to work with and to specify the type of annotation used[64] (aka SAMPA or CV).



The following tiers were found in the file chosen. Select the one that contains the labels to be used for computing rhythm metrics and specify the type of labelling that was carried out (SAMPA or CV).

● Bagnolo CV

Optical segmentation: 1 pixel = 5 milliseconds ■ Show segments Line width: 4

Figure 4.4. *Correlatore*'s segmentation window.

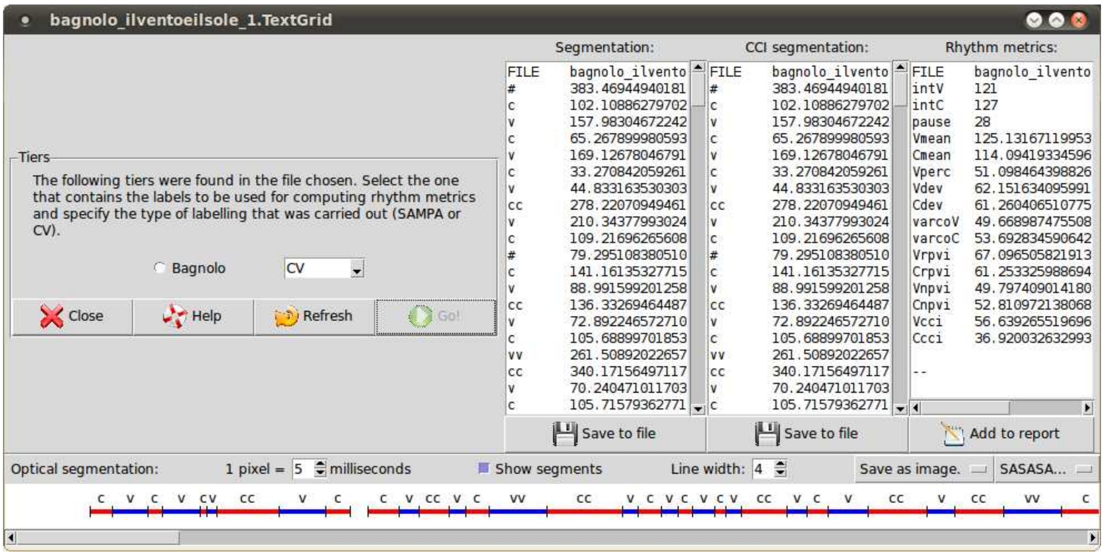
The user should makes his/her choices and press "Go!". The three boxes on the right will filled (see figure 4.5) and, in case of problems, a log window will pop up (for example, if *Correlatore* finds unexpected labels, such as a |b| in a *TextGrid* which has been annotated as CV). In the first box on the left, it is be possible to see how the data were segmented (*i.e.* the consonantal and vocalic intervals with the corresponding durations in ms) for the deltas, the varcos and the PVIs. In the second box you will see how the data has been segmented for the CCI: note that there will only be a difference between the contents of those two boxes if the *TextGrid* has been annotated with a CV transcription following the conventions specified above. Both segmentations can be saved in TXT format by pressing "Save to file". In the third box you will see some information about the file (n° of V and C intervals, n° of pauses, mean duration of V and C segments) and the values of rhythm correlates. It is possible to save these results to a report by clicking on "Add to report" and then

---

[64] *Correlatore* does try to detect whether every tier has been labelled as SAMPA or CV but the algorhythm used is extremely simple and should not be trusted blindly.

by selecting the report that should contain them (by default they will saved in the active report).

At the bottom of the window, it is possible to see a graphic representation of the vocalic and consonantal segments (the colours, size and scale of the lines can be customised using the appropriate controls). Using the controls on the right at the bottom, it is also possible to listen to a *SASASA* file which *Correlatore* builds automatically during the segmentation[65]: it consists of a rudimentary synthesis of C intervals as [s] and of V intervals as [a] that can be used for perceptive tests. It can also be saved in WAV format.



The following tiers were found in the file chosen. Select the one that contains the labels to be used for computing rhythm metrics and specify the type of labelling that was carried out (SAMPA or CV).

Segmentation:

```
FILE      bagnolo_ilvento
#         383.46944940181
c         102.10886279702
v         157.98304672242
c         65.267899980593
v         169.12678046791
c         33.270842059261
v         44.833163530303
cc        278.22070949461
v         210.34377993024
c         109.21696265608
#         79.295108380510
c         141.16135327715
v         88.991599201258
cc        136.33269464487
v         72.892246572710
c         105.68899701853
vv        261.50892022657
cc        340.17156497117
v         70.240471011703
c         105.71579362771
```

CCI segmentation:

```
FILE      bagnolo_ilvento
#         383.46944940181
c         102.10886279702
v         157.98304672242
c         65.267899980593
v         169.12678046791
c         33.270842059261
v         44.833163530303
cc        278.22070949461
v         210.34377993024
c         109.21696265608
#         79.295108380510
c         141.16135327715
v         88.991599201258
cc        136.33269464487
v         72.892246572710
c         105.68899701853
vv        261.50892022657
cc        340.17156497117
v         70.240471011703
c         105.71579362771
```

Rhythm metrics:

```
FILE      bagnolo_ilvento
intV      121
intC      127
pause     28
Vmean     125.13167119953
Cmean     114.09419334596
Vperc     51.098464398826
Vdev      62.151634095991
Cdev      61.260406510775
varcoV    49.668987475508
varcoC    53.692834590642
Vrpvi     67.096505821913
Crpvi     61.253325988694
Vnpvi     49.797409014180
Cnpvi     52.810972138068
Vcci      56.639265519696
Ccci      36.920032632993


--
```

Figure 4.5. *Correlatore*'s segmentation window after the computation of rhythm metrics.

Finally, it is possible to compute the metrics on other tiers by clicking on "Refresh" or to go back to the main window by clicking on "Close".

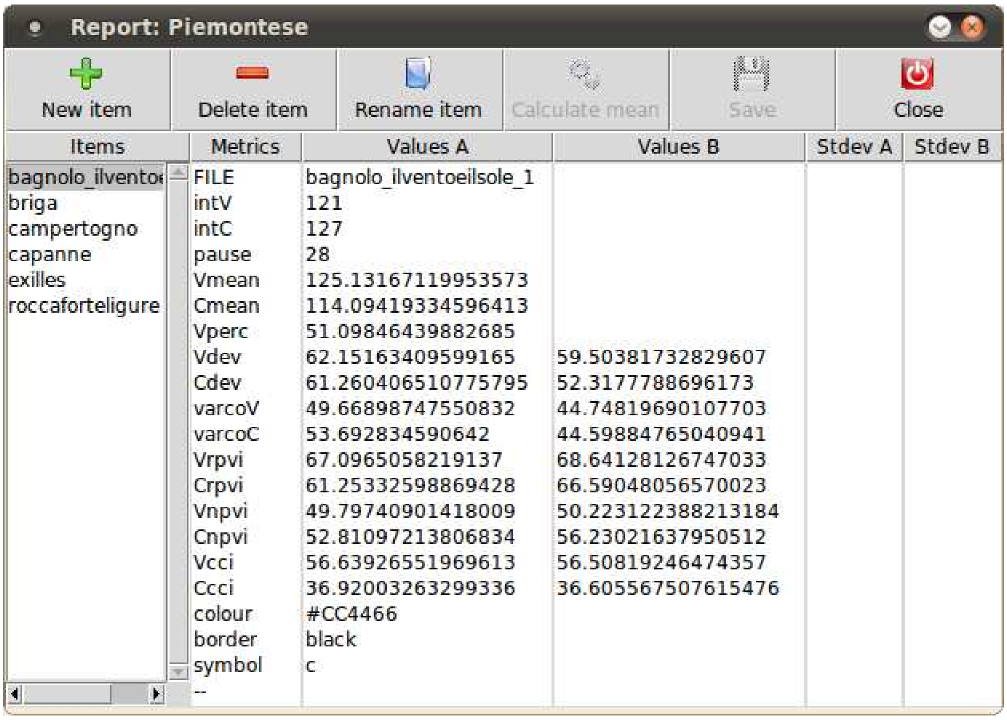
4.2.3 Reports

Reports contain the results of correlates computed on one or more files. They can be viewed, modified and exploited from the right frame of the main window: a pop-down menu allows the user to select one report among the existing ones. Pressing "Open report" will open a new window which allows to see the results of the metrics by clicking on the name of each item (see figure 4.6). The user can view and edit the items stored in the active report: it is possible to rename one or more items, to delete them or to calculate the mean of their values. In the last case, a new item will be created containing the means and the standard deviation, which will be used as the value of error bars when building charts. So, for instance, it is possible to have a sound file annotated by 2 different people, to calculate the correlates on both resulting TextGrids, to save data in the report and to calculate the mean: this way, when charts will be created with these data, a circle will be shown to indicate the value of the mean, while error bars will reflect inter-operator variability. Also, one can annotate say 10 sound files from different speakers of the same language and save the results of the metrics in the report, then calculate the mean and draw the

---

[65] If *Correlatore* is executed from the sources, the *Snack Sound Toolkit* needs to be installed. If it is not, this feature is disabled.

chart in order to visualise the mean value with error bars indicating inter-speaker variability within the same language[66].



Items

bagnolo_ilvento
briga
campertogno
capanne
exilles
roccaforteligure

Metrics	Values A	Values B	Stdev A	Stdev B
FILE	bagnolo_ilventoeilsole_1			
intV	121			
intC	127			
pause	28			
Vmean	125.13167119953573			
Cmean	114.09419334596413			
Vperc	51.09846439882685			
Vdev	62.15163409599165	59.50381732829607		
Cdev	61.260406510775795	52.3177788696173		
varcoV	49.66898747550832	44.74819690107703		
varcoC	53.692834590642	44.59884765040941		
Vrpvi	67.0965058219137	68.6412812674 7033		
Crpvi	61.25332598869428	66.59048056570023		
Vnpvi	49.79740901418009	50.223122388213184		
Cnpvi	52.81097213806834	56.2302163795 0512		
Vcci	56.63926551969613	56.5081924647 4357		
Ccci	36.92003263299336	36.605567507615476		
colour	#CC4466			
border	black			
symbol	c			
--				

Figure 4.6. *Correlatore*'s report window.

Select the report you would like to use.

geolinguistique.txt
geolinguistique_stdev.txt
geolinguistique_sterr.txt
iasi_medie.txt
iasiA.txt
iasiB.txt
IPA0.txt
IPA1.txt
IPA2.txt

New report: .txt

Figure 4.7. *Correlatore*'s window from which it is possible to clone, rename, delete, export and import reports.

---

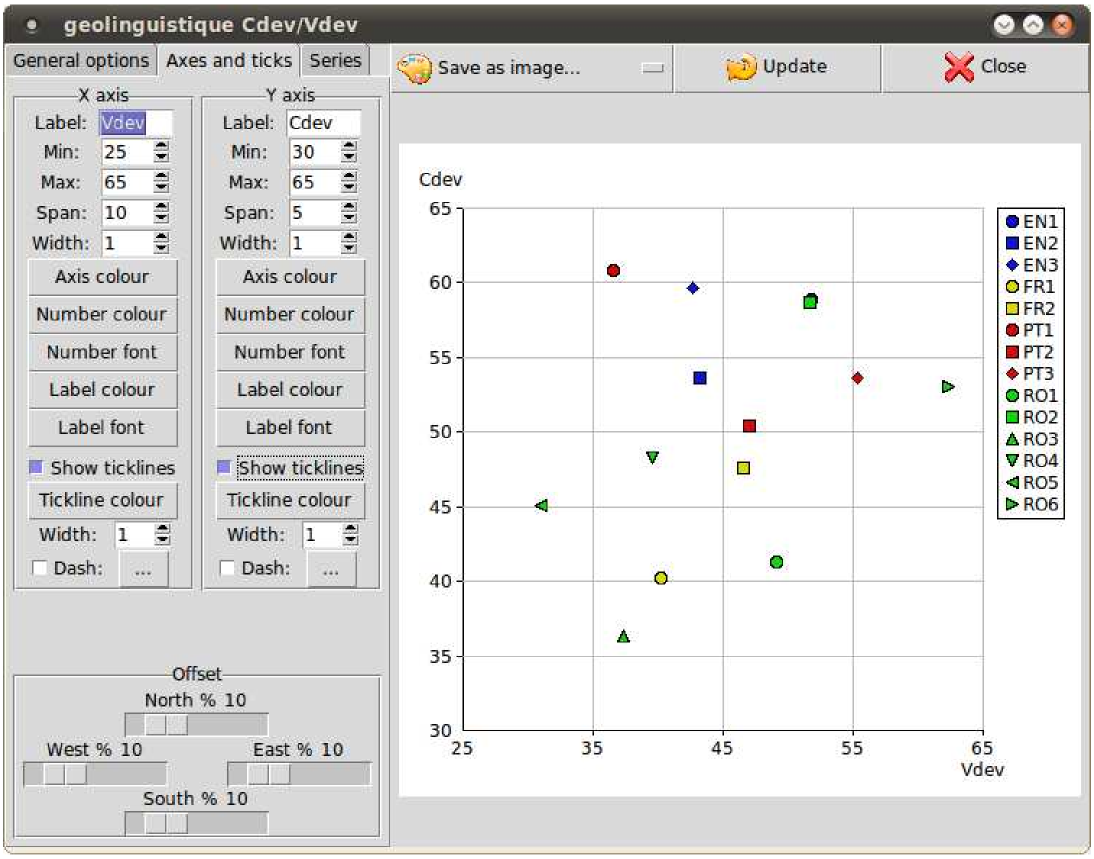
[66] One may be surprised when visualising *Correlatore*'s error bars, as they are greater than error bars in many similar studies. This is because these works use the standard error, whereas *Correlatore* uses the standard deviation. The standard error is the standard deviation of the sampling distribution associated with the estimation method. So, in order to get the value of the standard error, one has to divide the value of the standard deviation by the square root of the number of samples used to calculate the mean: the standard error is therefore smaller than the standard deviation (unless the mean is calculated on one only sample, which definitely is neither useful nor advisable).

Of course it is possible to create new reports, to rename them, to export and import them. These operations can be carried out by clicking on the asterisk-button beside the pop-down menu of the main window, which will pop up a new window (see figure 4.7).

Although the import/export facility allows the user to easily exchange data among different computers and/or users, one should be careful as *Correlatore* does not check the validity of imported reports (it only checks that they are in TXT format) and even a small change may make them unusable or faulty. Importing valid reports is considered to be the user's responsibility.

4.2.4 Charts

Charts can be built from data in the report. In the main window (see figure 4.3) it is possible to choose which metrics have to be represented in the x and y axes using the two pop-down menus at the right. Then, by pressing “Draw chart”, a window will open (see figure 4.8) with a chart and several controls for customisation: one can specify preferences as for the size of the chart, the indicators' shapes and colours, the legend, the labels, the title, the axes, etc.



geolinguistique Cdev/Vdev

X axis
Label: Vdev
Min: 25
Max: 65
Span: 10
Width: 1
☑ Show ticklines
Width: 1
☐ Dash: ...

Y axis
Label: Cdev
Min: 30
Max: 65
Span: 5
Width: 1
☑ Show ticklines
Width: 1
☐ Dash: ...

Offset
North % 10
West % 10
East % 10
South % 10

Figure 4.8. *Correlatore*’s chart windows. The chart can be modified using the controls on the left (not all are visible because they are distributed on three tabs).

Charts can also be exported to several image formats (JPEG, PNG, GIF, BMP, GIF, etc.[67]) by clicking on “Save as image” in order to be inserted into

---

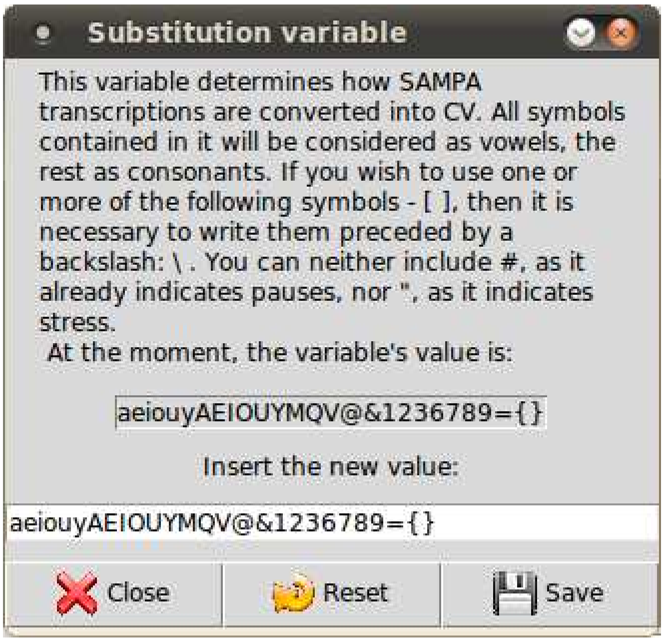
[67] If the user is running *Correlatore* from the sources, the extension *Tkimg* needs to be installed. Otherwise, it will only be possible to export charts in *PostScript* format.

publications. Most charts presented in the previous chapter have been created this way.

4.2.5 Preferences and configurations

Configuration options are stored in a configuration file in order to make them persistent. This means that they will be remembered if you close and restart *Correlatore*.

The SAMPA **substitution variable** is used in the transformation of SAMPA transcriptions into CV sequences. It contains all the symbols which are to be considered as vocalic: that is to say, when a *TextGrid* labelled with SAMPA is opened, every label containing one of the symbols in the substitution variable is replaced with V, in all other cases with C (except for # which indicates pauses). Its default value is aeiouyAEIOUY@MQV&1236789={} (so syllabic consonants are included, while glides are considered as consonantal), but you can modify it by clicking on “Edit variable” or through the menu “Edit” (see figure 4.9).



This variable determines how SAMPA transcriptions are converted into CV. All symbols contained in it will be considered as vowels, the rest as consonants. If you wish to use one or more of the following symbols - [ ], then it is necessary to write them preceded by a backslash: \ . You can neither include #, as it already indicates pauses, nor ", as it indicates stress.

At the moment, the variable's value is:

aeiouyAEIOUYMQV@&1236789={}

Insert the new value:

aeiouyAEIOUYMQV@&1236789={}

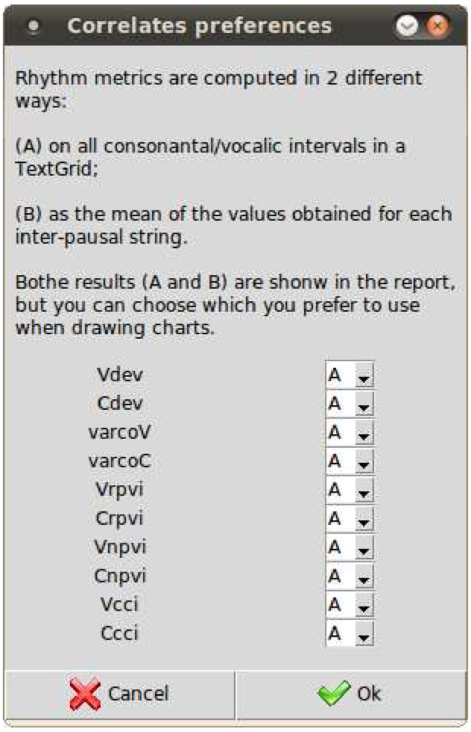
Figure 4.9. *Correlatore*’s window for the modification of the substitution variable.

Rhythm metrics preferences control how the metrics are computed. There are two possibilities:

A) they can be calculated by applying the formulae (delta, varco, rPVI, nPCI or CCI) to all the vocalic and consonantal intervals found in a tier;

B) they can be calculated by applying the formulae (delta, varco, rPVI, nPCI or CCI) to the vocalic and consonantal intervals of every single inter-pausal segment and then calculating the mean of the values obtained.

Starting from *Correlatore* 2.0, all correlates are computed both ways (and both results are saved in the report); however, it is necessary to specify which type of results you wish to use when building charts: *Correlatore* uses method A by default, but it is possible to modify this behaviour by clicking on “Metrics” in the toolbar, or through the menu “Edit” (see figure 4.10).



Rhythm metrics are computed in 2 different ways:

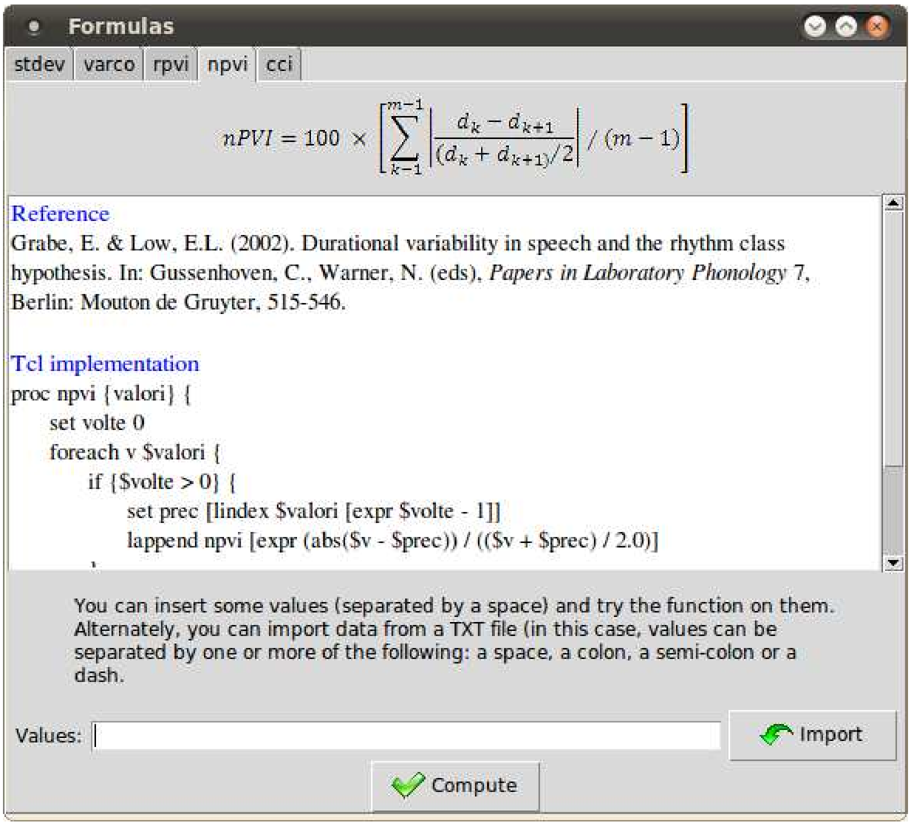
(A) on all consonantal/vocalic intervals in a TextGrid;

(B) as the mean of the values obtained for each inter-pausal string.

Bothe results (A and B) are shonw in the report, but you can choose which you prefer to use when drawing charts.

Vdev A
Cdev A
varcoV A
varcoC A
Vrpvi A
Crpvi A
Vnpvi A
Cnpvi A
Vcci A
Ccci A

Figure 4.10. *Correlatore*'s window for setting the preference on the A/B methods of computing rhythm metrics.



$$nPVI = 100 \times \left[\sum_{k=1}^{m-1} \left| \frac{d_k - d_{k+1}}{(d_k + d_{k+1})/2} \right| / (m-1) \right]$$

Reference

Grabe, E. & Low, E.L. (2002). Durational variability in speech and the rhythm class hypothesis. In: Gussenhoven, C., Warner, N. (eds), *Papers in Laboratory Phonology* 7, Berlin: Mouton de Gruyter, 515-546.

Tcl implementation

```
proc npvi {valori} {
    set volte 0
    foreach v $valori {
        if {$volte > 0} {
            set prec [lindex $valori [expr $volte - 1]]
            lappend npvi [expr (abs($v - $prec)) / (($v + $prec) / 2.0)]
```

You can insert some values (separated by a space) and try the function on them. Alternately, you can import data from a TXT file (in this case, values can be separated by one or more of the following: a space, a colon, a semi-colon or a dash.

Values:

Figure 4.11. *Correlatore*'s window showing the formulae and their Tcl implementation. The user can try the formulae by inserting values in the text field at the bottom and clicking on "Compute".

If one wishes to see how rhythm metrics are computed, it is possible to click on **Formulae** or on the menu “Edit” and then on “View TCL implementation of rhythm metrics”. A new window will pop up (see figure 4.11), showing the formulae of rhythm metrics and their TCL implementation. It is possible to insert numerical values or to import them from a TXT file in order to try the formulae.

Moreover, *Correlatore* is available in English and Italian, it is possible to switch language simply by clicking on the corresponding button. Moreover, it is possible to control other more futile preferences, such as hiding/showing the statusbar, the toolbar and the tooltips; on Unix machines (other than MacOsX) one can also choose three different themes for the interface.

4.3 The implementation of Correlatore

Correlatore was developed in Tcl/Tk and consists of 4663 lines of code in total (plus all the documentation in English and Italian). All procedures[68] (including the ones for the creation and customisation of charts) were written by me in order to make *Correlatore* completely independent from other projects and to better suit to my needs. I only used two external libraries (*Tkimg* and *Snack*), for two extra features: the first controls the conversion of charts into several image formats (jpeg, gif, png, tiff, etc.), whereas the second is used for the manipulation of sounds for the synthesis of *SASASA* files. However, these two libraries are optional, meaning that if for some reason they are not provided, *Correlatore* will run normally, except for the fact that these two extra features will be disabled.

I shall now present how it was implemented, first explaining the reasons for choosing Tcl/Tk, then providing an overview of its structure and then focusing on specific issues.

4.3.1 Why Tcl/Tk?

Tcl (Tool Command Language) is a scripting language created by John Ousterhout and first appeared in 1988, while Tk (ToolKit) is an extension to Tcl that makes it possible to build graphic user interfaces (GUIs). The combination of the two is generally referred to as Tcl/Tk and has been used widely, also in several academic projects[69]. The reasons for choosing it over other languages are the following:

1) It is open-source and licensed under very liberal terms.
2) It is a multi-platform interpreted procedural language, which allows the sources to run unmodified on many operating systems.
3) It provides several useful features such as regular expressions (which have been essential for the analysis of Sampa-labelled TextGrids) and a canvas widget (which has made possible the development of a module for the creation of charts).
4) Tk has sometimes been criticised because the graphic interfaces created with this toolkit are said to look ugly and do not integrate with the operating system. If ever this has been true and of any relevance, it is no longer so starting from version 8.5, which uses native widgets on Windows and

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[68] Subroutines are called procedures in Tcl.

[69] For instance, *Wavesurfer,* a well-known sound visualisation and manipulation tool, is written in Tcl/Tk.

MacOsX (not yet on other Unix platforms – but the appearance has been improved here as well).

5) With Tclkit, it is possible and easy to create executables that do not need an installation of Tcl/Tk and that are extremly light in terms of system requirements (*Correlatore* for Windows requires less than 2 MB) and that do not even need any installation at all.
6) Several extensions exist for the simplification of some tasks: in particular I used Tkimg (for the conversion of charts into several image formats for use in articles and other publications) and *Snack* (which provides facilities for acoustic analysis and is used for the synthesis of simple *SASASA* files).

It has to be remarked that I have used many features of Tk 8.5 which are not available in the old but far more popular 8.4 version. However, it is possible to run Correlatore under Tcl/Tk 8.4 by installing an extension called *tile*, (which provides the missing widgets) as I made an effort to write Tcl code that is completely compatible with Tcl 8.4.

Finally, it is worth to mention that although the sources have been designed with portability in mind and should run unmodified on all platforms, *Correlatore* has been developed since the beginning on Ubuntu Linux and is only tested on this platform and on Windows XP.

4.3.2 Overview

Correlatore consists of eight source files and a folder containing a library (*plib*) which I developed specifically and which contains the most commonly used procedures. `correlatore.tcl` is the main file (the one that has to be executed to start *Correlatore* from the sources): firstly, it does a couple of checks (e.g. it controls Tcl/Tk's version), then it creates an interface to deal with any runtime error, finds its path, loads *plib*, all images for the GUI and the procedures contained in the other files, sets some preferences, checks if there has been a version upgrade (if so, it loads `versioni.tcl`, which fixes compatibility issues between versions) and finally loads `start.tcl`. This file prompts the user to accept the GPL license at the first execution, that it reads (or creates at the first execution) the configuration file, sets global variables and builds the graphic user interface (GUI) of the initial window. As in normal GUIs, all items in the window are associated to procedures that are executed at specific events: for instance, the button *Draw chart* is associated to the procedure `disegna`, which is executed when this button is pressed by the user.

I shall now discuss a number of issues that have posed problems or difficulties in the implementation.

4.3.3 How the segmentation and the transcriptions are dealt with

As has been said above in this chapter, *Correlatore* accepts CV and SAMPA transcriptions, as SAMPA transcriptions are internally converted to CV transcriptions before the segmentation. The first thing to be done is to fix SAMPA characters that may potentially interfere with Tcl, namely inverted commas, backslashes, as well as square and curly brackets. Then, SAMPA transcriptions are converted into CV transcriptions using the so called substitution variable: this variable (whose content is customisable and persistent as it is saved in the configuration file) contains a string with all SAMPA symbols that have to be considered as vowels. *Correlatore* compares each SAMPA annotation with the substitution variable and considers it to be a vowel/consonant if it matches/does not match any character of the substitution variable. This type of conversion is far from being sophisticated and should therefore be improved in the future. Instead, CV transcriptions are only checked: should one segment not contain any of the following five symbols "c", "C", "v", "V" or "#", it is discarded from the list and is appended to the error variable, which is then used for a final log.

As far as the segmentation is concerned, it is very complex mainly because of the different needs of the deltas, varcos, and PVIs on the one hand, and the CCI on the other hand, which requires a partially separate treatment. In fact, this is also the reason why annotation criteria for CV files are so complex (see above, 4.2.1). I shall now analyse the difficulties in the implementation and solutions adopted while illustrating the reasons for the constraints on transcription criteria.

The “older” metrics merely require a segmentation into consonantal and vocalic intervals so that the implementation would be simple both for CV transcriptions and for SAMPA annotations. As for CV transcriptions, the situation would be extremely straightforward as a simple |c| annotation for consonantal intervals and a |v| annotation for vowels would be enough: the script should just create two lists (C and V) and then apply the formulae to the durations. As for SAMPA transcriptions, each annotation only contains one phoneme: so, the implementation would simply need to construct consonantal and vocalic intervals by summing up the durations of, respectively, consonantal clusters and adjacent vowels (be they diphthongs or hiati).

Instead, the formula of the CCI divides each interval duration by the number of phonological segments that compose it. For SAMPA transcriptions, this does not imply any particular problem: as has been said, vocalic and consonantal intervals have to be constructed, so one simply has to keep track of who many segments are united to compose each interval and then divide the duration of the interval by that number. On the contrary, this does have some repercussions on CV annotations, as simple |c| and |v| labels for whole vocalic and consonantal intervals are no longer adequate. In fact, since *Correlatore* does not access sound files[70], there is no way it could distinguish a |c| indicating a simple consonant from a |c| indicating a cluster of two, three or more consonants; in short, *Correlatore* would not know how many segments compose the interval and, therefore, could not make a division by that number. So, each label needs to be annotated so that the number of segments is explicit: |c| for a simple consonant, |cc| for a cluster of two consonants, |ccc| for a cluster of three consonants, and so forth. In the same way, |v| for a single vowel, |vv| for a diphthong, |vvv| for a triphthong. This results in an acceptable implementation of all correlates.

However, if one wants to stick to the indications on how to compute the CCI given by the two authors (Bertini & Bertinetto, 2009), there are further complications: hyati have to be considered as two separate segments. Again, the problem is that *Correlatore* does not access sound files and therefore cannot distinguish between a “vv” label indicating a diphthong from a “vv” label indicating a hyatus. Its implementation is be possible by slightly changing transcription criteria

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[70] And, even if it did, it would need to do some speech recognition in order to establish how many segments compose an interval, which is well beyond my purposes.

and conventionally establishing that diphthongs must be annotated in one single label, whereas hyati have to be annotated in two separate labels: so, |vv| (or, for instance, |aI| in SAMPA) should indicate a diphthong and |v|v| (or |a|I| in SAMPA) should indicate a hyatus. This has been implemented exclusively for CV transcriptions[71] and is also the reason while *Correlatore* (from version 2.2 onwards) presents two segmentations: the first is the one that is used for the computing of deltas, varcos and PVIs (where hyatus labels such as |v|v| have to be united and considered as a single vocalic interval); the second is the one that is used for the computing of the CCI (where such hyatus labels are kept separated).

In conclusion, the analysis of the transcription and the process of segmentation are fairly complicated and reserve a separate treatment to SAMPA and CV transcriptions as well as to deltas, varcos, and PVIs on the one hand, and to the CCI on the other hand. The procedures dealing with them are all contained in the file `calcoli.tcl`: while reading the *TextGrid*, the content of each tier is stored in a Tcl list where the annotation of each segment and its duration in ms are appended one after the other. Once the user chooses the tier that contains the CV or SAMPA annotation, each element of the list is analysed in a `foreach` cycle[72] in which SAMPA transcriptions are converted to CV transcriptions and where the two groups of metrics are dealt with separately.

Future improvements of the process of segmentation should include a new implementation of the SAMPA to CV conversion and the possibility of using IPA transcriptions.

4.3.4 How formulae are dealt with

All formulae of rhythm metrics are implemented as single and independent procedures[73] and it is even possible to visualise them within *Correlatore* itself (by pressing the *Metrics* button in the toolbar). Their implementation is reported in appendix 3a.

Deltas, varcos and the PVIs require just one argument, that is to say a list of numeric values (on which the formulae are applied). Instead, the CCI is slightly more complex and it requires the number of phonological segments for each vocalic or consonantal interval to be passed as an argument as well. So, the CCI procedure has to be called with two parallel lists as arguments, the first being a the list of the durations of each interval, the second being a list of the number of segments contained in the corresponding interval.

It has to be noted that these procedures simply apply the formula on the numeric values that are passed as arguments; the job of make a difference between consonantal and vocalic segments is done previously and separately.

4.3.5 How reports are dealt with

As it has been said, results of the metrics can be saved in reports. Of course, reports have to be persistent through different instances of *Correlatore*, that is to say that

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[71] The reason for not implementing this for SAMPA transcriptions is that it would create further problems because of the method used for the SAMPA to CV conversion (that is to say, the substitution variable). Since this method is not sophisticated and at any rate will be improved in the future, I decided not to implement it for the moment.

[72] The `foreach` cycle is reported in appendix 3b for inspection.

[73] Apart from %V, which does not have a procedure for itself as it is simply implemented in-line.

they should not be lost when *Correlatore* is closed or when the computer reboots; for this reason, they cannot simply be stored in variables. The choice was that of either using a small database (maybe using Metakit, which is readily available as it is embedded in Tclkit), or to save them in text files. I finally opted for the latter possibility and decided that report files should be saved in *Correlatore*'s hidden configuration folder (whose path is `~/.correlatore`[74]). Each report is a file contained in the `report` sub-folder, and includes all data saved to that report in text format (with a UTF-8 encoding). The structure of each entry in the report is as follows:

```
FILE    Esempio
intV    216
intC    212
pause    15
Vmean    72.71495663716493
Cmean    90.27291956026146
Vperc    45.076053559321686
Vdev    32.11878816751892    33.03864836735656
Cdev    39.43809243378562    39.67276512149737
varcoV    44.17081389154383    44.439752814033504
varcoC    43.687622629130566    42.58782999749963
Vrpvi    32.05840505039406    34.38483639549482
Crpvi    49.90414965937686    50.76376358755145
Vnpvi    40.39055981686158    41.689759668844076
Cnpvi    54.545009862312966    53.72203260830348
Vcci    33.552866292942625    36.812405375916605
Ccci    21.073056103497294    20.830852059951457
colour    #662211
border    black
symbol    c
```

The first line (FILE) reports the name of the entry and is followed by the number of vocalic and consonantal segments, the number of pauses, the mean duration of vocalic and consonantal intervals (which are useful for calculating speech rate[75]), then the values of %V and all the other metrics (the first column reports the results obtained with the A method, the second column reports the results obtained with the B method, see above for details). The last three lines include the fill and border colours as well as the symbol to be used for chart indicators: the first

---

[74] According to Unix conventions, the symbol ~ indicates the path of the home folder. So, `~/.correlatore` translates differently on different platforms: `/home/paolo/.correlatore/` on all Unix platforms (including MacOsX), `c:\Documents and Settings\paolo mairano\.correlatore\` on Windows XP, `c:\users\paolo mairano\.correlatore\` on Windows Vista.

[75] If CV annotation criteria have been attended, it can be inferred that every vocalic interval corresponds to a nucleus because hyati are assigned to two separate labels and syllabic consonants are considered as V (by default, at least). Of course, the number of nuclei is also equal to the numbre of syllables. So, it is possible to compute the number of syllables by simply 1000/Vmean. The rate of syll/s is one of the possible indicators of speech rate.

is a random number generated on the fly at the time of saving, while the other two are set by default to “black” and “c” (for circle) respectively.

During the visualisation of reports (which is dealt with by a set of procedures contained in `report.tcl`), all items in the report are stored in a complex data structure (based on a set of arrays[76] containing lists) for analysis and modification. Only when/if the user decides to save the modifications, the arrays are saved back in the report.

4.3.6 How charts are dealt with

Reports can be used to simply save data (which can then be put in a spreadsheet or in other applications for further treatment), or they can be used to build charts. The creation of charts is rather complex (as I did not rely on any external libraries) and includes several procedures. The two main ones are called `disegna` (685 lines) and `grafico` (81 lines): to put it shortly, they read all items in the report and get the values of the two metrics under consideration (for the x and y axes) as well as the values of “colour”, “border” and “symbol”; then, most of the job consists in building the GUI components that interact with the chart: in fact, the values of all chart elements are attached to a global variable whose value is controlled by a GUI widget and can thus be customised by the user (e.g. the distance from the border and the axes, the scales, width, font and colours of the axes, etc.). However, nearly all of these parameters are set to default each time the chart module is initiated; the only parameters that are persistent are those saved in the report, that is to say the fill and border colour and the symbol used for each indicator (this is essential in order to have the same items constantly represented in the same way); so they are saved to the report every time the user modifies them.

Finally, the actual drawing of the chart into the canvas widget is done by a set of several procedures contained in *plib*, which include the conversion of pixels to chart scale and vice versa, the drawing of the axes, labels, grids, legend, indicators, etc. Drag-and-drop is implemented within the chart exclusively for the title, the legend, the axes labels and indicators labels. For the rest, charts are redrawn from scratch every time the user changes something[77].

4.3.7 *SASASA* files

As has already been said, one of the extra features of *Correlatore* is a module that synthesizes *SASASA* files: these are sound files in which an [s] sound replaces all consonantal intervals of the original file, whereas an [a] sound replaces all vocalic intervals of the original file. Such files have been previously used for perceptive tests (see chapter 6) and can have numerous variants. In particular, the original pitch and intensity contours can either be preserved or leveled.

Correlatore only produces flat *SASASA* files (with leveled pitch and intensity contours). During the process of segmentation and metrics calculation, the durations of vocalic and intervals are passed to a procedures that builds a visual segmentation (which is visible in the lower part of the window). The same values are also used for

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[76] Arrays are a common data structure found in most programming languages. In short, they are composed of a set of values, each of which corresponds to a unequivocal key.

[77] This solution may not be very economical in terms of system resources, but certainly it is so in terms of ease of implementation.

the synthesis of *SASASA* files with the help of *Snack*[78] through a very rudimentary method: the sources of *Correlatore* (only from version 2.2 onwards) include three WAV files, `c.wav`, `v.wav` and `silence.wav`, which contain the recordings of a stable [a] and a stable [s] respectively, both for a duration of 10 seconds. In order to create the synthesis, the procedure takes the necessary duration of [a] for vocalic intervals, of [s] for consonantal intervals and of silence for pauses and concatenates them one after the other. So, for instance, a sample utterance [wɒtʃɪt] (<watch it!>) with [#]=100ms [w]=80ms [ɒ]=90ms [tʃ]=110ms [ɪ]=50ms [t]=70ms [#]=200ms would be synthesised taking the first 100ms of `silence.wav`, then the first 80ms of [s] from `c.wav`, then the first 90 ms of [a] from `v.wav`, then the first 110 ms of [s] from `c.wav`, then the first 50 ms of [a] from `v.wav`, then first 70 ms of [s] from `c.wav` and, finally, the first 200 ms from `silence.wav`. Should a vocalic or consonantal interval be longer than 10 s (which is highly improbable in normal situations), that interval will be set to 10 seconds (the recordings last 10 s, so evidently I cannot provide syntheses longer than that).

This procedure is far from being sophisticated as of course shifts from [s] to [a] and vice-versa are abrupt and without formant transitions, but the result is auditively acceptable. I did the recordings personally at the Laboratory of Experimental Phonetics *Arturo Genre* of Turin in a sound-proof booth in order to get the best possible quality. Future perspectives include of course an improvement of this feature.

4.4 Conclusion and future perspectives

The functioning and implementation of *Correlatore* has been shown and it has been explained that it is possible to use for a quick computing of the most used rhythm metrics. The data presented in chapter 3, based on the calculation of these measures for the 61 samples and on the segmentation carried out by 2 different phoneticians (totalling nearly 110 *TextGrids*), would not have been possible without a tool like this.

As of now, its main default seems to be the fact that it is not flexible as to choices in how to label data. Future perspectives should include improvements in this sense, at least enhancing a better interpretation of SAMPA transcriptions, and of the technique for creating *flat SASASA* syntheses.

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[78] The *Snack Sound Toolkit*, which has already been quoted above, is a Tcl and Tk extension that allows for the analysis and manipulation of sound files. It has been written by Kåre Sjölander at the Department of Speech and Hearing, University of Stockholm. It is also used as the base for *Wavesurfer*, a programme for the phonetic analysis of speech by the same author,

5.

Rhythm variation and variability

5.1 Introduction

Variation is a recurrent theme throughout linguistics, at all levels of analysis, and it even stands at the base of specific disciplines, such as dialectology, geolinguistics and, above all, socio-linguistics[79]. For this reason, I have decided to devote it an entire chapter of the thesis, focusing, of course, on rhythm variation and variability.

Firstly, I shall specify what I mean by *rhythm variation* and *rhythm variability*. The term *rhythm variation* will be used to refer to linguistic variation that pertains to the *langue* of a linguistic community (to put it in Saussurian words) or to a subset of a linguistic community; instead, the term *rhythm variability* will be used to refer to individual fluctuations which pertain to the *parole*, which are given by the context or by other extra-linguistic factors or even by chance.

After a brief summary of the most important authors who worked on rhythm variation (in 5.2) and rhythm variability (in 5.3), I shall deal with specific aspects of rhythm variation and variability by presenting some data and analysing the most relevant results. Namely, I shall touch upon the variability of rhythm metrics when computed by different phoneticians (in 5.4). Then, I shall analyse intra-speaker (in 5.5.1) and inter-speaker (in 5.5.2) variability of rhythm metrics, finally discussing variation between speakers of regional or dialectal varieties (5.5.3). Finally, I shall discuss the possibility of distinguishing between different degrees of rhythm variability and rhythm variation through the use of rhythm correlates.

5.2 The study of rhythm variation

Rhythm variation across different dialectal or regional varieties has been firmly present in the literature along the evolution of rhythm speech theories. Many authors have tried to capture rhythm differences between different dialectal (or, in some cases, regional[80]) varieties attempting to categorise them as stress-timed or syllable-timed. The raising of rhythm metrics has of course given a new impulse to this type of research. I shall now briefly review (with no pretension of exhaustiveness) some

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[79] In particular, William Labov has devoted his career to the study of variation (see for instance Labov, 1972) and is now regarded as the founder of variationist sociolinguistics. In Italy, this discipline has also been influenced by Coseriu's ideas (e.g. 1958) and is most authoritatively represented by Sornicola (e.g. 1982). However, the bibliography on these themes is endless and a discussion on this topic is well beyond the scope of this thesis.

[80] The distinction between dialectal and regional varieties has been drawn from Italian dialectology (between *varietà regionali* vs. *varietà dialettali*). Dialectal varieties of Italy (which notoriously do not correspond to English *dialects*) are the language varieties which developed from vulgar Latin; they form a continuum in Italy, which is usually broken into smaller areas according to isoglosses by scholars attempting to provide a classification. Dialectal varieties differ one another (and from Standard Italian, which, actually, could itself be considered as a dialectal variety) greatly and on all levels - phonological, morphological, syntactic and phonetico-prosodic. Regional varieties of Italian are different versions of Italian spoken locally and which often reflect at least some characteristics of corresponding dialectal varieties. Regional varieties, as well, can differ one another on all levels, but variation is on a smaller scale, phonetico-prosodic differences being perhaps the most perceptively salient. The bibliography on these subjects is simply huge: for sake of brevity, I shall only mention Maiden & Parry (1997) and Loporcaro (2009), both of which contain many further references.

of the authors who attempted a rhythm categorisation of dialectal or regional varieties.

Most of the works that studied rhythm variation across different dialectal (or, less often, regional) varieties are fairly recent and therefore use recent approaches, such as the metrics. However, the rhythm variation of the dialects of Italy had already been the object of investigation by some scholars, mainly on the basis of vowel durations and of syllable structure. In particular, Mendicino & Romito (1991) as well as Romito & Trumper (1993) attempted a first rhythm classification of some dialects based on the duration of stressed vowels: the authors found several differences across dialectal areas (Ventian and Tuscan dialects being syllable-timed, Apulian dialects being stress-timed, Calabrian dialects being half-way), finally confirming the existence of a continuum and introducing the notion of "fuzzy poles". Mayerthaler (1996) proposes a different classification based on diachronic processes (which alternatively caused a simplification or a complexification of the syllable structure of dialects): from the dialects of extreme Southern Italy (characterised by a simple syllable structure), through two intermediate areas (central and Southern dialects), to the dialects of Norther Italy (mainly of Piedmont and Romagna), which are characterised by a more complex syllable structure.

More recently, Schmid (2004) conducted an experiment which combines a study of the syllabic structures of different dialectal varieties of Italy (Piedmontese, Milanese, Bitontino, Neapolitan, Venetian and Pisan) and their rhythm properties. Firstly, he checked which and how many different syllable-types each of these varieties allows for (the breadth of the syllabic inventory is in fact one of those phonological properties which are believed to play an important role in the classification of a language as more or less syllable-timed or stress-timed) and, subsequently, ordered them as follows: Pisan (18 different possible syllable-types), Neapolitan (21), Venetian (24), Bitontino (26), Milanese (28), Piedmontese (35). He then calculated the three rhythmic correlates proposed by Ramus *et al.* (1999) and put the results on charts. As expected, Pisan, Neapolitan and Venetian occupy a position of syllable-timing, while Bitontino, Milanese and Piedmontese occupy a position which could easily be associated with stress-timing, thus confirming the relation between the breadth of the syllabic inventory and Ramus' parameters.

Deterding (2001) investigated rhythm differences between Singapore and British English on the spur of previous studies by Low and co-workers (also see chapter 3) by applying a variability index to syllable durations. Despite the difficulties encountered in establishing clear criteria as to how to measure syllable durations, results (lower values of syllable variability) confirm Low's previous findings (obtained on vocalic intervals) that Singaporean English shows a tendency towards syllable-timing, at least if compared to British English.

Ghazali, Hamdi & Barkat (2002) studied rhythm variation in 6 Arabic dialects: Moroccan, Algerian, Tunisian (Western dialects), Jordanian, Syrian and Egyptian (Eastern dialects). The three authors computed %V and ΔC on versions of *The North Wind and the Sun* and found that Western dialects resulted in lower values of %V and higher values of ΔC. The authors consider this to be in compliance with the general impression that Western Arabic dialects tend to have a stronger-tendency towards stress-timing than Eastern dialects, which has been reported by previous studies on the basis of perceptive experiments (e.g. Barkat 2000, quoted by Ghazali, Hamdi & Barkat, 2002).

Mok & Dellwo (2008) computed a variety of rhythm measures (%V, ΔV, ΔC, ΔS[81], VarcoV, VarcoC, VarcoS, rPVI_C, rPVI_S, nPVI_V, nPVI_S) on Cantonese, Beijing Mandarin, Cantonese English and Mandarin English. Speakers read *The North Wind and the Sun* in Cantonese or Mandarin, then retold it without having access to the script (semi-spontaneous speech) and finally read the English version of the story. Cantonese and Beijing Mandarin are found to be syllable-timed by all rhythm measures despite a high degree of variation of %V values for the two different speaking styles (reading and retelling the story). Results are less clear for Cantonese English and Mandarin English, which are perceptively syllable-timed, but whose categorisation varies according to different rhythm measures. The authors state that these results "pose a challenge to the acoustic measures" (Mok & Dellwo, 2008:4/4).

Mairano & Romano (2008b) calculated the deltas, the varcos, the PVIs and the CCI on strictly controlled comparable dialectal samples from linguistic areas of Italy and Romania (data came from fieldwork and belongs to the AMPER database). It was found that dialectal varieties (even of the same linguistic area) could present notably different results and that the categorisation was slightly different using different rhythm metrics.

O'Rourke (2008) computed the deltas and the PVIs for 3 groups of Peruvian Spanish (3 native speakers from Lima, 3 native speakers from Cuzco, 3 native bilingual speakers of Spanish and Quechua - 9 speakers in total) and compared the results with data from other languages published by White and Mattys (2008). Despite the author's claims, results look controversial as VarcoC shows a very different scenario for Peruvian Spanish data from that offered by VarcoV, rPVI and nPVI. Furthermore, it seems hazardous to combine results from different studies in one chart because of potential differences in the segmentation or in the treatment of data. However, sticking to Peruvian Spanish, the author remarks a statistically significant difference between Lima and Cuzco speakers, while (quite unsurprisingly) there does not seem to be any significant difference between monolingual and bilingual speakers from Cuzco.

Romano, Mairano & Pollifrone (2009) calculated several rhythm measures on 6 dialectal varieties of Piedmont (speakers translated *The North Wind and the Sun* in their dialect and re-read it aloud). Final results showed great differences among the 6 samples, but confirmed an overall tendency of Piedmontese dialects towards stress-timing/compensation.

White, Payne & Mattys (2009) calculated various metrics on samples of regional Italian (Venetan and Sicilian): they chose, on the basis of their previous studies, the varcoV/%V chart as the most representative and found that samples of both regional varieties clustered in the syllable-timed area. The authors claimed that such results are "perhaps" surprising as "Southern Italian (e.g. Sicilian) has been frequently described as more 'stress timed' than northern Italian (e.g. Venetan)" (2009:151). However, I believe that some considerations are necessary here. First of all, I have the impression that the authors do not clearly distinguish between *regional* and *dialectal* varieties: in fact, since thet did not give any specification, one may well wonder who made such claims; it is, in effect, the case that much has been said about rhythm variation in Italy, but it concerned dialectal variations (see below) and I am not aware of many reports on the rhythm of regional varieties of Italian

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[81] S refers to phonological syllables.

(apart from Giordano & D’Anna, who published their contribution in 2010). Furthermore, if the authors referred to dialectal varieties, only some of the northern varieties are classified as syllable-timed (Venetan among them, but certainly not Piedmontese, for example) and only some southern varieties are classified as stress-timed (not Sicilian, at least according to Mayertaler, 1996).

Romano & Mairano (2010) attempted to provide a rhythm categorisation of 6 regional varieties of Romanian by testing various metrics on speech samples of *The North Wind and the Sun*. Differences were remarkable and went from syllable-timing (Brasov, Bucovina, Moldavia and Muntenia) to mild stress-timing (Bucharest and Oltenia).

Giordano & D’Anna (2010) computed %V, the deltas, the varcos and the PVIs on samples by 34 speakers of 15 regional varieties of Italian (Bari, Bergamo, Cagliari, Catanzaro, Florence, Genua, Lecce, Milan, Naples, Palermo, Parma, Perugia, Rome, Turin) and on 3 speech styles (pre-planned monologic speech, spontaneous dialogic speech and read speech) using data from the CLIPS corpus. The ΔC value is found to increase from read through dialogic and to pre-planned speech, while, conversely, ΔV is found to decrease; consonatal rPVI values are found to reproduce ΔC’s behaviour, while, once again, nPVI is found to be stable. The variation of rhythm metrics across the 15 regional Italian varieties was calculated on read passages only: results for different Italian varieties vary greatly from each other, ranging from delta and PVI values associated with syllable-timing to values usually associated to stress-timing.

In conclusion, most studies in the field show that dialectal varieties can differ one another in terms of rhythm properties as much as different languages. Yet, there seems to be less agreement on the degree of rhythm variability given by different regional varieties of the same language. This could be motivated by the fact that regional varieties do not usually show great differences in phonotactics and syllable structure, which therefore do not have remarkable repercussions on rhythm properties. However, testing these different types of rhythm variation provides interesting perspectives and will be dealt with in 5.5.

5.3 The study of rhythm variability

The study of rhythm variability has been far more neglected than the study of rhythm variation, apart of course from the fluctuations caused by speech rate. The fact that the effects of speech rate on speech rhythm have been studied extensively is of course perfectly understandable as they are related phenomena. Yet, other aspects of rhythm variability have often been shunned and, indeed, in many cases, treated as spurious data. However, before the “rhythm metrics era”, Major (1981, already reported in chapter 2) found rhythm differences across different speech styles for Brazilian Portuguese studying durational properties and some phonological characteristics of this language variety in citation and casual speech: formal Portuguese (represented by his citation data) seems to show the properties typical of syllable-timed languages, whereas informal Portuguese (represented by his casual speech data) seems to show the properties typical of stress-timed languages (most emblematically the shortening or even the deletion of unstressed syllables). On the basis of these observations, he puts forward a singular hypothesis: since historical change in languages generally occurs in the direction of casual speech, “Portuguese is in the process of changing from a syllable-timed language to a stress-timed language" (1982:350).

Again, the rhythm metrics have offered a framework against which it is possible to test rhythm variability. This certainly explains the flourishing of studies on speech rhythm in relation to speech rate, which are not reported here as they have already been reviewed in chapter 3. Among the few who set out to analyse rhythm variability other than in relation to speech rate, Mairano & Romano (2007a) tested inter-subject variability on the values of the metrics proposed by Ramus *et al.* (1999) on 7 speakers of 4 languages (English, French, German and Italian). The segmentation and the measurements were carried out by the two authors independently and it was found that the values were fairly stable across different segmentators in spite of remarkable differences in the segmentation and in classification choices of phonologically ambiguous segments. General results were in compliance with expectations, with high values of ΔC and ΔV for German and English, and high values of %V for French and Italian. The authors also presented measures of inter-operator agreement rate.

A similar work appeared in a poster by White *et al.* (unpublished) presented at EASR 2008, in which the authors had independently segmented data from a few languages and presented similar measures of inter-operator agreement rate.

Widget *et al.* (2010) tested the robustness of several rhythm metrics (though only focusing on %V, varcoV and vocalic nPVI) in relation to various factors of variation, namely across 5 different measurers, 6 different speakers (of Standard Southern British English) and 5 different sentences. Results show that fluctuations due to different speakers and different measurers are smaller than those caused by different sentences. They conclude their study by giving pieces of advice to researchers intending to use rhythm metrics.

Yoon (2010) computed the varcos and the PVIs on conversational speech by ten American speakers from Columbus in order to check intra- and inter-speaker variability. Several minutes per speaker were taken in consideration as data was drawn from an annotated corpus just needing a script to convert SAMPA into CV. The author finds higher intra- and inter-speaker variability with the varcos (varcoV, in particular) than with the PVIs and more with consonantal rPVI than with vocalic nPVI; he therefore observes that data from the ten speakers tend to cluster tightly into a vocalic/consonantal nPVI chart thus minimising inter-speaker variability. He claims that "nPVI-V and nPVI-C both make a very compact cloud, suggesting that the normalised variability indices are the best rhythmic metrics that capture the speaker's dialect similarity in this study" (2010:4/4). However, the author does not seem to be aware that the rPVI and the nPVI are not directly comparable on the same scale. Furthermore, measures that are able to capture similarity are not necessarily able to capture difference: since the author did not include any other language or dialect, it seems impossible to determine whether the combination of consonantal and vocalic nPVI is effectively able to "capture similarities" between dialects or whether it simply levels differences of any kind.

5.4 Inter-operator variability of rhythm metrics

As has been said, nearly all data in the corpus presented in chapter 2 and 3 have been segmented and labelled separately by two phoneticians (PM and AR). This has of course been done in an effort to make measurements less bound to subjective evaluations and therefore more reliable. In effect, apart from discrepancies in the boundaries set for each segment by the two phoneticians[82], many differences can also be found in phonological choices as to, for instance, whether certain segments exist or not, or about the vocalic or consonantal status of some sounds. This is because segmentation, to a certain extent, is a phonetic transcription.

Figure 5.1 represents segmentation choices by the two phoneticians (AR on the x axis, PM on the y axis) for the Italian samples 2-7. The values on both axes represent the duration in ms of each vocalic or consonantal interval calculated on the boundaries set respectively by AR and PM. As it can be seen, measurements align more or less along the bisecting line, sometimes with more remarkable deviations. In fact, the more the values on the chart tighten along the bisector, the higher is the correlation between the two segmentations; in a purely hypothetic condition, two perfectly corresponding segmentations would draw a bisecting line. It also has to be noted that dots resting on the x or on the y axis indicate that one of the two phonetician considered the corresponding segment as non-existent (hence 0 ms), while the other labelled it (e.g. in cases of epenthetic schwas).

However, what is relevant for this study is the influence given by differences in the segmentation/labelling on the final values of the metrics. In order to get an idea of this, the values of the different metrics were also computed on the basis of the segmentation carried out by PM and AR separately: the results can be seen in figure 5.2, where the final values for the PVIs (above) and the CCI (below) for each sample are shown separately for AR and PM. Only the samples segmented by both PM and AR were included in the chart, which is already overloaded and difficult to read. Variability exists but is not impressive: PVI variability goes from the very low scores of Romanian Muntenian, Finnish2, Estonian, Australian English and Lebanese Arabic, to higher scores for Czech, Caracas and Bogota Spanish, Bucharest Romanian and Italian07. CCI variability goes from the very low scores of Lima Spanish (the two samples are practically superimposed), Italian02, Sao Paulo Portuguese, Brasov and Muntenian Romanian, to higher scores of the 2 Finnish samples and of Moldavian Romanian.

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[82] Such discrepancies are of course inevitable in manual segmentation and they would likewise exist even across two segmentations of the same sample done by the same person.

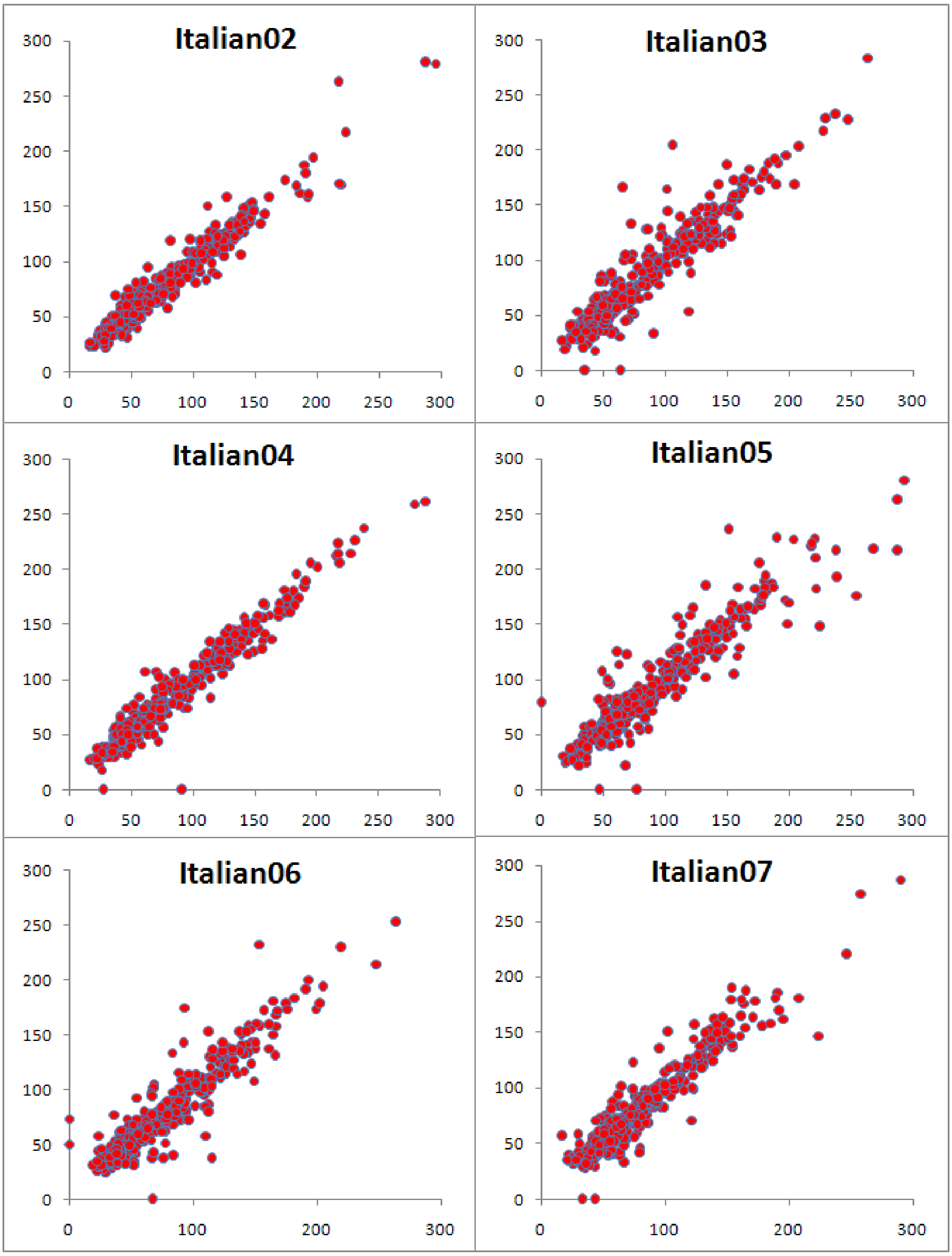

Figure 5.1. Durations in ms of consonantal and vocalic intervals measured on the boundaries set by AR (x axis) and PM (y axis). Perfectly matching segmentations would result in a bisecting line.

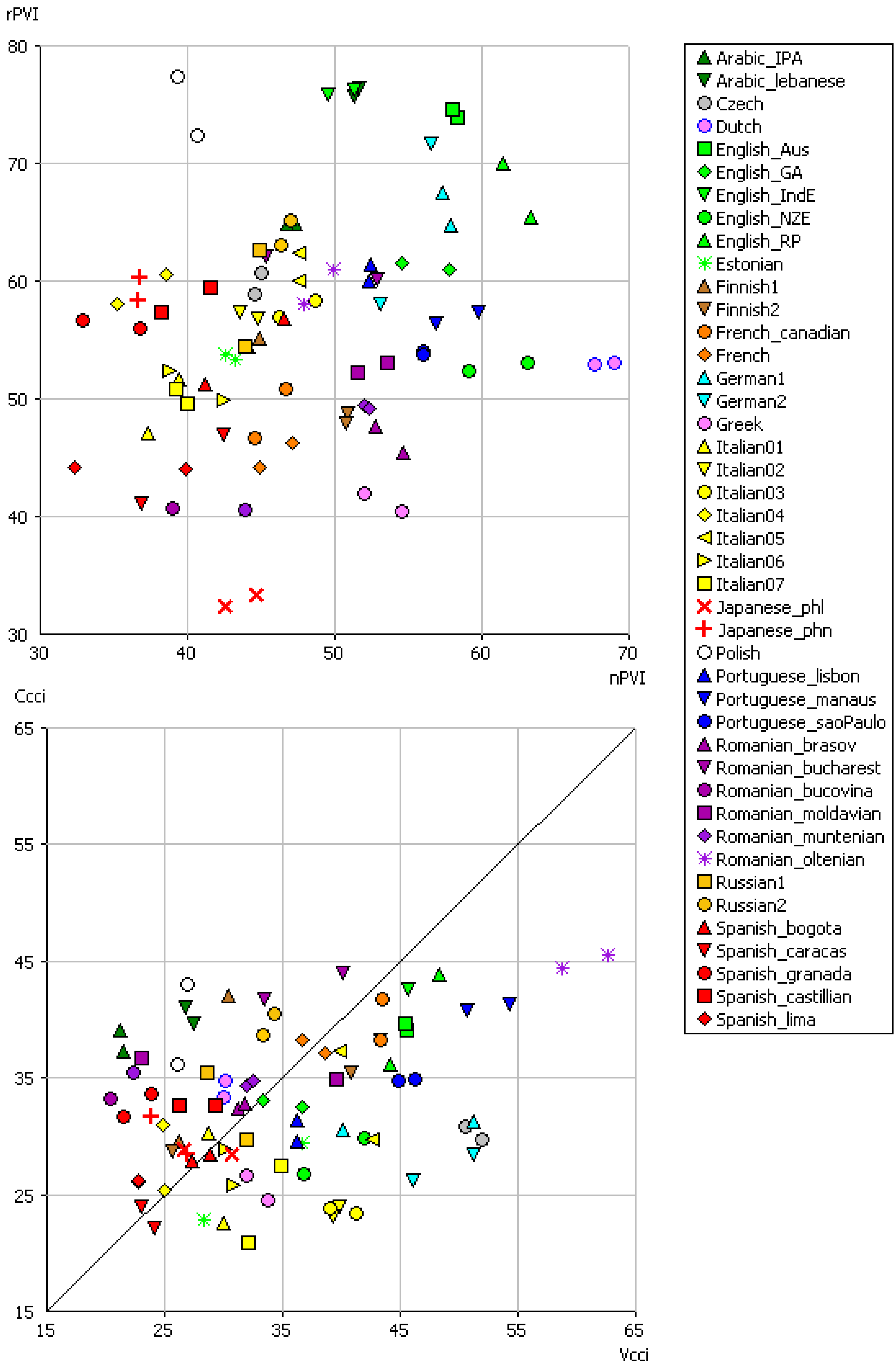

Figure 5.2. Values of the PVIs and the CCI for samples in the corpus. Each sample is represented twice, reflecting the segmentation by the AR and PM.

It is also remarkable that some samples present very limited variability with one metric and high variability with other metrics: it is the case of Lima Spanish, which has nearly the same values of vocalic and consonantal CCI as well as rPVI for PM and AR, but which has very different values of nPVI. This suggests that inter-operator variability is not directly proportional to inter-subject agreement. That is to say that a speech sample might be segmented very differently by two phoneticians and still yield similar results or, *vice versa*, the same sample segmented very similarly by two phoneticians might yield considerably different results of the metrics. Moreover, it is also possible that some metrics are more stable than others in respect to segmentation differences: in order to check that, for each rhythm metric, I calculated the mean of the standard deviation[83] between the values obtained on PM and AR *TextGrids* (see appendix 2 for all single values of inter-operator standard deviation); results are shown in Table 5.1 and show that the CCI seems to be more sensitive to this parameter. This is in effect understandable as it demands a phonological interpretation of each segment, instead of a (comparatively) simpler segmentation into vocalic and consonantal intervals *tout court*. It has also to be noted that the varcos and the nPVI are normalised values and therefore represent completely different entities from the other metrics and cannot be direcetly compared to them. However, it has to be noted that a higher sensitivity is in itself not necessarily a drawback: as suggested by Bertinetto & Bertini (2008 and following), normalising might mean losing some relevant information. So, high sensitivity to segmentation choices might also mean high sensitivity to other rhythm-related phenomena. Normalisation brings of course more stability but the issue of whether to normalise or not is probably solved case by case depending on data and according to the aim of the study: for a cross-language rhythm categorisation it is probably best to normalise vocalic durations even if this has a risk in terms of a possible loss of relevant information. Instead, for a sophisticated study on specific rhythm properties of a group of speakers or within different styles in the same language, it is probably better not to normalise in order to be able to capture all possible nuances (keeping in mind that, at the state of the art, it is difficult to confidently attribute changes in the values of rhythm metrics to specific phenomena).

%V	Vdev	Cdev	varcoV	varcoC	nPVI	rPVI	CCI(v)	CCI(c)
1,33	1,36	1,21	1,33	0,90	1,12	1,13	3,55	1,47

Table 5.1. Inter-operator variability expressed as the mean of the standard deviations between the values obtained on PM and AR segmentation for each rhythm metric.

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[83] It was chosen to calculate the mean of the standard deviations for each sample and not the standard deviation tout court. This is because a global standard deviation would include the differences between each possible pair of values, which does not make sense in this case: instead, I computed exclusively the differences between each pair of values obtained on the same sample by PM and AR. Therefore, the difference between the ΔC value as calculated on, say, Estonian by PM and on Finnish by AR was not considered (while it would be taken in consideration by calculating the overall standard deviation for each metric). This implies that the standard deviation was calculated at each time only on two values and thus it would have been possible to use simply the difference; however, it was chosen to use the standard deviation for comparative reasons.

5.5 Speakers and rhythm variability

5.5.1 Intra-speaker variability

Apart from the studies on rhythm and speech rate, the other aspects of intra-speaker variability have been completely neglected by the literature and, as far as I am aware, none of them has been extensively treated in any study making use of the metrics. A partial exception consists in some studies that considered productions by bilingual subjects or L2 learners in more than one language (such as the already quoted studies by Mok and Dellwo, 2008, and White & Mattys, 2007). Computing rhythm metrics on multilingual speakers in order to study their rhythm characteristics and, perhaps, to be able to evaluate their level of adaptation to a certain model is no doubt an interesting perspective (see below). However, it by no means constitutes the only aspect of intra-speaker variability: in fact, differences between styles and registers also pertain to this domain. Moreover, it is possible to check variability within equivalent productions by the same speaker in order to uncover pure intra-speaker variability at comparable speech rate, style, register and context. I believe there are good reasons for testing this type of “pure” variability. Most importantly, it has to be done as a first step in order to have a term of comparison in order to evaluate other types of variation and variability. In other words, it is not possible rate intra-speaker variability if we do not rate inter-speaker variability first.

I decided to set up data in order to test at the same time “pure” intra-speaker variability as well as “multilingual” variability. I recorded one single speaker in five different languages, segmented his productions[84] and, as usual, computed the metrics with *Correlatore*. The subject is a male speaker in his twenties with university education, a native speaker of Italian, proficient L2 speaker of English and French, also possessing a fairly good competence of German and a limited competence of Icelandic. He was recorded while reading versions of *The North Wind and the Sun* twice in each language (therefore a total of 10 productions). Results are shown in figure 5.3 for the PVIs and the CCI. Samples of native speakers for each language have been included for comparison: RP English (because the speaker model is definitely British English), Standard French, Standard German and the mean of the 10 Icelandic speakers as well as the mean of the other 3 Piedmontese regional Italian speakers taken from the corpus.

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[84] The segmentation and labelling of his productions were carried out by PM only as they are not part of the corpus (since they are mostly L2 productions). To be precise, the first Italian production of the speaker is actually part of the corpus (Italian06) and has therefore also been labelled by AR. However, for a better comparability with the rest of his productions, only the segmentation by PM was kept in consideration for the present study on intra-speaker variability.

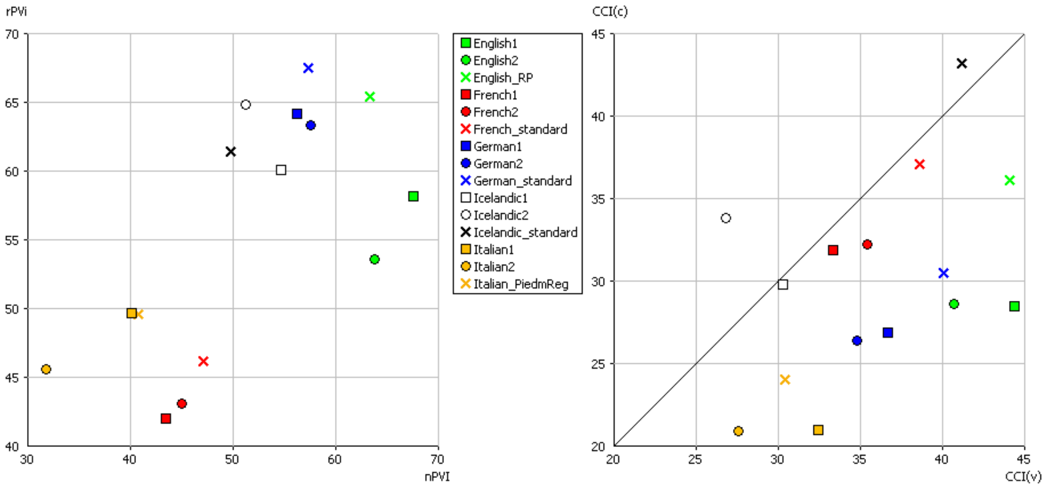

Figure 5.3. Values of the PVIs (above) and the CCI (below) for 10 productions of Italian, English, French, German and Icelandic of one (native Italian) speaker. Values of an RP speaker, a standard French speaker, a standard German speaker and the mean of 10 Icelandic speakers and 3 Piedmontese regional Italian speakers (all taken from the corpus presented in chapter 2 and 3) have been added for comparison.

It can be seen that the rhythm categorisation suggested by the PVIs is very coherent within the values of this speaker, although variability within each pair of samples of the same language is remarkable. Productions in French show low PVI values and are disposed along the bisecting line in the CCI chart, whereas productions in English and German exhibit high values of the PVIs and are disposed below the bisecting line in the CCI chart. This seems to confirm that this speaker is fairly proficient in these languages and that he masters control and compensation phenomena. As for his productions of (Piedmontese regional) Italian, they come to be categorised as syllable-timed by the PVIs and as more or less compensating by the CCI, while the opposite happens to his Icelandic productions, which come to be categorised as stress-timed by the PVI and as controlling by the CCI. As for this variety of regional Italian, it is difficult to comment as Italian should be a syllable-timed/controlling language, but the Piedmontese dialect is usually categorised as stress-timed/compensating (see for instance Schmid, 2004 and Romano *et al.*, 2010): it is therefore possible that the CCI value reflects the influence of the Piedmontese dialect on the speech rhythm of the speaker (regional varieties of Italian will be treated in more detail below). As for Icelandic, as well, the situation is complex; first of all, this language should perhaps be regarded as a mixed language, allowing for fairly complex consonantal clusters without having macroscopic phenomena of vowel reduction. It is thus expected to yield low vocalic nPVI and high consonantal rPVI values. Given these features, then, it is perfectly understandable that, in contrast to compensating languages, it falls around the bisecting line in the CCI chart: vocalic CCI is not expected to be low enough to place it below the bisector because the difference between stressed and unstressed vowels is not supposed to be as remarkable as, for instance, in English or German. Also, a further complexity is given by the low competence of this language on the part of the speaker: in this case, it is of course well possible that he does not master all segmental compensation phenomena of Icelandic.

It is also interesting to observe that values or all metrics are slightly lower for this speaker than for the corresponding native speakers. This probably does not have to be attributed to differences in segmental control, but rather to a slightly faster speech rate, as is demonstrated in figure 5.4:

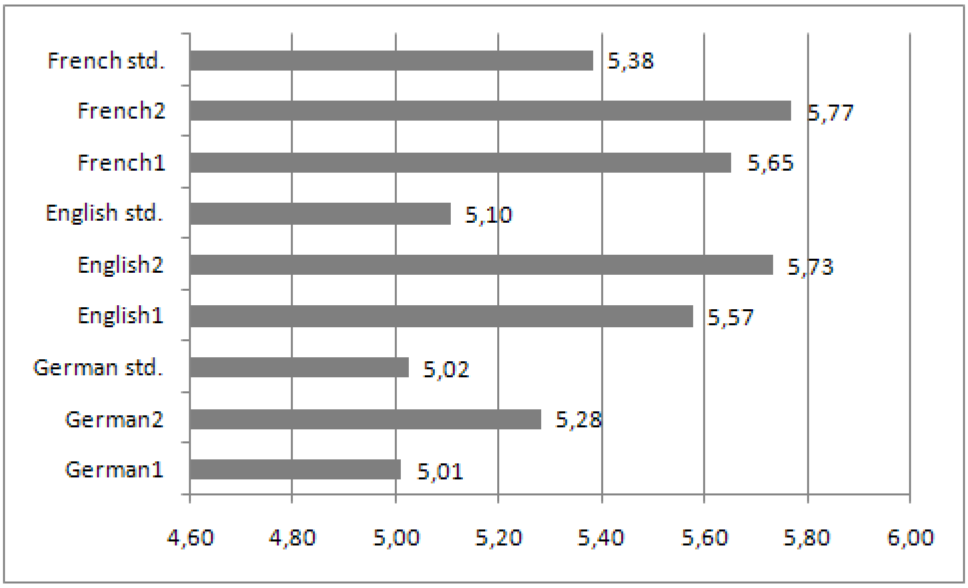

Figure 5.4. Speech rate for samples of English, French and German by the L2 speaker and native speakers from the corpus.

Speech rate has been calculated by dividing the total duration (exluding pauses, of course) by the number of vocalic intervals. This procedure might seem arbitrary but is grounded on the fact that each vocalic interval labelled corresponds to a syllable nucleus[85] and therefore gives and indication of the number of syllables. It also has to be noticed that English and German present lower values of speech rate than French, which is compliance with what suggested by Dellwo (2008).

As for “pure” intra-speaker variability, the difference between each pair of productions in the same language is perhaps greater than expected. Table 5.2 shows the mean of the standard deviations between the values obtained for each pair of samples by the speaker. Indeed, the mean values of variability are comparable to the ones obtained for inter-operator variability (given by different phoneticians working on the segmentation of the same sample) apart from the CCI.

Finally, it is interesting to remark that this test provides a sound and original confirmation of the validity of these metrics: the scenario offered is consistent with expectations and, since the 10 samples are perfectly comparable as for speech style, register, speech rate and context and since they all pertain to only one speaker, they cannot be attributed to idiosyncrasies of different speakers representing each language. It seems therefore natural to conclude that the metrics can provide a reliable representation of the segmental properties related to rhythm in controlled productions of this type.

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[85] In fact, hiati were labelled as two separate intervals, as suggested by Bertini & Bertinetto (2009).

	%V	Vdev	Cdev	varcoV	varcoC	nPVI	rPVI	CCI(v)	CCI(c)
Engl.	0,86	1,10	3,16	0,49	3,11	1,87	2,27	1,86	0,04
French	0,35	0,11	0,66	0,59	0,72	0,81	0,54	1,06	1,15
Germ.	0,51	2,04	5,40	1,12	4,43	0,64	0,44	0,96	0,24
Icel.	0,61	2,09	0,21	2,28	0,93	1,74	2,33	1,76	2,01
Italian	1,21	3,19	1,25	4,37	0,62	4,14	2,05	2,39	0,08
mean	0,71	1,71	2,14	1,77	1,96	1,84	1,53	1,61	0,70

Table 5.2. Intra-speaker variability expressed as the mean of the standard deviations between the values for each pair of productions in the same language for this speaker.

5.5.2 Inter-speaker variability

Inter-speaker variability refers of course to variability within different speakers of the same language or linguistic variety. A number of authors have already proved that the metrics yield different results for such data. So, I decided to test inter-speaker variability with the data available in my corpus and compare it with intra-speaker and inter-operator variability. Unfortunately, the only exploitable samples from the corpus are the 10 Icelandic speakers, 3 (out of 15) Italian speakers, the 2 German and the 2 Finnish ones: speakers for the other national languages in the corpus, in fact, present some dialectal/regional differentiation (see below) and thus cannot be considered as representative of simple inter-speaker variability. All 10 Icelandic speakers are from Reykjavík and claimed to have no dialectal/regional accent[86]; the 4 Italian speakers are number 6, 7, 8 and 15 and all live in Turin and speak Piedmontese regional Italian; the Finnish and German speakers all speak the standard variety of their language. Since the ten Icelandic speakers as well as Italian14 and Italian15 have only been segmented and labelled by PM, the values obtained by AR on Italian06, Italian07 and on the Finnish and German samples were not considered for the present analysis. Results for the PVIs and the CCI are shown in figure 5.5.

As can be seen, PVI variability is definitely high, above all for the ten Icelandic speakers and for consonantal intervals more than for vocalic intervals (which is easily explained as an effect of normalisation[87]). The scenario offered by the CCI seems to be more stable: variability is lower - in effect the 10 Icelandic speakers (despite showing a fairly high variability) do not mix with those of other languages. In both charts there is some overlapping between speakers of different languages.

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[86] The geolingusitic differenciation within Iceland is, however, very limited (though it does exist, in contrast to what is usually claimed).

[87] In fact, the ΔC/ΔV chart (in which normalisation is neither applied at consonantal level nor at vocalic level) shows that variability is equally important on both axes.

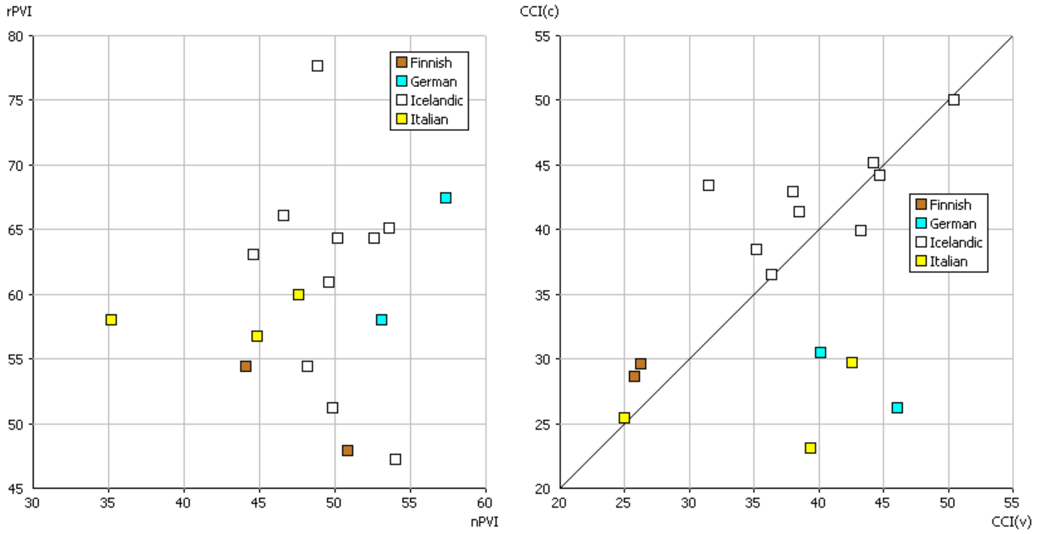

Figure 5.5. Values of the PVIs (above) and the CCI (below) for the 10 Icelandic speakers, 3 standard Italian speakers, 2 German and 2 Finnish speakers.

Similarly to what has been done with intra-speaker variability, inter-speaker variability has been evaluated by computing the mean of the standard deviation among samples of the same language. Results are shown in table 5.3.

	%V	Vdev	Cdev	varcoV	varcoC	nPVI	rPVI	CCI(v)	CCI(c)
Finnish	0,05	2,09	1,76	4,64	0,43	3,34	3,23	0,27	0,48
Germ.	1,31	4,03	2,86	3,48	0,72	2,06	4,75	2,99	2,17
Icel.	0,67	1,91	2,62	0,80	1,24	0,95	2,74	2,02	1,41
Italian	0,92	5,10	1,64	3,62	0,70	3,76	0,93	5,40	1,95
Mean	0,74	3,28	2,22	3,14	0,77	2,53	2,91	2,67	1,50

Table 5.3. Inter-speaker variability expressed as the mean of the standard deviations between the values obtained for different speakers of the same language.

5.5.3 Geographical variability vs. variation

For the present study on rhythm metrics, geographical variation and variability refer to fluctuations in the results of rhythm metrics given by a different geographical provenance of speakers. It therefore includes dialectal and regional variation (see above for the difference between dialectal varieties and regional varieties).

In order to test dialectal variation, I have exploited data of 6 speakers of 6 different dialectal varieties of Piedmont, namely those of the following villages: Bagnolo Piemonte (CN), Briga Alta (CN), Campertogno (VC), Capanne di Marcarolo (AL), Exilles (TO), Roccaforte Ligure (AL). Data are perfectly comparable with the corpus as speakers read *The North Wind and the Sun* after translating the Italian version into their own dialectal variety. These 6 dialectal varieties belong to the same group of dialects, but each of them has specific characteristics at all linguistic levels: this means that the 6 texts are all different from one another (see Romano et al., 2010, for more details on the speakers and on these dialects and for an orthographical transcription of the texts).

In order to test regional variation, I exploited data from the corpus, namely 10 of the 15 Italian speakers (each speaking a different regional variety of Italian)[88], the 5 English speakers (RP, American, Australian, New Zealand, Indian), the 3 Portuguese speakers (from Lisbon, Sao Paulo and Manaus), 6 Romanian speakers (from Braşov, Bucharest, Buchovina, Moldavia, Muntenia and Oltenia), 5 Spanish speakers (Castillian, Granada, Bogotá, Caracas and Lima). In contrast to dialectal varieties, the texts of different regional varieties of the same language were the same for all speakers: so, all Italian speakers read the same text (as well as all English, Portuguese, Romanian and Spanish speakers). Since not all 12 speakers had been labelled by AR, measurements by PM only were taken in consideration for consistency across all samples. The results for the PVIs and the CCI obtained on these data are shown in figure 5.6.

Observing the charts, it can be noticed that regional varieties show a moderately high variability, which is greater among dialectal varieties. In effect, despite remarkable differences, samples pertaining to different regional varieties of a language still cluster in the same area of the chart and there seems to be very limited overlapping between stress-timed/compensating languages and syllable-timed/controlling languages. On the other hand, the 6 samples of Piedmontese show a higher degree of fluctuation, particularly for the rPVI values, which range from typical stress-timed values for most samples to the very low values of Capanne di Marcarolo (which are even lower than those for Spanish varieties). Results for Piedmontese varieties seem to be more consistent using the CCI, suggesting that they all allow for a remarkable amount of compensation.

As in the previous cases, I computed the mean of the standard deviations among the values obtained for regional varieties of the same language (see table 5.4); separately, I also computed the standard deviation[89] of the values obtained for Piedmontese varieties (see table 5.5).

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[88] The different provenance of the 15 Italian speakers are reported in chapter 2 in the presentation of the corpus. Italian speakers 6, 7 and 8 were excluded because they all spoke Piedmontese regional Italian, which is already represented by speaker 15. Speakers 4 and 5 were excluded because they spoke a standard variety, which is already represented by speaker 2.

[89] Obviously, as Piedmontese varieties are taken as the only representation of dialectal (vs. regional) variability, there is no need to compute the mean of the standard deviations (there is just one standard deviation).

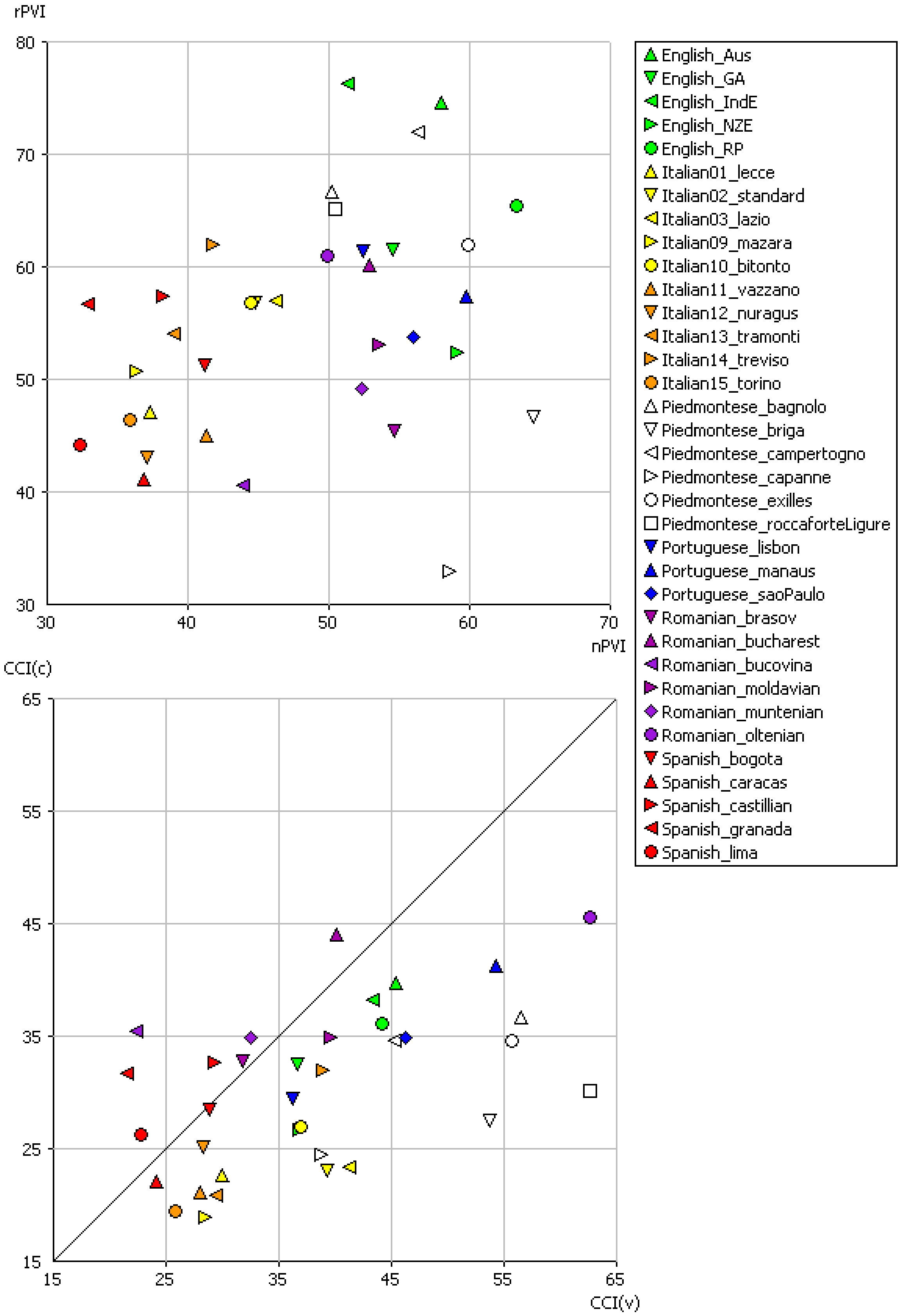

Figure 5.6. Values for the PVIs and the CCI on dialectal varieties of Piedmontese and on regional varieties of Italian, English, Romanian, Portuguese and Spanish.

	%	Vdev	Cdev	varcoV	varcoC	nPVI	rPVI	CCI(v)	CCI(c)
Engl.	0,31	2,37	2,84	3,08	0,70	2,06	4,38	1,86	2,33
Italian	0,44	1,87	1,69	1,05	1,14	1,21	2,01	1,82	1,24
Port.	2,11	7,16	3,28	2,64	2,53	2,13	2,19	5,21	3,41
Rom.	1,71	5,23	3,07	2,05	1,99	1,59	3,32	5,58	2,22
Span.	0,45	1,91	2,94	1,94	2,39	1,66	3,26	1,60	1,91
MEAN	1,00	3,71	2,76	2,15	1,75	1,73	3,03	3,21	2,22

Table 5.4. Inter-regional variation expressed as the mean of the standard deviations among different regional samples of the same language.

	%V	Vdev	Cdev	varcoV	varcoC	nPVI	rPVI	CCI(v)	CCI(c)
Piedm.	1,94	3,52	4,26	2,58	0,51	2,29	6,03	3,51	1,94

Table 5.5. Inter-dialectal variation expressed as the standard deviation among speakers of different dialectal varieties of Piedmont.

5.5.4 Discussion on rhythm variation and variability

After testing variability and variation across different axes and dimensions, it is natural that one may want to compare results. The most obvious approach is to try and rate the degree of variability given by the different factors. In other words, I shall try and establish a “scale of variability”, determining which factors condition a smaller or a greater degree of variability on the metrics. The hypothesis is that variability causes smaller fluctuations than variation and, more particularly, inter-operator and intra-speaker variability should be somehow smaller than inter-speaker variability, which in turn should be smaller than regional variation (which is simply a certain type of inter-speaker variability but which introduces one more factor – geographic provenance), which yet should be smaller than dialectal variation (thus reflecting what happens at other linguistic levels). In other words, I expect the following scale:

intra-speaker/inter-operator < inter-speaker < inter-regional variation < inter-dialect

This hypothesis can be easily verified by observing the values reported in tables 5.1-5.5 and resumed here in table 5.6 and in figures 5.7 and 5.8:

	%V	Vdev	Cdev	varcoV	varcoC	nPVI	rPVI	CCI(v)	CCI(c)
inter-oper.	1,33	1,36	1,21	1,33	0,90	1,12	1,13	3,55	1,47
intra-spkr.	0,71	1,71	2,14	1,77	1,96	1,84	1,53	1,61	0,70
inter-spkr	0,74	3,28	2,22	3,14	0,77	2,53	2,91	2,67	1,50
inter-regvar.	1,00	3,71	2,76	2,15	1,75	1,73	3,03	3,21	2,22
inter-dialect	1,94	3,52	4,26	2,58	0,51	2,29	6,03	3,51	1,94

Table 5.6. A comparison of the variability of metrics in function of different parameters (inter-operator, intra-speaker, inter-speaker, inter-regional varieties, inter-dialectal varieties – in order of expected crescendo).

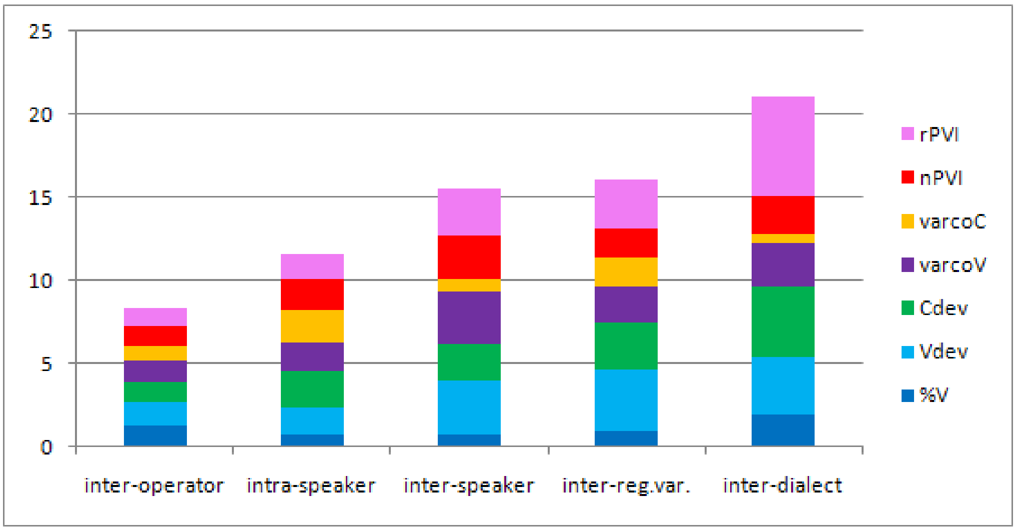

Figure 5.7. Fluctuations of %V, ΔV, ΔC, varcoV, varcoC, rPVI and nPVI for the different types of variation and variability.

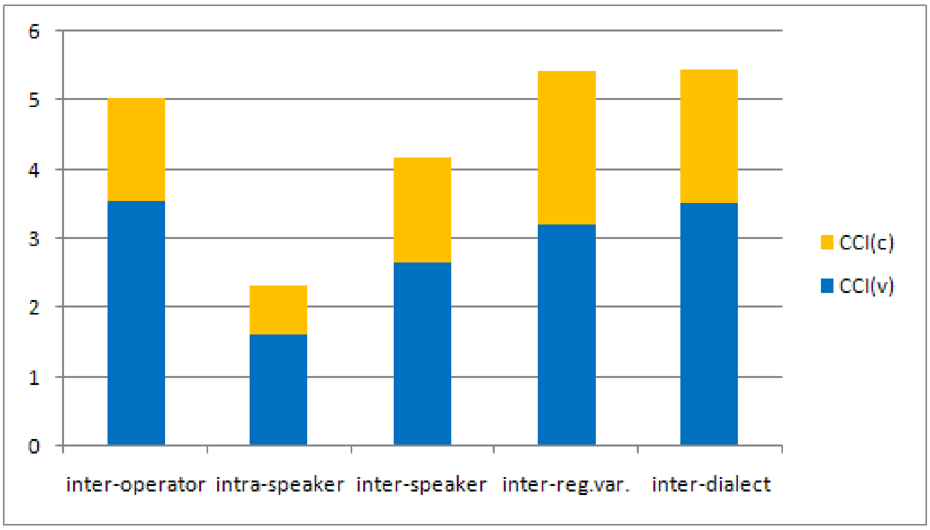

Figure 5.8. Fluctuations of vocalic and consonantal CCI for the different types of variation and variability.

First of all, it can be observed that the CCIs seem to follow a different logic from the other metrics (for this reason they have been separated from the others in the charts). In fact, inter-operator variability is, as expected, the lowest type of variability for all metrics except for the CCI, for which it seems to be very high: this can be easily explained by the fact that, as already mentioned, the CCI requires not only a segmentation into vocalic and consonantal intervals, but also a phonological interpretation of each segment, which introduces a further element of subjectivity in the work and which is therefore likely to be the cause of more evident fluctuations in the results. As for the rest, both charts seem to agree on the following:

intra-speaker < inter-speaker < inter-dialect

This was of course expected and is perfectly understandable: variability between one speaker is lower than variability among speakers of the same linguistic community which is turn is lower than variability among speakers of different (though related) communities. However, the status of inter-regional variability is not clear: fluctuations of the CCI seem to distinguish between inter-speaker variability and inter-regional variation, but not between inter-regional variation and inter-dialect variation; conversely, the other metrics do not seem to distinguish between inter-speaker variability and inter-regional variation, but they do distinguish between inter-regional and inter-dialect variation. In effect, as has been explained in chapter 3, the CCI aims to capture different phenomena from the other metrics, namely the degree of compensation allowed by a language. It is therefore plausible that the regional varieties considered in this study allow for very different degrees of compensation resulting in high fluctuations of the final CCI values (indeed so high that they are comparable to fluctuations for inter-dialect variation). On the other hand, the failure of the "classic" metrics in distinguishing between inter-speaker variability and inter-dialect variation would seem to suggest that rhythm variation across different regional varieties of the same language is perfectly comparable to differences given by the idiosyncrasies of different speakers.

At any rate, we should consider the following: the CCI tries to measure the degree of compensation, the other metrics attempt to measure the syllabic structure given by phonotactics. This could suggest that the degree of compensation of a language (reflected by the CCI) is more variable across different regional varieties and is not directly linked to its phonotactics (reflected by the other metrics), which is of course different across dialectal varieties. However, a word of caution is needed for the number of samples used to rate variability is small. Therefore, further investigation is needed to confirm these results.

5.6 Conclusion

Different types of rhythm variability and variation have been tested. On the whole, variability can be said to be high across several dimensions and I have tried to build a "variability scale". The initial hypothesis resumed as:

intra-speaker/inter-operator < inter-speaker < inter-regional variation < inter-dialect

has only been confirmed for the following:

intra-speaker < *inter-speaker* < *inter-dialect*

However, results have provided a coherent paradigm for the study of speech rhythm and interesting perspectives for the future, which certainly include the necessity of enlarging the samples analysed.

6.

A perceptive test

6. A perceptive test

6.1 Introduction

6.1.1 Why perceptive tests?

In the past chapters, it has been made clear that the alleged difference between stress-timed and syllable-timed languages was issued out of perception (actually, according to some authors, on perception and nothing else[90]). The traditional dichotomy has often enclosed perceptual evaluations even in its numerous denominations, such as *languages with machine-gun rhythm* vs. *languages with Morse code rhythm* (Lloyd James, 1940). Also the terms introduced by Pike (1945) and then adopted by the community reflect the impression that languages might sound as stress-timed or as syllable-timed. The existence of this impression was usually confirmed even by those authors who set out to look for isochrony and who did not find it, as is evident by the already quoted sentence by Roach: “a language is syllable-timed if it *sounds* syllable-timed” (1982:78).

So, given such a widespread consensus that syllable-timed languages sound syllable-timed and that stress-timed languages sound stress-timed, one would expect that a number of experimental tests have confirmed these claims. However, it seems that this is not the case: some perceptive tests have indeed been conducted on related issues (see for instance those by Allen, 1975, and Lehiste, 1977, reported below), but very few authors set out to verify precisely to what degree languages are perceived as belonging to different rhythm categories (see for instance Miller, 1984). Only recently, a number of authors have started to investigate this field with sophisticated test formats.

After testing the correlates on various languages, it has been difficult to give an evaluation of the results obtained since there is no proper theoretical framework against which one can compare results. Therefore, researchers are forced to comment on their charts by simply stating where each language is factually situated and where they “expected” it to be situated. Unfortunately, the expectations by researchers are usually based on impressions described by other researchers in previous studies (most typically Pike, 1945, and Abercrombie, 1967) or, sometimes, on impressions of their own; rarely are these “impressions” based on data (that is to say on perceptive tests). So, whenever there is a discrepancy between the researcher’s prediction and the actual results, it is not clear whether this has to be attributed to a malfunctioning of the metrics or, rather, to the fact that the language in question belongs to a different rhythm class from what had been inferred (which implies that the impressions were wrong). In short, it is not clear whether we should trust the metrics to be better indicators (or “correlates”, as they were initially called) of rhythm than impressions. For the same reason, it is risky to use metrics to give a rhythm assessment of previously unstudied languages. These characteristics indicate that the model is not entirely “predictive”, to use the words by Bertinetto & Bertini (2010).

A partial solution to this problem is to carry out perceptive tests and put them in relation with the values obtained with metrics. However, it has to be stated that the non-predictiveness is inherent in the metrics (deltas, varcos and PVIs) and perceptive tests do not make them any more predictive; it is nonetheless true that a

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[90] See the “perception illusionists” reported by Bertinetto (1989).

correlation might be found between the results of perceptive tests and the values of metrics: this would certainly imply that the metrics do give an acceptable account of the perception of language rhythm (if not an account of language rhythm tout court) and might thus improve their trustworthiness.

So, I decided to carry out perceptive tests with the initial aim of comparing results obtained with the various rhythm metrics and to check if there really was a correspondence between the two. After all, Ramus *et al.* intended the metrics as “correlates of the perception of rhythm” and specified that their study was “meant to be an implementation of the phonological account of rhythm perception” (1999:274). The authors themselves presented the results of a series of tests carried out on adults and infants on the discrimination of languages on the basis of rhythm. It seems therefore natural that a study on rhythm metrics that does not take perception in any account could be considered as wanting in some respects.

This chapter introduces the test that has been conducted, describes its format and discusses its (controversial) results.

6.1.2 Previous tests on rhythm

As has been stated above, very few authors cared to test the perception of speech rhythm until recently. One of the few who did was Miller (1984), who carried out a test on four groups of participants (a- English phoneticians, b- English non-phoneticians, c- French phoneticians, d- French non-phoneticians). He used recordings of read speech (*The North Wind and the Sun*) and spontaneous speech in Yoruba, Japanese, Argentinean Spanish, Indonesian, Arabic, Polish and Finnish. He extracted balanced samples of these data and asked the four groups of participants to rate them as either syllable-timed or as stress-timed (non-phoneticians were first given an explanation of these terms that involved clapping hands in synchrony with stress and syllables). Audio samples were not manipulated in any way. Results showed that phoneticians’ ratings were unsurprisingly more consistent with expectations and that Arabic was nearly universally perceived as stress-timed, while Indonesian, Yoruba and Japanese tended to be classified as syllable-timed; a high level of indecision was found for Finnish, Polish and Spanish.

More recently, the perception of speech rhythm has raised a new interest, above all since the publications of the research by Ramus and co-workers. They conducted numerous tests, proving that languages belonging to the two alleged rhythm classes are distinguished by adults and even by new-borns. Their experimental protocol departs completely from Miller’s and involves delexicalising speech in order to prevent listeners from rating stimuli on the basis of lexical information. This is achieved through a re-synthesis of the original speech samples in a degraded signal. Ramus & Mehler (1999) present four possible re-syntheses: (1) *SALTANAJ* synthesis is achieved by substituting all plosives with [t], all fricatives with [s], all liquids with [l], all nasals with [n], all glides with [j], all vowels with [a] and preserving the original pitch and intensity; (2) *SASASA* synthesis substituting all consonants as [s] and all vowels as [a] preserving the original pitch; (3) *AAAA* synthesis is obtained bu substituting all phones with [a] preserving only the original pitch; (4) *flat SASASA* synthesis is obtained like (2) but levelling the fundamental frequency at 230 Hz. They tested 64 students on the 4 types of re-synthesis on samples of English and Japanese and it was found that participants could discriminate the two languages with *SALTANAJ*, *SASASA* and *flat SASASA* syntheses, but not with *AAAA* synthesis. The authors consider the *flat SASASA* synthesis the most adequate to test the perception of speech rhythm.

Ramus, Dupoux & Mehler (2003) used the *flat SASASA* synthesis for discrimination tests of English vs. Spanish, English vs. Dutch, Polish vs. English, Polish vs. Spanish, Catalan vs. English, Catalan vs. Spanish and Polish vs. Catalan. Results confirmed expectations, with listeners discriminating languages belonging to different rhythm classes (English vs. Spanish), but not being able to distinguish between languages of the same rhythm class (English vs. Dutch and Spanish vs. Catalan). Interestingly, Polish was moderately discriminated from English, Catalan and Spanish, suggesting either that it is a mixed language or that it belongs to a different rhythm class.

White *et al.* (2007b) carried out *SASASA* tests to check whether the results would correlate with the values of the varcos and %V for the same samples (SSBE having high varcoC and low %V, Orkney Islands and Welsh Valleys English having medium values of both measures, Castilian Spanish having low varcoC and high %V). Data included heavily controlled sentences by three English speakers (Welsh Valleys, Orkney Islands and SSBE) and 4 Castilian Spanish speakers. The authors used an MBROLA synthesis to convert vocalic and consonantal intervals into *SASASA* at a constant fundamental frequency of 230 Hz and applied a series of normalisations to samples[91]. Final results confirmed that listeners could discriminate Castilian Spanish vs. the three types of English, but that they could not distinguish between Orkney Islands and Welsh Valleys English.

Dellwo (2008) carried out a test to verify whether speech rate plays a role in the perception of rhythm classes. Participants had to listen to de-lexicalised stimuli of "syllable-timed German and stress-timed French"[92] (consonantal intervals were re-synthesised as white noise, vocalic intervals were re-synthesised as complex periodic waveforms with a constant f_o at 230 Hz + 2nd and 3rd harmonics) and to rate them on a scale of regularity. They were unaware that they were listening to manipulated speech samples. Results showed that listeners generally rated the stress-timed French samples as being more regular than the syllable-timed German samples: this proves that they did not use the variability of vocalic and consonantal intervals as cue of regularity. Instead, the author suggests that they used CV rate (the number of vocalic and consonantal intervals per second), which is confirmed by the linear regression in cross-plots of listener ratings of regularity in function of CV-rate.

Arvaniti & Ross (2010) drafted a critical summary of perceptive tests carried out on the matter claiming that

> *new protocols may be needed to test the idea of distinct rhythm classes. Such protocols should go beyond simple discrimination (which could be due to a variety of confounding factors) and should*

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[91] In particular: they truncated sentences after the last stress to avoid final lengthening; they eliminated the first syllable and other following syllables in order to obtain 10 syllables per sample; they stretched or compressed each utterance uniformly in order to obtain a total duration of 1900 ms, thus preventing speech rate effects.

[92] By syllable-timed German and stress-timed French, the author means, respectively, German sentences that showed high %V and low varcoC, and French sentences that showed low %V and high varcoC.

> *be neither too indirect […] nor too explicit, like the categorization task of Miller (1984).*
> *(2010:2/4)*

They built a test in which stimuli were obtained by low-pass filtering sentences of English, German, Greek, Italian, Korean and Spanish at 450 Hz. Sentences of each language were divided into 3 types (syllable-timed, stress-timed, uncontrolled). Listeners (of three different mother tongues, namely English, Greek and Korean) listened to a synthetic trochee series[93] and to a sentence, repeating this task for each sentence. They were asked to rate the similarity of each stimulus to the trochee series on a 7-step scale. Final results show that the native language of speakers did not significantly affect the ratings, that stimuli of English were rated less similar to the trochee series. The three sentence types were rated as more similar to the trochee series along the following scale: syllable-timed - stress-timed - uncontrolled. This is at odds with expectations and the authors conclude that "language classification by means of rhythmic classes cannot be achieved on the basis of listener impressions anymore than it can rely on measuring consonantal and vocalic variability in production" (2010:4/4).

This summary of perceptive tests for the discrimination of rhythm classes has shown that results are controversial among different studies, each of which uses a different protocol. I shall now pass on to describe how the test for the present study was conceived.

6.1.3 The conception of the test

When I set out to build perceptive tests (in 2008), I had no general framework[94] on which to base myself and not many previous studies to learn from. The so-called *SASASA* tests have been used in most recent studies of this type (see above), in several slightly different variations (for instance including/excluding the original pitch contour and/or intensity values). Such tests normally follow the so-called ABX or the AAX formats[95] and share what I consider to be a basic limitation: they ask for a clear-cut decision on the part of subjects[96] as to whether the stimuli are either A or B. There is no way to let them say, for instance, that stimuli n° 4 and n° 5 are both more similar to A than to B, but that n° 4 is even more similar to A than n° 5 is. In other words, they ask for a clear-cut categorisation of languages, reproducing the stress-timed vs. syllable-timed dichotomy, leaving no chance to the subjects to spread the different stimuli along a continuum. Leaving that choice to the subjects certainly would be no easy task as it would introduce variability and add many complications, but it could bring to interesting results and it would connect to the

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[93] The authors report that the trochee series has been created with the MacOsX "frog" sound.

[94] such as the AMPER project, which not only includes precise prescriptions on how to collect data and how to analyse them, but also offers a standard model for perceptive tests.

[95] ABX tests are conceived as follows: the subject hears a first auditory stimulus (A), than a second (presumably different) auditory stimulus (B) and finally a third one (X): he/she is then asked whether X is more similar to A or to B. This test format is also widely used in other fields and for other purposes, such as to evaluate digital audio data compression methods. Intuitively, AAX tests provides listeners with two identical or similar stimuli plus a third one which has to be categorised as "similar" or as "different".

[96] I am of course talking about adults subjects. Testing the rhythm perception of infants, though certainly a fascinating ground, was definitely not a possibility for me. So, I shall make no more reference to tests devised for such a purpose.

theories proposed by Dauer (1987) and Bertinetto (1983) and dealt with in detail in chapter 2. One more difficulty consisted in the fact that I needed participants not to be aware of what was being tested and (in some tasks) of what the language in question was. This, of course, because I did not want the results to be influenced by any ideas or preconceptions on the part of participants.

Moreover, I have a feeling that not everybody is equally sensitive to linguistic/phonetic phenomena in general and to prosodic phenomena in particular, so I wanted a means of verifying the level of participants’ prosodic sensibility and, perhaps, of identifying those subjects that were likely not to perform well: this is not to say that I intended to discard their answers, but simply that it may be relevant to see whether their answers were comparable to those given by other subjects.

As for the practical implementation of the test, I had the choice of using specific software or to build it myself with some programming language. The advantage of the former possibility consisted of course mainly in speed and easiness. Nevertheless, I chose to build the test from scratch, using HTML and JavaScript[97] in order to have an absolute control and no limitations as to the format and configuration of each task. Moreover, the choice of HTML and JavaScript over other programming languages or programming toolkits allowed me to build a test which is easily executed on any computer (one just needs a browser) and which could, one day, reside on a website. I have not exploited the possibility of publishing the perceptive test on the world wide web within my PhD: of course, this would bring remarkable advantages in terms of numbers (all Internet users are potential subjects for the test); yet, it does have the very negative side-effect that I would completely lose control over the selection of subjects and their trustworthiness. In fact, there is not even an effective way to make sure that each person takes the test only once[98].

In the end, the output was a perceptive test written in HTML and JavaScript which consisted of three parts: after filling in a form with personal data, the first part was meant as a preliminary phase to check the prosodic sensibility of subjects (see 6.2.1), the second part consisted of auditory stimuli to be rated on a limited set of possibilities not unlike ABX tests (see 6.2.2), the third part consisted of auditory stimuli to be rated on a continuum scale (see 6.2.3). The results of each participant were contained in a log file which was saved in txt format at the end (a sample log file can be seen in appendix 4).

I shall now describe each part of the test separately and in detail: note that the results are not presented at the end, but within the discussion of each single part. It should be noted that such a presentation was chosen merely for the reader’s comfort, but subjects carried out all the parts of the test thoroughly and without any interruption.

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[97] I also exploited Macromedia® Flash technology in order to play sound in HTML pages.

[98] Checking the IP address is not safe, because one person might use more than one computers from different IP addresses and, conversely, more than one user might share the same IP address. Similarly, cookies are not safe because they can easily be deleted or modified by the user.

6.2 The preliminary phase

6.2.1 Personal data

The first part was not properly meant to test anything. It was a simple questionnaire[99] with personal data (reproduced in figure 6.1): participants entering the test were asked their name, age, level of studies, whether they had taken any exams in linguistics and phonetics (and, if applicable, how many exams they had taken and/or how many university credits[100] they were attributed in these subjects)[101], their mother-tongue and their level of proficiency in any foreign languages[102]. The age range was between 19 and 60 years averaging 25.25. 36 participants had Italian as a mother tongue, 2 French, 1 English, 1 German, 1 Romanian, 1 Arabic and 1 claimed that the dialect of Verona was his mother tongue. The mean number of university credits acquired in phonetics was 3.72 (spanning between 0 and 10), while the mean number of university credits acquired in linguistics was 8.04 (spanning between 0 and 10).

Per favore, riempi i campi con i tuoi dati.

Nome	
Cognome	
Età (anni)	
Titolo di studio	Maturità ▼
CFU sostenuti in fonetica e/o fonologia	
CFU sostenuti in linguistica (esclusi fonetica e fonologia)	
Madrelingua	
Conoscenza dell'inglese	no ▼
Conoscenza del francese	no ▼
Conoscenza del tedesco	no ▼
Conoscenza dello spagnolo	no ▼
altro(specificare)	no ▼
altro(specificare)	no ▼

Figure 6.1. The form which had to be completed by participants entering the test.

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[99] As it can be seen in question 6.1, it was not a paper questionnaire, but a digital one. It was in HTML and was attached to the rest of the test without interruption: participants were already sitting for the test when they completed it.

[100] For those who completed university studies before university credits were introduced, I established the equivalence of 1 exam with 10 university credits, in line with the choice taken by the University of Turin.

[101] The rationale behind this question is of course that students who had taken exams in linguistics and/or phonetics are more likely to be aware of the traditional stress-timed vs. syllable-timed dichotomy and to be sensitive to prosodic phenomena.

[102] Participants should self-evaluate their competence using the European common framework (A1 to C2). Participants who did not know the meaning of these levels usually asked information about it, so the data should be fairly accurate (keeping in mind the obvious limitations of self-evaluations, of course).

The 43 participants did not gain any compensation (neither pecuniary, nor in terms of university credits or else) for taking the test and all of them gave me permission to use the results for research purposes. They were mainly (though not exclusively) recruited among students of the Faculty of Foreign Languages of the University of Turin. Some students came to the Laboratory of Experimental Phonetics Arturo Genre of Turin and took the test inside the sound-proof booth. However, most took the test straight after passing their first exam of general linguistics because that was the moment in which they were most easily available. This exam is usually taken in the first year, which means that most candidates were at the beginning of their university career. It has been decided that it was best to let students take and register the exam first, in order to avoid stress and to prevent them from thinking that their performance in the test might somehow have an influence on their final mark of the exam. Students who did not pass the exam were not asked to take part in the test[103].

I supervised personally all participants taking the test, so some of them felt free to ask me indications if they did not understand some tasks or else. The test was not designed to keep track of the time taken by each participant to reach the end, and not even of the time taken to complete each task. For this reason, I have no precise data as to time variables, but since (as already said) I was present during all the tests, I can give an estimate of the time generally needed by participants in order to get through the end, spanning roughly from 20 to 40 minutes but probably averaging a little more than 30.

6.2.2 Testing prosodic sensitivity

In the second part, participants started the real test and had to respond to auditory samples. Yet, it was a kind of introductory task in which they were presented with the orthographic transcription of an Italian sentence and a recording by a professional speaker of that very sentence. They had to mark stresses on the transcription according to how the sentence was actually pronounced by the speaker (less prominent stresses on the first level, more prominent ones on the second level)[104]. Instructions were given at the top of the page, while in the middle there was an example sentence and its recording. Participants could listen to both the example sentence and the target sentence as many times as they wished by clicking on the corresponding icon[105]. The task was controlled by a JavaScript routine so that it was not possible to proceed with the test until at least one primary stress had been marked. This task was repeated five times, each time with one of the following target sentences:

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[103] This choice was not taken on any “discriminatory” grounds. Simply, it was felt that asking students who had just failed our exam to kindly take a test for our research purposes was not precisely courteous. It is true, however, that students might also have been upset by their negative performance and, consequently, they might not have been able to concentrate properly for the test.

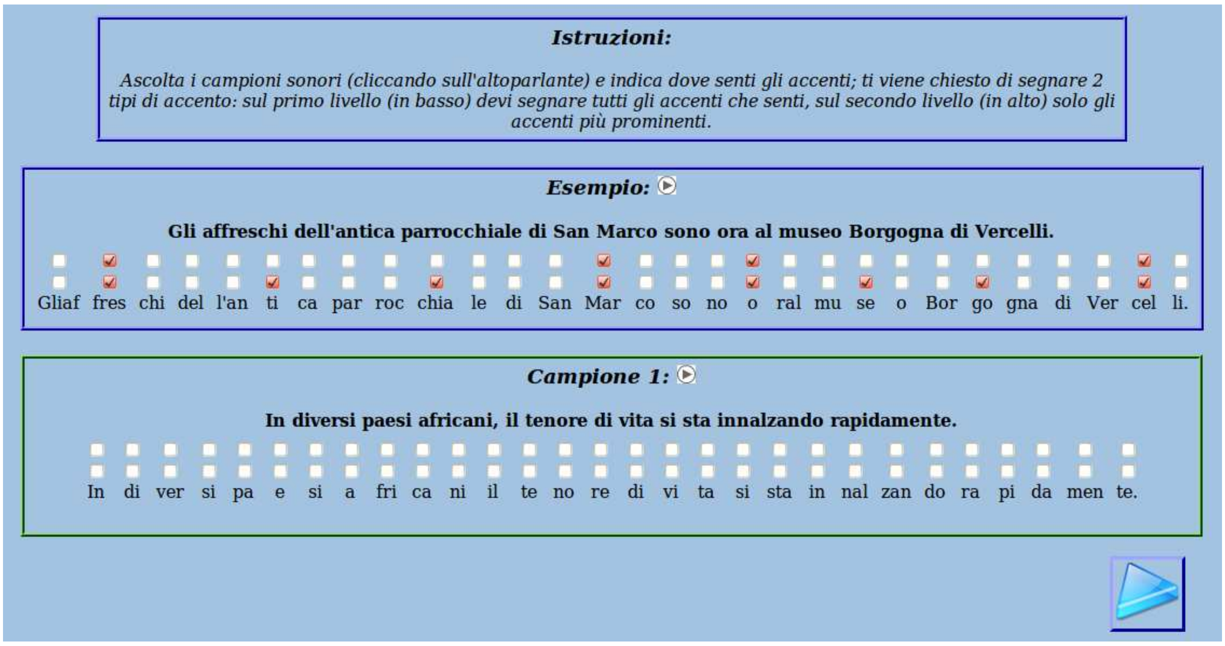
[104] I am aware that this distinction poses theoretical and practical problems. By “more and less prominent” stresses , I actually meant the distinction between stresses and accents (the latter are usually defined as those stresses that carry prosodic relevance). I initially included the distinction between first-level and second-level stresses in order to provide participants with an extra difficulty, I realised only too late that this complicated things enormously.

[105] The audio player used is an open-source and is called XSPF Web Music Player. It has been retrieved at the following webpage: http://musicplayer.sourceforge.net/

1. In di**ver**si pa**e**si afri**ca**ni, il te**no**re di **vi**ta si sta innal**zan**do **ra**pida**men**te.
2. **L'uo**mo ha ricono**sciu**to **sin** da **tem**pi anti**chis**simi l'impor**tan**za dell'**ac**qua per la **vi**ta.
3. Allo **sta**to **so**lido è **no**ta come **ghia**ccio, allo **sta**to aeri**for**me è **no**ta come va**po**re **ac**queo.
4. Sono **no**te **an**che altre due **for**me **so**lide, **que**lla del **ghia**ccio ve**tro**so e **que**lla del **so**lido a**mor**fo.
5. Per**ché** non pro**via**mo a ri**sol**vere il pro**ble**ma in**sie**me, in**ve**ce di liti**ga**re?

Sentences were of course given without the stress indications reported above. Here they have been marked with first-level stresses (in bold) and second level stresses (in bold and underlined)[106]. Such an evaluation was of course necessary in order to have a term of comparison against which to compare the answers given by participants. I then calculated the correlation between her answers and those given by each participant, which ranged between 3.08% and 80,62% with a mean of 49.57% (quartiles at 37.67% , 54.26%[107] and 63.13%).

The instructions given and the format of the test can be seen in figure 6.2 (English translation in the footnote).



Istruzioni:

Ascolta i campioni sonori (cliccando sull'altoparlante) e indica dove senti gli accenti; ti viene chiesto di segnare 2 tipi di accento: sul primo livello (in basso) devi segnare tutti gli accenti che senti, sul secondo livello (in alto) solo gli accenti più prominenti.

Esempio:

Gli affreschi dell'antica parrocchiale di San Marco sono ora al museo Borgogna di Vercelli.

☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐
☐	☑	☐	☐	☐	☑	☐	☐	☐	☑	☐	☐	☐	☑	☐	☐	☐	☑	☐	☐	☑	☐	☐	☑	☐	☐	☐	☑	☐
Gliaf	fres	chi	del	l'an	ti	ca	par	roc	chia	le	di	San	Mar	co	so	no	o	ral	mu	se	o	Bor	go	gna	di	Ver	cel	li.

Campione 1:

In diversi paesi africani, il tenore di vita si sta innalzando rapidamente.

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
In	di	ver	si	pa	e	si	a	fri	ca	ni	il	te	no	re	di	vi	ta	si	sta	in	nal	zan	do	ra	pi	da	men	te.

Figure 6.2. A screenshot of part 1 of the test (the first sentence). It is possible to see the instructions at the top[108], the example in the middle and the task at the bottom of the page. Participants could mark stresses by simply clicking on check-buttons corresponding to each syllable.

The rationale behind this task is to have an evaluation of the prosodic sensitivity of participants to prosodic phenomena and, if needed, to be able to

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[106] It can be seen that, although recordings were made by a professional speaker of Standard Italian, the accentuation is sometimes atypical, above all at the second level.

[107] The second quartile corresponds, of course, to the median.

[108] English translation of the instructions: *Listen to the audio samples (by pressing on the loudspeaker) and mark where you hear stresses; you are asked to mark two different types of stresses: on the first level (below) you have to mark all stresses that you hear, on the second level (above) you have to mark only the more prominent stresses.*

identify those participants who appear to have a limited prosodic sensitivity. It is true that we do not have any proof that a limited sensitivity to stresses necessarily implies a limited sensitivity to rhythm phenomena; however, at least intuitively, this is likely to be so, as stresses and rhythm are both realised through prominences (see chapter 1 for a discussion on what rhythm is and for more details about the relation between rhythm and prominence).

6.2.3 The results

I shall now illustrate the answers given by participants for the five sentences. They are shown by the histograms in figure 6.3, which represent the amount of participants that marked a first-level stress (in blue) and a second-level stress (in red) on each syllable. On the whole, it can be claimed that most participants found it difficult and did not perform splendidly. When supervising participants who took the test, I was surprised at seeing that, even though it was meant as a preliminary task, people took often long time to complete each sentence, listening various times to the recordings and taking long to mark (often very few) stresses. It should also be noted that this cannot be attributed to a misunderstanding of the instructions, because those who were not sure about what the task involved were free to ask me clarifications (and some did).

Despite the difficulties encountered by single participants, the overall results reflect quite well expectations set by the model and phonological evaluations *a priori*. In particular, effectively stressed syllables have been marked with either a first-level or a second-level stress by usually a high number of participants, whereas completely unstressed syllables have been usually marked by no or few participants (most emblematically, sentence final syllables). Interestingly, the most frequent mistakes involve marking a stress on syllables immediately preceding stress (such as ‘pa’ in *paesi*, ‘te’ in *tenore* and ‘nal’ in *innalzando* in sentence 1, as well as ‘è’ in *è nota* twice in sentence 3).

I shall not discuss these results in more detail here, as their role within the test was simply that of providing an idea of the prosodic sensitivity of participants (a detailed analysis is in preparation and is thought to appear soon). So, for this purpose, what matters are the scores of correlation (see above) between the answers given by each participant and the answers considered as the model. It has to be made clear that the correlation is not meant to be a sophisticated and faultless evaluation of listeners’ prosodic sensitivity: needless to say, this would not be feasible by simply calculating the correlation with answers by one model because, clearly, such a task has more than one acceptable answer. However, the values of correlation should be enough to identify those participants whose performance was extremely low. The problem consists in establishing the exact threshold under which participants might be considered as “prosodically insensitive”: the distribution is fairly homogenous apart from 2 participants who scored 3.08% and 6.89% (the rest of the population ranging from 18.54% upwards). I decided not to exclude any sample, at least for a first analysis, which means that the results presented above refer to the entire population of 43 participants. The results by segments of the population will be discussed at the end.

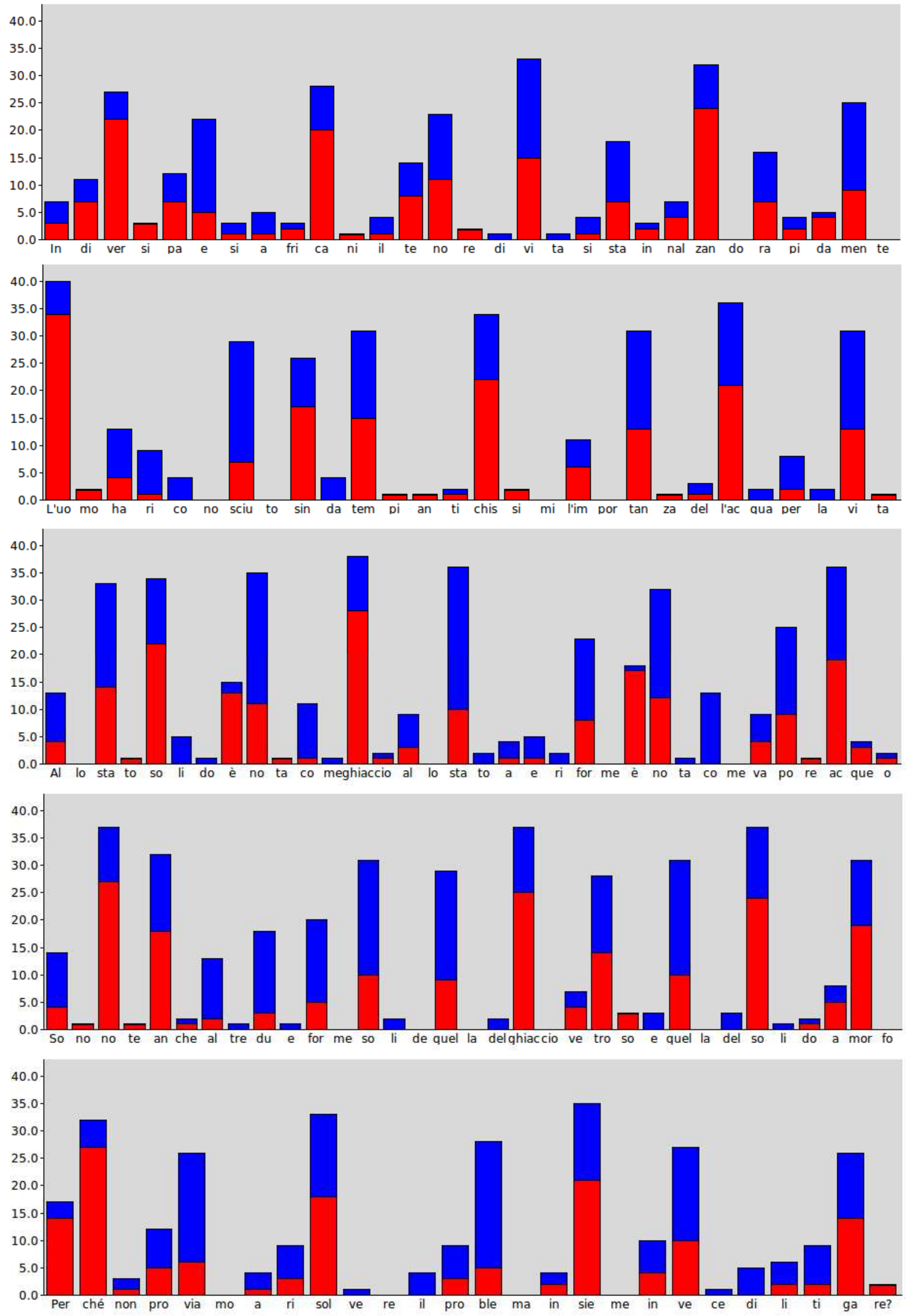

Figure 6.3. Histograms representing the answers given to the preliminary phase of the test. Syllables are shown in the x-axis, while the y-axis represents the number of people who marked a stress on each syllable (first level stresses in blue, second level stresses in red).

6.3 Testing the perception of discrete rhythm classes

6.3.1 The format and the interface

After the preliminary phase, participants started the real test, in which I meant to verify the discrimination of rhythm classes in discrete terms, that is to say in the traditional way, asking people to decide whether a sample is stress-timed or syllable-timed, without any gradient. This part was divided into two similar tasks, each consisting of 15 samples.

Participants were first asked to listen to masked synthetic audio samples and decide which language was being spoken: they had the possibility of choosing between: (1) *Spanish, French or similar* (2) *English, German or similar* (3) *Other* (4) *I don't know* (the two possible choices obviously reflected the two traditional rhythm classes). Samples were synthesised using the AMPER routines (see below for details) and preserved the duration, pitch and intensity of the original samples: in short, they reproduced the prosodical but hid the lexical information of speech. Participants could listen to each sample only once. Instructions were given immediately before starting the task and read as follows (see footnote for an English translation):

> *Ora ascolterai dei campioni audio e dovrai cercare di capire se si tratta di inglese/tedesco o francese/spagnolo. Il parlato è stato modificato in modo che tu non possa riconoscere le parole delle due lingue, quindi dovrai giudicare solo dall'impressione che ne ricevi. Per ogni frase clicca sul tasto "francese spagnolo o simile" o "inglese tedesco o simile"; se il campione audio non ti sembra simile a nessuna di queste lingue, clicca su "altro"; se invece non hai idea, piuttosto che premere un bottone a caso premi "non so", ma ti preghiamo di cercare di utilizzare il meno possibile questa soluzione. Nota che i campioni sonori vengono estratti da un database ampio in ordine del tutto aleatorio. Ora premi il tasto avanti per iniziare.*[109]

The interface was extremely simple and intuitive, consisting exclusively of the stimulus label and the four buttons, as can be seen in figure 6.4. Participants only had to press the button corresponding to their answer and they were immediately put forward to the next audio sample. So, the procedure was very strict: it was not possible to listen to the audio sample more than once nor to go back and correct the answer once it was given[110]. Each stimulus lasted between 4 and 8 seconds.

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[109] *You will now listen to some audio samples and you will have to understand if they are English/German or French/Spanish. Speech has been modified so that you will not be able to recognise the words of these languages, so you will have to judge exclusively on the impressions you get. For each sentence, press "French, Spanish or similar" or "English, German or similar"; if you think that the audio sample does not sound like any of these languages, press on "other"; if you really have no idea, press on "I don't know" rather than taking a wild guess, but we kindly ask you to try and avoid this solution. Please note that audio samples are randomly retrieved from a large database. Press "forward" to start.*

[110] One may think that it was possible to navigate back and forward with browser controls. Actually, participants could not do that because browser controls were disabled by Javascript and, at any rate, the test was executed in full-screen mode. Furthermore, all 15 samples resided in one HTML page, so, even succeeding in navigating back would have led the participant to the instruction page.

The synthesised stimuli included 15 different languages. Audio samples were taken from the Illustrations of the IPA (with the exception of the Italian, Icelandic, Romanian, Finnish and Japanese samples, which were recorded at LFSAG), either included as an attachment to IPA (1999) or in various articles appeared in the *Journal of the IPA*, and synthesised as described below. They corresponded to some of the data used in chapter 3 to test rhythm metrics (which can be consulted for further details and for the bibliographic reference corresponding to each sample).

The hypothesis was that participants would classify tendentially stress-timed languages as "English, German or similar", tendentially syllable-timed languages as "Spanish, French or similar" and mixed languages as "other" or "I don't know". Of course, I did not expect all participants to agree on each sample, rather it was presumable that the alleged rhythm classification would emerge as a general trend.

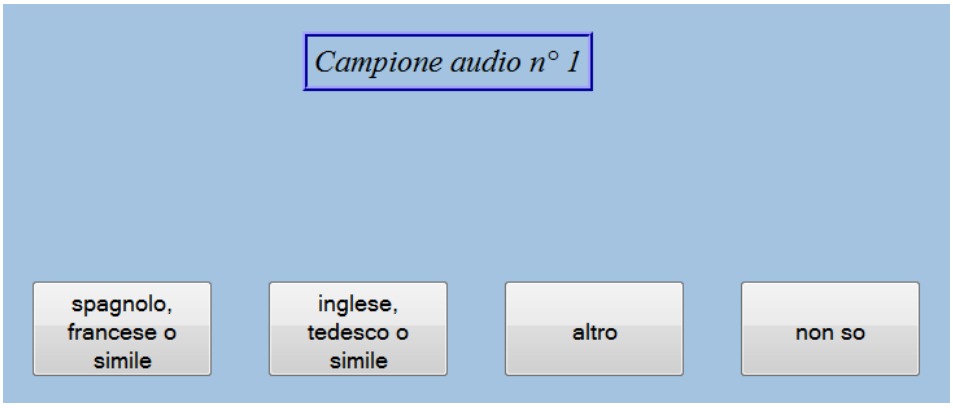

Figure 6.4. Screenshot of the interface. It consists merely of a label indicating the stimulus number and the four buttons. There is no button to listen to audio samples nor to proceed, as the succession of events is completely controlled by JavaScript.

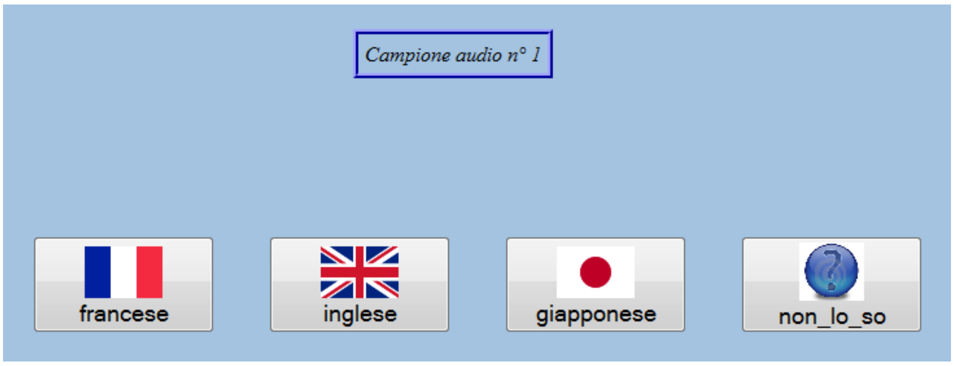

Figure 6.5. Screenshot of the interface. As for the former task, there is only the stimulus number and the four choice buttons as participants have no control over the succession of events.

After the first 15 stimuli, the test proceeded with a similar task made up of another series of 15 stimuli, in which participants were, again, asked to listen to differently synthesised audio samples and had to decide which language was being spoken. In this case, the possible choices included: (1) *English* (2) *French* (3) *Japanese* (4) *I don't know* (representing respectively stress-timing, syllable-timing, mora-timing). The audio samples of these three languages were similar to the ones presented in the former part of the test, but were manipulated in order to normalise at each turn one or two of the three prosodic parameters (pitch, intensity and duration, see below for details).

The interface (see figure 6.5) is very similar to the one in part 3 and the instructions given read as follows (English translation in footnote):

> *Ora ascolterai altri campioni audio e il tuo compito è simile a prima, dovrai cercare di capire se si tratta di inglese, francese o giapponese. Tuttavia, questa volta il parlato è stato mascherato in maniera diversa.*
> *Ora premi il tasto avanti per iniziare.*[111]

6.3.2 Differences from other tests.

The format is not so different from *SASASA* tests. However, in this case, participants did not hear three stimuli (A, B and X), but only one (X), and had to classify it on the basis of categories which they presumably already knew[112]. This has been done in order to avoid that the results be marred by the choice of A-B sentences. In fact, the choice of A and B in ABX tests is a very delicate matter: I feared that the classification of X in ABX tests might be influenced by the choice of A and B, that is to say that using one particular sentence in language A might bring to (slightly) different results from those that one would get by using some other sentence in language A (and the same could be said about B). So, I preferred to rely on participants' knowledge of languages A and B. Furthermore, in this way, the participants' task is far simpler and this contributes to decrease the impact of errors due to misunderstandings.

An argument that has been raised concerns the fact that participants who speak a certain language might tend to classify audio samples as that language because they are more familiar with it[113]. Of course, this cannot be excluded *a priori*; yet, on the other hand, one could also hypothesise the opposite, *i.e.* that participants who speak a certain language might tend NOT to classify audio samples as that language precisely because they know it and they find that artificial stimuli sound different. Be it as it might, if need be, it would be possible to verify these hypotheses since questions about foreign language proficiency were included in part 1 of the test.

Another fundamental difference from other similar tests consists in the way the audio samples were synthesised. In fact, as in most perceptive studies on rhythm categorisation, I needed to find a way of hiding lexical information and the segmental characteristics of speech. Obviously, asking participants to categorise an overt speech sample as either Italian/French or as English/German would not allow to discover anything about rhythm: participants would most likely recognise speech

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[111] *You will now listen to other audio samples and your task is similar, you will have to understand if English, French or Japanese are being spoken. However, this time speech has been masked in a different way. Press "forward" to start.*

[112] It could be argued that not everybody has ever heard Italian, French, German and English. The answer to this is that, first of all, it is not necessary to know all four of them: it is enough to have heard at least Italian or French and English or German. Secondly, most participants were university students at the faculty of foreign languages, who should then be fairly knowledgeable about languages. Finally, nobody complained that they did not have a sufficient knowledge of these languages in order to complete the task.

[113] I am grateful to Lea Glarey for raising this observation.

samples on the basis of lexical information as well as of segmental clues (and even if they did not, it would be difficult - if not impossible - to make sure of that).

So, long time was spent in deciding how to mask speech. Most studies of this type (see above) make use of the already quoted *SASASA* method, by which consonantal intervals are re-synthesised as [s], while vocalic intervals are re-synthesised as [a]. However, for the purpose of this test I decided to use a different procedure for masking speech, the one already used within the AMPER project, where it is exploited for different purposes. I shall spend a few words about it.

6.3.3 Perceptive tests within the AMPER project.

The AMPER (*Atlas Multimédia Prosodique de l'Espace Roman*) project (which saw the light at the *Centre de Dialectologie* of the *Université Stendhal Grenoble 3*) enhances the creation of a multimedia prosodic atlas of the Romance area through a cooperation of different research teams belonging to each Romance linguistic area. Members of each research team collect data of their own linguistic domain according to a shared protocol, which includes various utterance types, various syllable and stress patterns as well as three repetitions for each sentence. Data are then labelled by members of the research teams and first processed with a *Praat* script and then with a programme called *Interface*, which has been developed by Albert Rilliard (currently LIMSI - *Laboratoire d'Informatique pour la Mécanique et les Sciences de l'Ingénieur*, Orsay, formerly *Université Stendhal Grenoble 3*) on the basis of Matlab procedures written by Antonio Romano (currently University of Turin, formerly *Université Stendhal Grenoble 3*) for his PhD thesis. The *Praat* script outputs a text file with the durations of each vocalic interval and their relative values of pitch and intensity at the onset, middle and offset. Taking these text files as input, *Interface* computes the values of prosodic cues (pitch, intensity and durations) for each set of three repetitions, creates charts for visualising the results and produces sound files which are then used for perceptive tests with the aim of validating the data collected. The sound files are synthesised by averaging the values of the three prosodic parameters at the onset, middle and offset of each vowel. Currently, consonants are not considered and consequently not re-synthesised (they result in silence), as their relevance at the prosodic level is thought to be limited. However, the possibility of including them in future analyses is being discussed.

The values obtained are meant as the standard prosodic contour for that utterance type in the linguistic variety taken in consideration and sound files are then used for perceptive tests for validation (see, for instance, Felloni, 2010, and Interlandi, 2003 and 2004). The usefulness of this synthesis has already been proved by several studies conducted by the various members of the numerous AMPER teams. For further details on the AMPER project, see Contini *et al.* (2002).

6.3.4 Synthesising audio files with AMPER routines for testing rhythm perception.

The 15 re-synthesised sentences which have been used as stimuli for the first part of the test are the incipit of the narrative *The North Wind and the Sun* in 15 different languages (in the order, German, Italian, Russian, Icelandic, Brazilian Portuguese, Romanian, European Portuguese, Finnish, Turkish, Japanese, Spanish, RP English, GA English, French, Czech). Only the first sentence was selected, because of course the stimulus should not be too long in order to avoid that the subject gets confused or tired: for instance, as far as the English version is concerned, I only used "The North Wind and the Sun were disputing on which was the stronger, when a traveller came along wrapped in a warm cloak". I then labelled it following AMPER conventions (which involve marking the boundaries of vowels[114]) and processed data with *Interface* in order to get the synthesised sound files.

A relevant issue concerns the choice of preserving vs. levelling the original pitch and intensity contours. Leaving these parameters lets the participants free to use all prosodic cues to complete the task, while removing them forces the subjects to concentrate on durations. The decision has very important implications because, of course, samples for which f_o is not levelled could be recognised by their pitch contour; on the other hand, if f_o plays a role in rhythm perception, levelling it might bring to inconsistent results. Probably, the choice of what to do depends on the conception of rhythm, and I am fairly convinced that duration (although undoubtedly being an important factor – probably the most important) is not the only parameter on which rhythm is perceived (see also Allen, 1975, Cumming, 2009, and Romano, 2010). I could find no satisfactory solution to the problem as it seems to be impossible to separate the rhythmic aspect of f_o from its pitch aspect. So, after a long hesitancy and several perplexities, I finally decided to leave the original pitch and intensity contours of the samples (however, see part 2 of this task). When interpreting results, one will have to keep in mind this decision.

In the first task, participants had to give their judgment as to whether each synthetic stimulus was more similar to French/Italian or to English/German. As has been said, the 15 sound samples corresponded to 15 different languages, so only 4 of them were truly French, Italian, English or German (5 to be precise, because I included both RP and GA English). However, this has no importance at all, as I was not testing people's ability to recognise a language on the basis of synthetic stimuli and I did not expect them to; rather, I was prompting them for a categorisation of languages based on prosodic cues (even though, of course, they were not aware of this and they were bound to think they were taking a discrimination task).

In the second task, participants had to judge whether they were listening to English, French or Japanese. Effectively, they were always listening to samples of these three languages, but in this case they were manipulated as for f_o, intensity and duration. The audio samples were similar to the ones presented in the former task as they were also created by applying the AMPER routines on the initial sentence of *The North Wind and the Sun*. However, in turn, the following manipulations were applied to each of the three samples:

1) *ergconst*: intensity levelled to 80 dB (f_o and durations untouched);
2) *f0const*: f_o levelled to 200 hz (intensity and durations untouched);
3) *dconst*: vocalic durations levelled to 80 ms (intensity and f_o untouched, each vocalic onset is placed at the original distance from the preceding vocalic onset);

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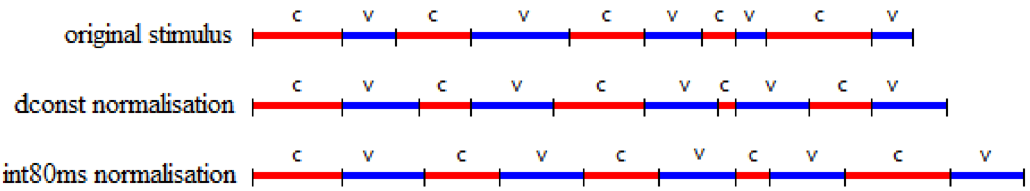
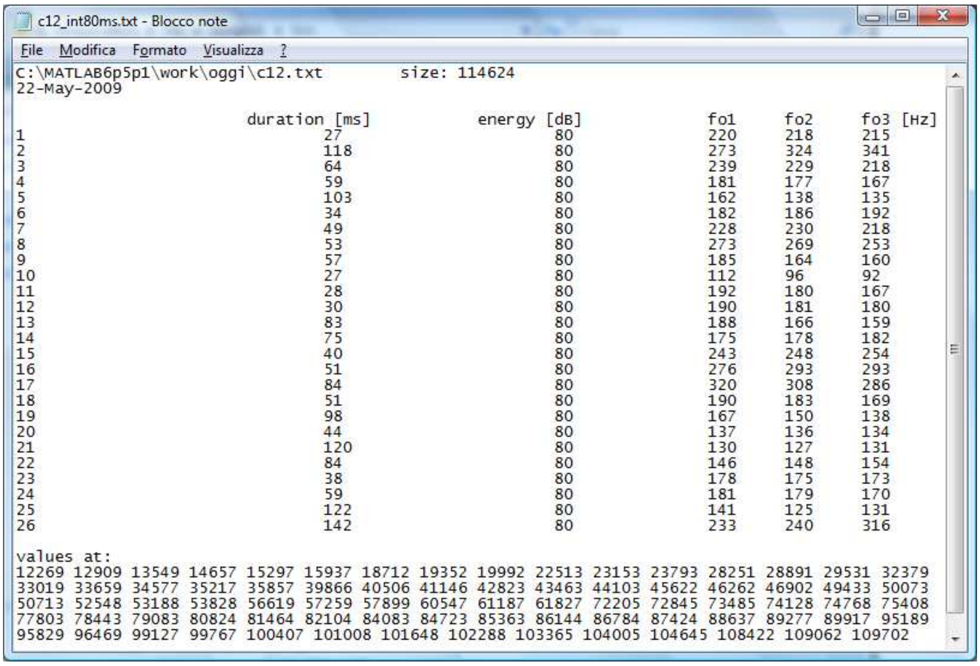
[114] While AMPER does not currently grant any importance to consonants, one of its creators and coordinators (Antonio Romano) felt that they also play a relevant role and advised that I should insert the spikes of consonantal clusters involving more than one plosive in the synthesised sound files. The rationale behind this choice is that spikes constitute a prominence within the speech chain which might have some relevance as far as the perception of rhythm is concerned. Only clusters were considered, anyway, as pre-vocalic plosives are of course followed by a vocalic onset and therefore their presence needs not be emphasised.

4) *int80ms*: vocalic durations levelled to 80 ms (intensity and f$_0$ untouched, each vocalic onset is placed at the original distance from the preceding consonantal onset);
5) *dconstconst*: consonantal and vocalic durations levelled to 80 ms (intensity and f$_0$ untouched).

So, a total of 3x5=15 manipulated samples were obtained and inserted in the test in random order. I shall briefly clarify the difference between manipulation (3) and (4): in both cases, vowels are normalised to a duration of 80 ms; however, in (3) the consonantal interval (which is synthesised with silence) is either enlarged or shrunk in order to let the following vocalic onset be at the original distance from the preceding vocalic onset as illustrated below.



In practise, the manipulation has been done by manually modifying the values in the text files (which are produced by the *Praat* script quoted above and which are given as inputs to *Interface*). As has been said above, these text files contain the durations of all vocalic and consonantal segments and the values of f$_0$ and intensity at their onset, middle and offset. So, the manipulation is easily done by changing the numeric values of the text files: for example, figure 6.6 shows a manipulated text file (for French) with levelled intensity.



```
C:\MATLAB6p5p1\work\oggi\c12.txt        size: 114624
22-May-2009

                        duration [ms]           energy [dB]             fo1     fo2     fo3 [Hz]
1                               27                      80              220     218     215
2                               118                     80              273     324     341
3                               64                      80              239     229     218
4                               59                      80              181     177     167
5                               103                     80              162     138     135
6                               34                      80              182     186     192
7                               49                      80              228     230     218
8                               53                      80              273     269     253
9                               57                      80              185     164     160
10                              27                      80              112     96      92
11                              28                      80              192     180     167
12                              30                      80              190     181     180
13                              83                      80              188     166     159
14                              75                      80              175     178     182
15                              40                      80              243     248     254
16                              51                      80              276     293     293
17                              84                      80              320     308     286
18                              51                      80              190     183     169
19                              98                      80              167     150     138
20                              44                      80              137     136     134
21                              120                     80              130     127     131
22                              84                      80              146     148     154
23                              38                      80              178     175     173
24                              59                      80              181     179     170
25                              122                     80              141     125     131
26                              142                     80              233     240     316

values at:
12269 12909 13549 14657 15297 15937 18712 19352 19992 22513 23153 23793 28251 28891 29531 32379
33019 33659 34577 35217 35857 39866 40506 41146 42823 43463 44103 45622 46262 46902 49433 50073
50713 52548 53188 53828 56619 57259 57899 60547 61187 61827 72205 72845 73485 74128 74768 75408
77803 78443 79083 80824 81464 82104 84083 84723 85363 86144 86784 87424 88637 89277 89917 95189
95829 96469 99127 99767 100407 101008 101648 102288 103365 104005 104645 108422 109062 109702
```

Figure 6.6. A text file issued as output by a *Praat* script and used as input for *Interface* (see above). This file has been manipulated by setting all intensity values to 80 ms. A similar operation has been done to level pitch and durations. More details about this file format can be found in Romano (2010:62-64).

6.3.5 The results

The results are reported in figure 6.7; histograms show the answers given by the 43 participants for each sample. For the first task (see the 15 samples reported in the chart above), red bars indicate ratings for “English, German or similar”, green bars indicate ratings for “French, Spanish or similar”, blue bars indicate ratings for “Other”, while yellow bars indicate ratings for “I don’t know”. For the second task (see the 15 samples reported in the chart below), red bars indicate ratings for “English”, green bars indicate ratings for “French”, blue bars indicate rating for “Japanese”, while yellow bars indicate ratings for “I don’t know”.

Results are quite surprising and dot not confirm expectations: the German, Brazilian and European Portuguese, Romanian, Japanese and French samples display the highest ratings as “*English, German or similar*”, while the Russian, Finnish and English (both GA and RP) samples display the highest rating as “Spanish, French or similar”. High levels of indecision seem to affect the classification of Italian, Icelandic, Turkish, Spanish and Czech. It goes without saying that this scenario does not reflect the traditionally accepted rhythm classes. It is particularly surprising to notice that Japanese (an alleged mora-timed language, which should be at the other end of the supposed rhythm continuum) has been rated together with German (an alleged stress-timed languages): these two languages present opposite values of deltas and PVIs for these very samples (see chapter 3).

Examining the answers given to the second task, three main observations emerge. Firstly, it can be seen that all three samples normalised as *dcostcost* (by levelling both vocalic and consonantal durations) have been most frequently classified as Japanese. This, in a singular and unexpected way, seems to confirm that participants have a mental representation of this language as having constant intervals: whenever they heard very regular sequences, they classified them as Japanese.

Secondly, it can be seen that indecision seems to be greater in correspondence of *f0cost* normalisations: in these 3 cases the yellow bars are in fact the highest of all 15 samples. This clearly suggests that participants were using f_o for the classification of samples and that its levelling disorients them.

Thirdly, in 4 out of 5 cases, Japanese has been correctly identified (the only exception being the *int80ms* normalisation). Interestingly, it seems to be the only one of these three languages that can be recognised, since samples of French and English are either classified as Japanese (in *dcostcost* normalisations, as remarked above) or are classified as French and English by roughly the same amount of participants. What is even more surprising is that the Japanese sample was classified as “English, German or similar” in the preceding task. However, if participants were able to recognise Japanese even when one of the three prosodic parameters was neutralised, there is no reason to believe that they could not recognise it when all prosodic parameters were original: this implies that speakers probably recognised that sample as “Japanese or similar”, but, in lack of such a label, they associated it with “English, German or similar”. However, as already stated, there is no way of telling whether this association has been made on the base of purely rhythmic properties or only on the basis of the pitch contour.

In general, it can be said that the results of this part of the test were far from confirming expectations, but an analysis of the answers given by participants revealed some aspects of coherence and opened interesting and challenging perspectives.

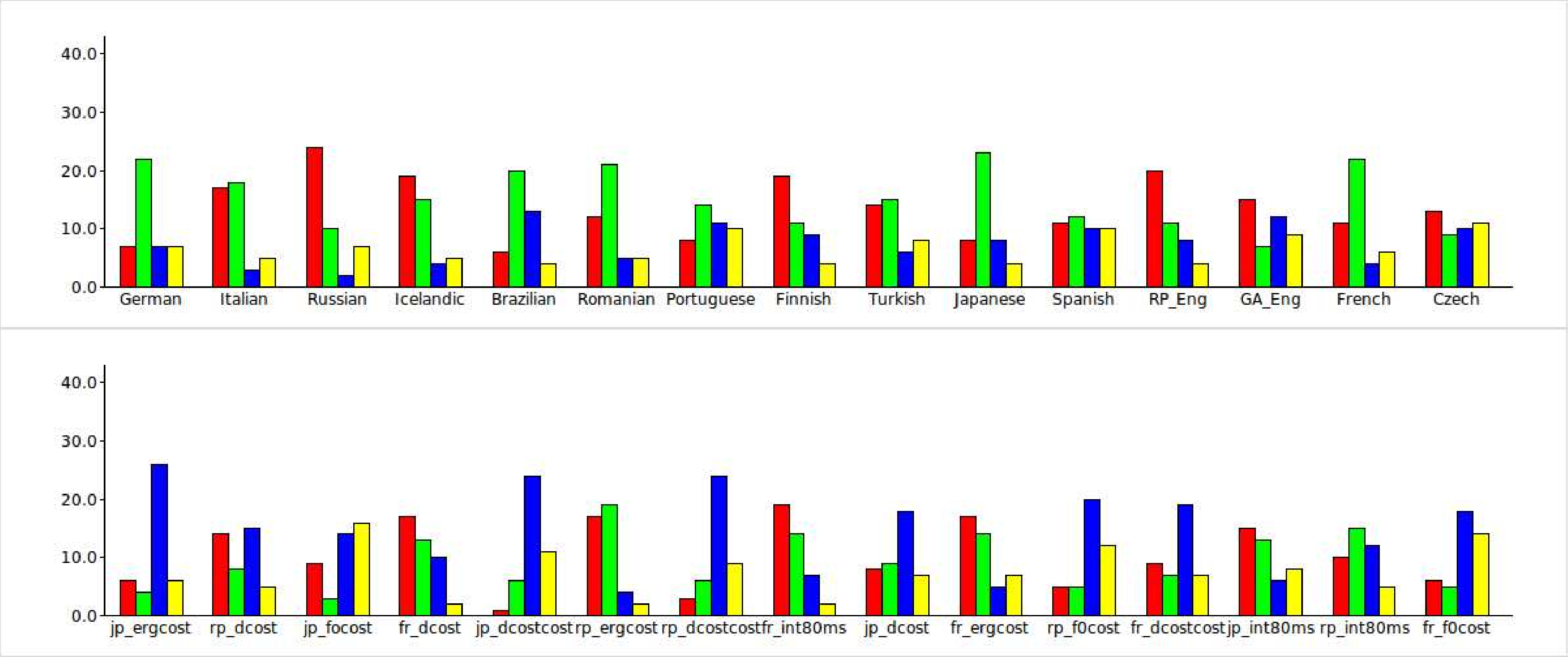
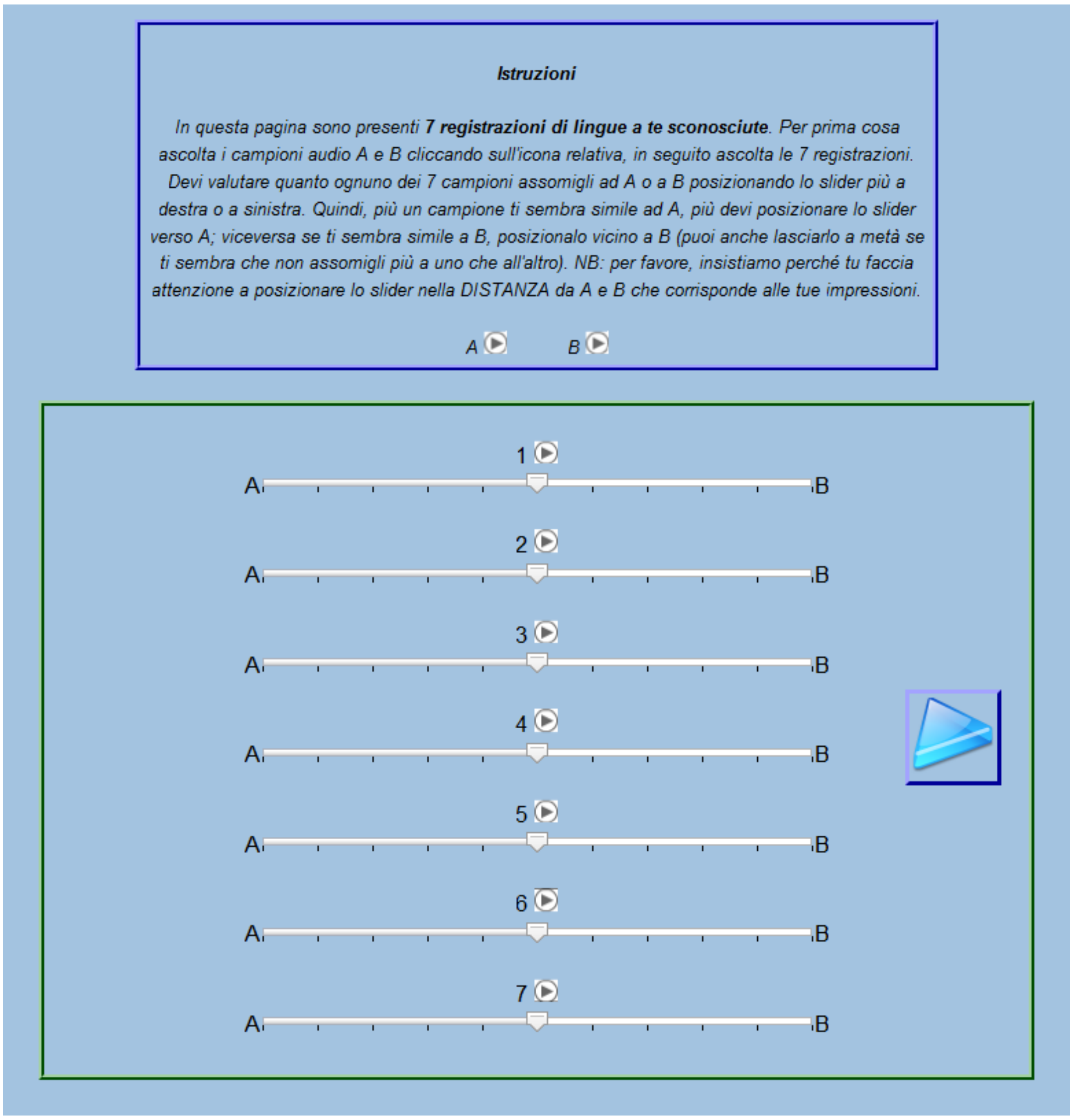


Figure 6.7. Answers given by the 43 participants for each audio sample. For the first task (above), red bars indicate ratings for "English, German or similar", green bars indicate ratings for "French, Spanish or similar", blue bars indicate rating for "Other", while yellow bars indicate ratings for "I don't know". For the second task (below), red bars indicate ratings for "English", green bars indicate ratings for "French", blue bars indicate rating for "Japanese", while yellow bars indicate ratings for "I don't know".

6.4 Testing the perception of a scalar characterisation of rhythm

6.4.1 The format and the interface

The final part of the test consisted in a “scalar” implementation of a traditional ABX format. Participants had to listen to two synthesised versions of the first sentence of the *North Wind and the Sun* in RP English (A) and Standard French (B), though of course they were not told it was French and English. The 2 samples were synthesised using the AMPER routines by neither modifying nor levelling the values of duration, pitch and intensity (in short, the stimuli were only masked, not manipulated). Then, they had to listen to 7 different stimuli of 7 presumably unknown languages (see below) and to decide whether they resembled more to A or to B. They had to express their judgment with the help of a slider, which went from A to B (see figure 6.8).



Istruzioni

In questa pagina sono presenti ***7 registrazioni di lingue a te sconosciute****. Per prima cosa ascolta i campioni audio A e B cliccando sull'icona relativa, in seguito ascolta le 7 registrazioni. Devi valutare quanto ognuno dei 7 campioni assomigli ad A o a B posizionando lo slider più a destra o a sinistra. Quindi, più un campione ti sembra simile ad A, più devi posizionare lo slider verso A; viceversa se ti sembra simile a B, posizionalo vicino a B (puoi anche lasciarlo a metà se ti sembra che non assomigli più a uno che all'altro). NB: per favore, insistiamo perché tu faccia attenzione a posizionare lo slider nella DISTANZA da A e B che corrisponde alle tue impressioni.*

Figure 6.8. The interface of the final part of the test. Participants could listened to A, B and the 7 samples by clicking on the corresponding icons. Sliders could be dragged left or right to reflect each sample’s resemblance to A and B.

They had to place the slider at the distance from A and B which corresponded to their impression: for instance, if they found that sample 1 was very similar to A, they had to drag the slider next to A; if they found that it was slightly more similar to B than to A, they had to drag the slider a bit more than half-way towards B, and so on; if they found that it was neither similar to A nor to B, they could leave it in the initial position half-way between the two. So, languages were rated on a continuum, the task did not prompt for a clear-cut bi-polarisation. This also allowed participants to create an order among the seven unknown languages as they were let free to adapt their judgments after one or more ratings. In other words, they could rate the first language as 80% closer to A, then listen to the second language and rate it as 85% closer to A, then modify the first at 70% closer to A because they felt that there still was a remarkable difference between the two. Even though the test was not conceived to keep track of how many times participants changed their mind, I noticed that the majority of listeners did modify their first ratings (at least once) after listening to the following ones.

This procedure was repeated twice: the first time with 7 supposedly unknown languages (in order of appearance: Amharic, Czech, Finnish, Standard Belgian Dutch, Icelandic, Indonesian and Turkish[115]), the second time with 7 regional varieties of English (in order of appearance: RP English, Tyneside English, New Zealand English, GA English, Australian English, Liverpool English, Southern Michigan English[116]). Like before, data samples were drawn from the illustrations of the IPA (apart from Icelandic, see chapter 3 for more details). In both tasks, the A and B stimuli remained unchanged and participants were free to listen to them as many times as they wished; likewise, they could listen to the 7 samples as many times as they wished and in the order they preferred.

The instructions for task 1 can be seen in figure 6.8[117], while the instructions for task 2 read as follows:

> *In questa pagina sono presenti 7 registrazioni di varietà regionali di inglese (cioè di inglese parlato con accenti diversi). Il tuo compito è lo stesso di prima; se vuoi puoi riascoltare A e B una o più volte, poi ascolta i sette campioni audio e dai una valutazione di quanto ognuno di essi assomiglia ad A e a B posizionando lo slider.*[118]

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[115] All samples were taken from the corpus (Czech, Finnish, Icelandic and Turkish) or from the Illustrations of the IPA (Amharic from Hayward & Hayward, 1999, Standard Belgian from Verhoeven, 2005, and Indonesian from Soderberg & Olson, 2008). It was chosen to refer to Standard Belgian Durch as *Flemish* for practical reasons despite the ambiguity of this term (the label *Standard Belgian Dutch* is too long to fit in the charts).

[116] They were all taken from the Illustrations of the IPA (see respectively Roach, 2004, Watt & Allen, 2003, Bauer et al., 2007, Ladefoged, 1999, Cox & Palethorpe, 2007, Watson, 2007, Hillenbrand, 2003).

[117] English translation of task 1: *In this page there are 7 recordings of languages which you don't know. First listen to the A and B audio samples by clicking on the corresponding icons, then listen to the 7 recordings. You have to evaluate how much each of the samples resembles A or B by dragging the slider to the left or to the right. So, if a sample sounds more like A, you have to drag the slider to the left; conversely, if it sounds more like B, drag it towards B (you can also leave it half-way if you think it does not sound more like one or the other). NB: we really ask you to pay attention to place the slider at the exact distance from A and B that corresponds to your impressions.*

[118] English translation of task 2: *In this page there are 7 recordings of regional varieties of English (that is to say different accents of English). Your task is the same as before; you can listen to A*

6.4.2 The Results

The answers given by participants to each of the 14 samples are shown in box-plots (showing the median and the quartiles) above and scatter-plots (showing the dispersion and the mean) below. Samples pertaining to task 1 are shown on the left, while those pertaining to task 2 are shown on the right.

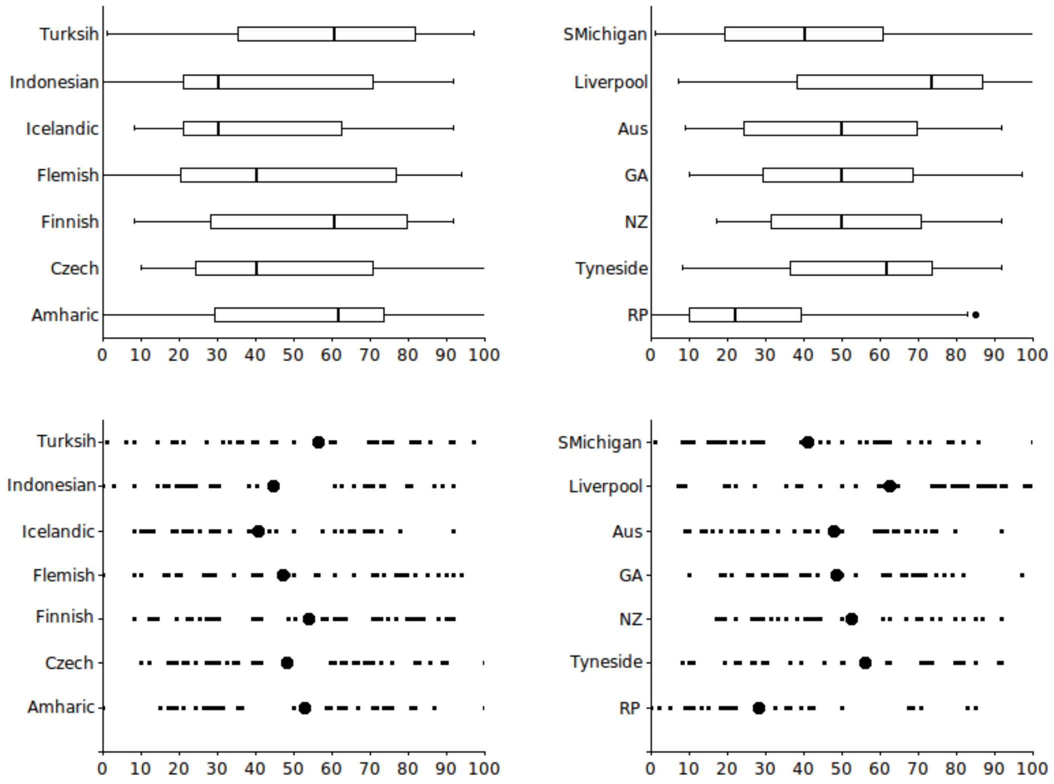

Figure 6.9. Results of the final part of the test, asking for a scalar categorisation of 7 samples of unknown languages (on the left) and 7 regional varieties of English (on the right). Data is presented on box-plots above and on scatter-plots below. 0 corresponds to A (synthesised RP English sample) and 100 corresponds to B (synthesised French sample).

Again, it seems that no decisive conclusions can be drawn on the basis of these results. The variability of the answers is impressing and mostly covers all available space, often without even a tendency to aggregate in a more dense area. Results of task 1 (unknown languages) show that mean values obtained for all samples do not depart from the middle, but median values indicate that there might be some differences: Indonesian, Turkish (and to a lesser extent Flemish and Czech) have been more frequently associated to A (RP English), while Turkish, Finnish and Amharic have been slightly more frequently associated to B (French).

Results for the second part (regional varieties of English) also show very comparable mean and median values, apart from Liverpool English (which seems to have been perceived slightly more similar to B than the other samples) and RP English which has been perceived as more similar to A. This is utterly unsurprising

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and B as many times as you need, then listen to the seven audio samples and give an evaluation of how much each of them resembles A or B by dragging the slider.

as A is precisely a synthesis of that sample of RP English: in other words, participants merely agreed on the fact that the RP English sample sounds like itself![119] This indirectly provides a confirmation (1) of the validity of the synthesis method adopted and (2) of the fact that in general participants were still concentrating on the test even in its final part and did not simply take wild choices.

6.5 Conclusion

The results of the test do not provide evidence that naive participants can discriminate between rhythm classes using prosodic cues, neither in terms of a discrete nor of a scalar characterisation. I shall simply mention that in language recognition tasks, participants classified Japanese, German and French (each traditionally representing a different rhythm class) in the same group (in particular as “English, German or similar”): this certainly does not correlate with the values of the metrics for these languages. In tasks asking for a scalar characterisation of data, answers exhibit a very high variability and mostly do not reveal relevant differences among the ratings of different languages. For these reasons, a detailed statistical analysis has not even been attempted: results are unclear and do not provide any relevant finding whose validity needs to be tested.

It seems to me that the failure of the test in confirming expectations might depend on one or more of the following three factors: 1) the participants 2) the design of the test 3) the fact that the rhythm class hypothesis might not be reflected by naive listeners’ perception. I shall comment on each of the three possibilities.

6.5.1 Participants

First of all, I have to make clear that the results were obtained on samples of mostly Italian native speakers, while most perceptive tests on rhythm categorisation have been conducted on English, French or Germans speakers. Results reported in the literature for perceptive ratings across native speakers of different languages are controversial: Miller (1984) reported differences between native speakers of English and French, while Arvaniti & Ross (2010) did not observe any significant difference. Still, it might be that Italian listeners get different rhythm impressions from listeners of other mother tongues.

However, it cannot be claimed that they did the test without concentrating or by mostly taking wild choices for at least two reasons: a) the results of the preliminary phase were overall good and b) in the final task, participants in general managed to categorise the RP English stimulus as A[120]. For the same reason, one cannot say that, given the length of the test, participants got tired after a while and performed badly.

Still, since the preliminary task provided a coarse evaluation of what was defined as the “prosodic sensitivity” of participants, it might be interesting to check if the results improve by considering exclusively those participants who performed well in the stress-related task: appendix 5 contains the results of those participants who scored a correlation higher than or equal to the median.

Observing these data, it can be noticed that the results of the preliminary task improve severely, concentrating on effectively stressed syllables or, to a lesser

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[119] Or, rather, like its synthesis.

[120] As said above, A was precisely a re-synthesis of that sample.

extent, on phonologically stressable/accentable syllables. This is not surprising at all, since the correlation was calculated precisely on these values.

Instead, results of the language identification test do not differ from overall results: emblematically, German and Japanese are still classified together (although French is in this case controversially classified into two different groups by roughly the same amount of participants). Remarkably, *f0cost* normalisation still caused a high degree of indecision, particularly in its first occurrence. Again, this suggests that they were using *fo* as an important cue for language recognition. Results of the sliders also present approximately the same scenario, with slightly more definite placements of Turkish towards 100 (which represents the B stimulus, *i.e.* French) and of RP English towards 0 (which represents the A stimulus, *i.e.* RP English). The only remarkable difference is that Southern Michigan English also leans towards A.

In short, it cannot be said that results improve much by considering only those participants who performed well in the stress-related task. Some distinctions are in effect more clear, but the overall scenario is comparable.

6.5.2 The design of the test

It is of course possible that the failure of the results to provide evidence for a perceptive distinction of the rhythm classes is due to the design of the test. It is in fact bizarre that other perceptive tests based on delexicalised speech (Ramus & Mehler, 1999, just to mention one) found different results. But these studies differ from the present one as for the format of the test (AAX or ABX) and for the fact that they usually concentrate on a limited set of oppositions (e.g. Ramus *et al.*, 1999, merely focus on the discrimination of English vs. Japanese), while this test probably introduced too many languages and too many variables (the 5 different types of normalisation). This is certainly one of the most probable causes of failure.

Moreover, it has to be remarked that I preserved the original pitch contour of synthesised stimuli, while traditional tests normally favour a *flat SASASA* re-synthesis. The choice of leaving the original pitch has also been made by Arvaniti & Ross (2010), who low-pass filtered the audios samples; even in that case, results did not confirm a classification of languages according to the traditional rhythm classes. This might imply that f_0 hinders more than helps participants in categorisation tasks: such a possibility is certainly weird and unexpected. At any rate, I believe that this aspect needs further clarification[121].

6.5.3 Perception of the rhythm class

Of course, another viable reason why the test did not work as expected concerns the possibility that the rhythm classes are simply not reflected by naive listeners' perception. This is what has been suggested by Arvaniti & Ross (2010) on the basis of their results. However, some tendencies in the classification of languages did emerge in this test, even though they did not reflect the expected rhythm groupings (just like in the study by Arvaniti & Ross). This means that listeners do provide some kind of categorisation when listening to delexicalised stimuli preserving prosodic information. I believe that these aspects need to be studied in further detail in the future.

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[121] I am currently pondering the possibility of administering the same test with flat syntheses to other participants in order to check for differences in the results.

6.5.4 Summary

In summary, it can be said that the results of this test are inconclusive. The perceptive categorisations (if any) do not reflect the scenario depicted by the metrics, but this could have various reasons, including a faulty design of the test. Further clarification is needed as for the role of f_o in rhythm discrimination tasks and on the influence of task format on the results.

7.

Final discussion

7. Final discussion

Drawing conclusions is, generally speaking, a hard task, and this is all the more true in this case for at least three reasons. Firstly, each chapter of the thesis focuses on a different aspect of rhythm typology and is self-contained, which obviously complicates things. Secondly, rhythm metrics are no longer a young approach (it has been more than a decade since Ramus *et al.*, 1999), so that it is difficult to be "original", and yet they are not old enough for researchers to take their validity for granted. Moreover, some problems persist (cp. Arvaniti, 2009, Barry, 2010, and Bertinetto & Bertini, 2010) and a categorisation of languages based purely on the results obtained with the metrics is possible but hazardous. Thirdly, as has been explained in the text, not all results obtained in the experiments can be considered to be "conclusive". So, this section is conceived as a final discussion that re-proposes and analyses some methodological points, the main findings of the experiments presented (be they conclusive or not) and future perspectives.

7.1 Methodological issues

This thesis has given a contribution to the understanding of rhythm metrics and to the evaluation of their stability/variability. A number of methodological issues have been raised.

The study of the metrics in terms of inter-subject comparison has shown a certain degree of variability, which is increased if more factors come in play (namely with the CCI, which requires phonological choices to be made). Therefore, results may change considerably across different studies in function of segmentation choices. This has at least two relevant implications. The first is that researchers should always specify their phonological criteria and segmentation procedures along with their results. The second is that cross-study comparisons should be considered carefully: charts built with data coming from different studies (cf. O'Rourke, 2008) should absolutely be avoided, except perhaps for specific purposes.

Speaking of segmentation criteria, an important issue concerns the adoption of a phonological vs. phonetic orientation. Results have proven to vary considerably between the two approaches. Namely, the Japanese sample has been labelled twice by both PM and AR because of the ambiguity caused by the interpretation of devoiced [i] (phonogically a vowel, phonetically a consonant): results have shown impressive differences, bringing to a recategorisation of the language due to the effects on consonantal delta and rPVI. These differences seem to be neutralised by the CCI, possibly in virtue of the division of intervals into the number of segments that compose them. In effect, labelling a devoiced [i] as a consonant results in a very long consonantal interval made up of (a) the preceding consonantal interval, (b) the devoiced vowel and (c) the following consonantal interval. Considering that consonantal intervals in Japanese tend to be extremely simple in other contexts, it is not a surprise that consonantal variability should result in high values for such a segmentation. Conversely, dividing the intervals by the number of segments that compose them results in similar values for consonantal and vocalic CCI because the segments are not compressed around devoiced vowels more than in other contexts. Actually, the fact that they are not compressed contributes to lengthen the already complex consonantal interval that would result from the labelling as the devoiced vowel as a consonantal segment.

The final answer to the question of whether it is advisable to adopt a phonological or a phonetic orientation remains open as both approaches present advantages and disadvantages. Much of it also depends on the eternal conflicts between phoneticians and phonologists, each claiming that their approach is more objective. In principle, both approaches are objective: a phonetic segmentation is supposed to be closer to the acoustic data (and should presumably better reflect perceptive impressions[122]), while a phonological segmentation should be objective in that it relies on external judgements *a priori* (e.g. on- and off-glides are consonantal segments, devoiced vowels are vocalic segments, syllabic consonants are vocalic segments and so forth). However, a phonetic labelling often risks being fairly subjective as the difference between, say, syllabic consonants and sequences of *shwa* plus a consonant is judged on impressionistic (and therefore subjective) grounds. In contrast, a phonological segmentation changes according to the phonological theories adopted and risks not reflecting the reality of acoustic data. Moreover, the distinction between the two approaches is not always simple and clear-cut, and most authors seem to adopt a mix of them. For instance, in this thesis syllabic consonants were considered as vowels (a choice that was grounded on a phonological evaluation), while on- and off-glides are considered as consonantal. Perhaps, this choice creates an overall balance between these two ambiguous categories of segments (both phonetically consonantal and phonologically vocalic) and between the two approaches.

Another methodological question concerns the inclusion vs. exclusion of specific controversial segments and of specific parts of the sentence. Some authors, in fact, decided to omit the final parts of sentences, usually from the last stress to the end (e.g. Bertini & Bertinetto, 2009), while others omitted on- and off-glides (e.g. White & Mattys, 2007)[123] to avoid classification problems. I of course understand the reasons that brought these authors to such choices, but it seems to me that the decision of excluding some controversial segments from the total computation is at least partly arbitrary. The omission of the final parts of the sentences can be perhaps justified as an attempt to cope with the disruptions of spontaneous speech (controlled speech is not fashionable in the linguistic milieu as of now and is therefore frequently frowned upon) and of capturing the rhythmic features that, perhaps, emerge in spite of the frequent hesitations, lengthenings, rephrasings and other possible eurhythmic features. Personally, I have tested the possibility of omitting the final parts of utterances (excluding everything that came after the final stress) on samples of read speech, but this has not brought to relevant differences (the results have been presented in Mairano & Romano, unpublished). For this reason, I have chosen to consider all segments of the utterance[124].

Correlatore has proved to be a usable framework for the study of speech rhythm with the metrics. Nearly all the results and the charts presented in this thesis have been obtained with this tool. The inclusion of so many samples (61 coming from the corpus + 6 Piedmontese speakers + 10 samples of L1/L2 by one speaker) would not have been possible without it.

A delicate point concerns normalisation. Bertinetto & Bertini (2008 and following) are right in claiming that important information may be lost by normalising. Still, without normalisation, a categorisation of languages is only

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[122] However, in the practise, this does not seem to be true, as shown by the Japanese sample, for which a phonological segmentation has better reflected perceptive impressions.

[123] Furthermore, one may wonder what conventions are adopted by the many author who do not state their segmentation criteria.

[124] I have only exluded utterances made up of one only segment, such as, typically, [e:::], [o:::] or [ø:::].

possible by using carefully controlled samples, all presenting the same speech rate. But this, in turn, raises many issues, not least the point of how speech rate should be measured[125]... So, perhaps, the decision of normalising or not is best taken by each author on the basis of his/her data and in view of his/her purpose. If the aim is to study rhythm in relation to (or as a function of) speech rate, normalisation clearly misses the point. Instead, if the aim is to provide a categorisation (or a comparison) of a set of languages, then normalisation is perhaps a good idea, unless the data are perfectly comparable and controlled in respect to speech rate.

The final methodological issue concerns the type of synthesis that was used for perceptive tests. Most experiments in this domain carried out by Ramus, Mehler and colleagues (as well as White *et al.*, 2007, and Dellwo, 2008) make use of the so-called *flat SASASA* synthesis, which levels pitch and intensity thus preserving exclusively the alternation between consonantal intervals (re-synthesised as [s]) and vocalic intervals (resynthesised as [a]). This choice depends on preliminary experiments by Ramus & Mehler (1999) showing that listeners were able to discriminate between languages of different classes purely on the basis of this synthesis. However, on the grounds that f_o plays a role in the perception of prominence and thus of rhythm (as proven by Allen, 1975, Lehiste, 1977, and Cumming, 2008, among others), I decided to leave the original pitch contour in the syntheses, as it has been done by Arvaniti (2009)[126]. However, the main problem of such an approach is that there is no way of distinguishing between the “prominence aspect” of f_o and its “intonational aspect”. In short, when analysing the results, it is impossible to tell whether listeners categorised a language on the basis of pitch contour or of prominence and it is difficult to establish which auditive cue has been used. This has also had a number of other implications that have been dealt with in detail in chapter 6. At the light of these observations and as an indication for the future, it is probably advisable to avoid mixing the various aspects of prominence (pitch, intensity and duration) in the same test.

7.2 Main findings

Results of rhythm metrics applied to a corpus of 61 speakers of 21 languages have provided an acceptable categorisation: stress-timed/compensating languages mostly present high delta, varco and PVI values and fall below the bisecting line of the CCI chart, whereas syllable-timed/controlling languages tend to show the opposite trend. In particular, English and German are confirmed to occupy the supposedly stress-timed/compensating area of the charts, while Greek, Spanish, French and Italian are confirmed to show up in the supposedly syllable-timed area. Some other languages, instead, show up slightly further away from their expected position. It is the case of the two samples of Russian (which unexpected show a limited vocalic variability), as well as of Estonian and Turkish, which are classified in intermediate positions tending towards stress-timing in most charts (apart from the CCI).

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[125] A discussion of this issue is well beyond the scope of the present thesis.

[126] Although she used a completely different solution. She did not actually re-synthesise audio samples, rather she filtered them.

However, there are several caveats: first of all, different metrics bring to potentially different results: this is the case of Icelandic[127], which is classified as stress-timed by the deltas and PVIs but as controlling by the CCI (it falls not far from the bisecting line). Similar considerations have been noticed for Danish and Swedish samples, as well.

Secondly, inter-speaker variability is often so relevant that it can bring to a remarkable degree of overlapping between languages and between rhythm classes. This of course complicates the interpretation of data and demands that conclusive caterisations be drawn exclusively on a conspicuous number of speakers per language (which is not always the case for my corpus).

Thirdly, some samples cluster in areas of the chart that are not classified, that is to say that they are not associated with either stress-timing or syllable-timing. It is mainly the case of Polish, which exhibits high consonantal and low vocalic variability.

Finally, and most importantly, there is no solid framework to test the results: expectations are only based on impressions by authors or by previous researchers. In other words, the metrics are not "predictive" (see below).

Moreover, it seems that, even though they were originally conceived to be applied to consonantal and vocalic durations, rhythm metrics seem to yield comparable results when applied to other domains: voiced and unvoiced intervals (see Galves *et al.*, 2002, and Dellwo *et al.*, 2007), inter-onset and inter-stress durations (see Wagner & Dellwo, 2004, and Asu & Nolan, 2006, partially confirmed by my experiment in chapter 2) as well as segmental durations (see the CCI, Bertinetto & Bertini, 2008). Lee & Todd (2004) reported that they obtained a classification of languages by applying the rhythm metrics to pitch and intensity (but this was not confirmed by my experiment presented in chapter 3). These observations seem to give credit to the already reported claim by Bertinetto that "the ultimate difference between iso-accentual and iso-syllabic languages might lie in the *different degrees of flexibility they exhibit at all relevant levels of structure*" (1989:123). In other words, syllable-timed languages can be considered to have a temporal structure that tends to be more fixed than stress-timed languages, which in contrast exhibit more durational variability at all levels.

Speaking of variability, the study presented in chapter 5 has attempted to provide a paradigm for the study of such aspects. For the moment, it is still in an embryonic phase but it has provided promising results. Different types of variability have been analysed, namely inter-subject (given by different segmentators), intra-speaker, inter-speaker and inter-dialect. It seems that all metrics reflect a growing variability following the scale below:

intra-speaker < inter-speaker < inter-dialect

Instead, samples labelled by different phoneticians seem to yield a lower degree of (inter-subject) variability for the "older metrics" than for the CCI. This was expected and very probably depends on the higher number of phonological choices demanded by this index: the need of dividing interval durations by the number of segments implies in fact an interpretation on phonological grounds, and therefore introduces a

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[127] I shall repeat that, on the basis of its phonological properties, this language could be considered as a mixed-type, as it allows fot a fairly complex syllable structure without presenting macroscopic phenomena of vocalic reduction.

further factor of possible “disagreement” between segmentators. This explains why inter-subject variability seems to be even higher than inter-speaker variability for the CCI, despite being lower than intra-speaker variability for the oher metrics.

Returning to the variability scale, it is interesting to note that inter-regional variation is not distinguished from inter-speaker variability by the older metrics, while it is not distinguished from inter-dialect variation by the CCI. A rational explanation for these results is that the traditional measures reflect the phonotactics, which is essentially the same across samples of the same language: so, it is understandable that samples of different speakers of regional varieties are classified with these metrics by the same standards as samples of different speakers *tout court*. Instead, the CCI measures compensation phenomena, which, apparently, seem to be fairly variable across regional varieties[128].

This finding is of interest and might have relevant implications, provided that the same results are replicated with more data, which will make statistical analysis possible. In fact, if it is confirmed, studies concentrating on the categorisation of regional varieties of a language (such as the one presented by Giordano & D’Anna, 2010) should accordingly favour the use of the CCI, while studies concerned with the categorisation of related dialectal varieties (such as Romano *et al.*, 2010) should perhaps opt for traditional metrics in order to obtain a clearer discrimination of data.

As for the need of integrating other parameters of prominence into a typological study of rhythm, the approach of calculating rhythm metrics on values of pitch and intensity has not confirmed expectations (which were based on the observation that stresses seem to be more prominent in stress-timed than in syllable-timed languages, see the end of chapter 3 for details). Unfortunately, the only viable data of which I disposed for such an experiment was constituted by 10 samples of 5 languages by an only speaker (Italian + 4 L2s). Although these very samples yielded good results with the metrics, the Δpitch and Δintensity chart seemed to categorise the two samples of Italian on one side and all L2 samples (English, German, Icelandic and French) on the other side. This poses severe interpretation problems: on the one hand, it could simply be that French has been miscategorised for some reasons; on the other hand, the fact that the categorisation separates L1 from all L2 is certainly suspicious. Methodological caveats (namely, the need for perfectly comparable data, also in terms of how the recordings are made) imply that no solution to this dilemma is available with my present corpus.

Undoubtedly, perceptive tests constitute the most controversial issue of this thesis. Initially, they had been conceived to provide a term of comparison to the results of the metrics in order to determine the validity of the latter (which have been defined as “acoustic correlates of the perception of rhythm” by Ramus, 1999). For this reason, they had been built mostly with syntheses of data from the corpus. However, the results have not provided evidence of a rhythmic categorisation of languages on the part of naive listeners, a conclusion that is at odds with studies by other authors (mainly F. Ramus, J. Mehler and colleagues). In a detailed discussion (see chapter 6) it has been suggested that such results may have at least three possible causes. Firstly, they might be attributed to listeners (after all, the test was administered only to 43 participants), but this is not likely because they provided

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[128] I have no scientific proof that compensation phenomena are indeed more relevant within regional varieties. It is just an inference based on the CCI results and needs to be verified.

sensible answers in a preliminary and related task[129] and because in the last task they proved that they had not lost their concentration (see chapter 6 for more details). Secondly, results might depend on the design and the format of the test: in particular, it was perhaps too ambitious in that it tested the categorisation of too many languages and three different types of syntheses. Finally, it may depend on the fact that (like suggested by Arvaniti, 2010), the distinction between rhythm classes by naive listeners is not so salient as it is thought to be. An interesting observation concerns the fact that, curiously, results of perceptive tests in which the original pitch contour is preserved seem to yield worse results (in terms of categorisation) than to *flat SASASA* tests (see the discussion on the methodology above). On these grounds, I have put forward the hypothesis that f_o might then be a factor of disturbance in the rhythmic categorisation of languages (probably because listeners rely on the pitch contour and use it as a cue for language recognition). However, this suggestion has to be verified on experimental data; for this reason I am planning to reproduce the same test but with levelled f_o. Results should tell if listeners are really able to provide a better categorisation.

7.3 Future perspectives

After having analysed the past and present developments of research in rhythm typology, and at the light of all that has been said in the text, I shall briefly pass on to discuss future perspectives in this field. For this purpose, I shall mainly base myself on the proposition by Bertinetto & Bertini (2010).

The two authors claim that a natural language rhythm model should have 3 requirements: (a) expliciteness, (b) predictivity and (c) unification. They proceed in analysing the various models proposed along the years for the study of rhythm and conclude that none of them possessed all three characteristics; I shall only deal with rhythm metrics, which are the main topic of this thesis. Rhythm metrics only provide an account of the first level of speech rhythm, *i.e.* the syllabic or segmental one; they provide no representation of the second level (within the stress or accentual domain)[130]. Furthermore, expectations are constructed on the basis of (1) the presence/absence of some phonological properties present in a language, whose individual contribution to the final value of the metrics is difficult to quantify; (2) on auditory impressions (whether by the author or traditionally accepted, but only rarely verified through perceptive tests). The results are analysed and interpreted mostly in relation to their correspondence to those auditory impressions and only in terms of relative positioning between points or regions of the charts. For these reasons, the two authors consider rhythm metrics not to fulfil criteria (c) and, at least partly, (b). They refer, in particular, to the fact that there is no way of predicting the values of the metrics on the basis of the phonological properties that they possess. Therefore, the exact position occupied by samples on the chart can only be commented on *a posteriori* and only in relative terms. In contrast, the expectation for the CCI is explicited in absolute terms: controlling languages should fall along

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[129] Moreover, it has been shown that the results do not improve in a relevant way by only considering best performers.

[130] At least, this is valid for their customary use. However, a few authors have applied the metrics or other similar measures to higher levels (e.g. Asu & Nolan, 2006).

the bisector, compensating languages should fall below[131]. So, the authors affirm the need for a *unified predictive model*, which could account for both levels of the rhythmic structure. Multi-layer models have already been proposed (see, for instance, O'Dell and Nieminen, 1999, – reported above), but, interestingly, Bertinetto & Bertini (2010) suggest that the two levels be relevant and independent, so that a language can either control or compensate at each level. This brings then to the scheme resumed in table 7.1 (adapted from Bertinetto & Bertini, 2010).

TYPE	*LEVEL-I*	*LEVEL-II*	*EXAMPLE*
1	*CTRL*	*CTRL*	*Italian*: relatively simple phonotactics, fairly rigid word stress pattern
2	*CMPS*	*CMPS*	*English*: fairly complex phonotactics, fairly mobile word stress pattern, density of secondary stresses yielding further prominence sites
3	*CMPS*	*CTRL*	*Polish*: complex phonotactics, fairly rigid word stress pattern
4	*CTRL*	*CMPS*	*Chinese*: simple phonotactics, uncertain word stress pattern

Table 7.1. The quadripartition of languages according to level I and II (adapted from Bertinetto & Bertini, 2010).

I believe that this view (shared by works that adopted very different approaches, such as Asu & Nolan, 2006) exemplifies a new conception, in which the two levels are no longer seen in contraposition, but as two independent (though most probably interacting) continua. This means that rhythm typology has passed from a dichotomic conception, through a bi-polar scalar categorisation along a continuum, to a bidimensional scalar characterisation at the segmental and accentual levels[132]. Future perspectives, of course, include the possibility of merging the two levels into a unique multi-layer model.

7.4 Conclusion

Finally, for those who really cannot make without clear conclusions, the list below offers a concise reading:

- Rhythm metrics work on controlled samples. This does not mean that they have to be trusted blindly: although they provide a working classification of languages, they are far from exhausiting the description of all aspects of speech rhythm. Furthermore, one can be sceptical about their use on data

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[131] However, it could be said that, even for the CCI, predictions are not really formulated in absolute terms. This applies above all to the prediction for compensating languages, because there seems to be no pratical way to establish how far from the bisector a certain sample should be in order to be classified as compensating.

[132] Mario Squartini (personal communication) sketched a stimulating comparison between the evolution of rhythm typology and other domains of linguistic typology, in particular morphological typology. Languages were at first considered on a continuum going from *isolating* through *agglutinating* to *inflectional*, until Comrie (1989) introduced two independent indeces, the index of synthesis and the index of analysis (see also Payne, 1997) so that languages came to be classified on two independent continua. This does indeed look similar to recent developments in rhythm typology, which seems to move from a monodimensional to a bidimensional classification.

coming from spontaneous speech (which has not been treated in the thesis) or critical about their theoretical formulation.

- Results suggest that there is no such thing as “the best metric” for the categorisation of languages (at least, this applies if “best” means “more consistent with the traditional categories of rhythm typology”). Moreover, the CCI is grounded on different rationales and measures different phenomena, which makes comparison difficult. Different metrics provide partially different results and the choice of using one or the other might depend on data and on the aim of the study.
- Similarly, the choice of whether to apply a normalisation to avoid the effects of speech rate depends on the data and on the aim of the study. As a general rule, perfectly comparable and controlled data do not need normalisation, which might only cause loss of information. Conversely, researchers using spontaneous speech and great amounts and different types of data might prefer to normalise, above all if the aim of the study includes a categorisation of languages.
- The high variability of the rhythm metrics is certainly a drawback that worries researchers. Yet, when studied methodically, it has been shown to follow regular patterns. Intra-speaker variability is overall more limited than inter-speaker variability, which in turn is more limited than inter-dialectal variability. Other types of variability seem to depend on the metrics used. These results, however, still have to be validated on more data and on statistical analyses.
- The application of rhythm metrics to pitch and intensity values of selected samples has yielded unclear results. These two parameters are certainly linked to prominence, and therefore they should be included in an ambitious rhythm model. However, there is still indecision as to determining at which level(s) they interact.
- Perceptive tests administered to 43 participants in Italy have failed to provide evidence of naive listeners’ ability to categorise languages in rhythm classes. This result seems to be at odds with many other studies on this subject. Yet, a number of methodological issues have been raised, mainly concerning the choice of including vs. excluding the original pitch contours in the syntheses. On the basis of the observation of data and at the light of similar results obtained by Arvaniti (2010), I have put foward the hypothesis (yet to be verified) that f_o hinders more than helps a rhythmic categorisation of languages.
- The original bi-polar dichotomy has first evolved into a mono-dimensional scalar characterisation and is now shifting towards a bi-dimensional scalar representation. The two levels (the segmental or syllabic one, and the accentual one) are no longer seen in opposition and are both conceived as continua. I agree with other authors that perspectives in this field include a merging of the two levels into multi-layer models

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The homepage of *LFSAG* (Laborotorio di Fonetica Sperimentale “Arturo Genre”, Università degli Studi di Torino).

http://www.lfsag.unito.it/correlatore/index_en.html
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9.

Appendices

Appendix 1: inter-onset values

Inter-onset values for ech sample analysed in the experiment presented in chapter 2 are reported in the table below (ordered by increasing values of the metrics).

delta		**varco**		**rPVI**		**nPVI**	
94,87	Eng_GA	47,11	Eng_GA	83,31	Italian11	43,42	Italian12
109,88	Greek	62,11	Polish	86,86	Italian1	43,65	Italian1
111,23	Italian11	63,91	Port_Lisbon	90,21	Greek	45,39	Finnish1
113,74	Italian1	64,16	Spanish_Lima	92,88	Italia15	45,74	Eng_GA
115,43	Spanish_Lima	66,11	Italian1	94,27	Italian6	46,15	Russian_ss
117,87	Italian6	68,01	Greek	96,34	Eng_GA	46,70	Greek
125,96	Italia15	68,14	Italian11	96,75	Italian9	47,04	Polish
141,41	Italian13	72,30	Italian6	100,59	Italian12	47,54	Spanish_Lima
145,86	Italian3	73,57	Italian2	100,64	Spanish_Lima	47,93	Spanish_Caracas
147,40	Eng_NZE	73,60	Eng_Aus	103,51	Italian7	48,11	Italian10
148,20	Port_Lisbon	73,88	French_IPA	106,83	Italian8	48,65	Italian11
148,32	Italian9	74,09	Port_SaoPaulo	108,92	Italian13	48,70	Japanese
148,73	Dutch	74,32	Italian10	114,31	Italian3	48,85	Port_SaoPaulo
149,31	Italian12	74,52	Eng_NZE	114,82	Italian10	48,87	French_IPA
149,92	Italian2	74,89	Dutch	114,95	Italian2	48,93	Italian7
151,11	Polish	75,75	Finnish2	125,31	Spanish_Bogota	48,94	Italian2
152,60	French_IPA	76,15	Italian3	125,66	Spanish_Caracas	49,19	Finnish2
153,23	Italian7	76,27	Italia15	126,10	Italian14	49,28	Port_Lisbon
153,74	Italian8	77,25	Italian13	127,03	Eng_NZE	49,67	Estonian
153,95	Italian10	77,72	Italian14	127,07	French_IPA	49,97	Italian9
160,63	Spanish_Bogota	79,14	Arabic Lebanese	128,34	Finnish2	50,25	Spanish_Bogota
164,20	Finnish2	79,28	Italian12	132,61	Port_Lisbon	50,28	Italian8
165,21	Italian14	80,40	Spanish_Bogota	133,31	Polish	51,14	Italia15
170,31	Port_SaoPaulo	80,42	Italian5	138,51	Port_SaoPaulo	52,59	Arabic IPA
170,47	Spanish_Caracas	81,89	Arabic IPA	143,88	Dutch	52,73	Italian3
176,04	Arabic IPA	82,16	Italian8	145,94	Arabic IPA	52,96	Port_Manaus
183,57	Eng_Aus	84,05	Italian7	149,39	Finnish1	53,14	Italian14
195,90	Italian5	84,43	German1	155,82	Russian_ss	53,38	Eng_NZE
203,70	German1	85,45	Italian9	163,22	Eng_Aus	53,64	Italian13
214,37	Russian_ss	85,84	Russian_ss	165,07	Spanish_IPA	53,69	Czech
217,61	Arabic Lebanese	87,91	Estonian	165,34	Italian5	54,06	Italian6
222,97	Estonian	88,35	Eng_Ind	171,72	German1	54,25	Eng_Aus
231,93	Spanish_IPA	89,95	Spanish_Caracas	174,23	Japanese	54,42	German1
234,94	Finnish1	90,62	Port_Manaus	175,95	Estonian	56,01	Eng_Ind
240,37	German2	96,54	Finnish1	185,99	German2	56,96	Spanish_IPA
258,68	Japanese	101,46	German2	188,68	Italian4	57,19	Arabic Lebanese
258,80	Eng_Ind	101,66	Czech	194,58	Arabic Lebanese	57,42	Italian5
273,58	Port_Manaus	106,34	Spanish_IPA	212,07	Port_Manaus	57,56	German2
296,82	Czech	113,57	Eng_RP	214,13	Eng_Ind	59,52	Italian4
297,27	Eng_RP	114,32	Japanese	217,86	Eng_RP	59,80	French_Can
300,06	Italian4	128,15	Italian4	224,02	Czech	59,86	Eng_RP
383,12	French_Can	135,56	French_Can	235,83	French_Can	60,46	Dutch

Appendix 2: *Correlatore*'s report

Correlatore's full report for the corpus presented in chapter 3 is reported below. It contains the values of rhythm metrics for each sample labeled by AR and PM. The first column contains the values of rhythm metrics calculated globally (A method), while the second column reports the values of rhythm metrics computed locally for each inter-pausal unit and then averaged (B method). The ten Icelandic samples have not been computed with *Correlatore*, but their values have been inserted manually in the report.

```
FILE   Arabic_IPA_ar
intV   206
intC   209
pause  16
Vmean  84.01895439337352
Cmean  100.2541003720087
Vperc  45.236400944564934
Vdev   46.71707063503773   35.73132296395354
Cdev   55.40657308332242   55.59657154745808
varcoV 55.60301359656322   44.207387923952204
varcoC 55.26614161189175   55.91733924570244
Vrpvi  46.09585714955108   38.08533786310822
Crpvi  64.82354449341445   60.78499671768318
Vnpvi  47.31087095530114   42.78219155621204
Cnpvi  61.64081506823253   57.656263002652175
Vcci   21.28052447660613   19.419772375991656
Ccci   39.14170804786835   38.00093998486181
colour #008000
border black
symbol tu
--
FILE   Arabic_IPA_pm
intV   207
intC   210
pause  16
Vmean  84.24361088114736
Cmean  99.25159468684845
Vperc  45.55342846076603
Vdev   47.008911891448605  36.51766941811486
Cdev   55.2330284747335    55.02223227192148
varcoV 55.801159755331184  44.695681050374134
varcoC 55.649512382144394  55.969818030033075
Vrpvi  45.88766679883041   39.02778019732789
Crpvi  64.8159222185428    59.72953733720691
Vnpvi  46.75848661979226   43.6197141677819
Cnpvi  62.245184196385395  57.68081305739059
Vcci   21.487352730804155  19.630610431746984
Ccci   37.18817878728444   34.81970458061868
colour #008000
border black
symbol td
--
FILE   Arabic_lebanese_ar
intV   223
intC   227
pause  28
Vmean  104.28250304774217
Cmean  116.45768251859973
Vperc  46.79931712138865
Vdev   54.68757368801902   54.80776956610877
Cdev   72.91773970669507   69.07138545671611
varcoV 52.44175397571939   51.491448390192915
varcoC 62.613078098174604  58.10220272846018
Vrpvi  60.75242641785179   58.92784353631968
Crpvi  75.74140015595356   76.50999231648342
Vnpvi  51.32609994659975   49.90429791540606
Cnpvi  60.263201375804464  61.85688193888051
```

```
Vcci   26.829196094845344  24.2799792568974
Ccci   40.97730045108358   40.93342959849843
colour #008000
border black
symbol td
--
FILE   Arabic_lebanese_pm
intV   224
intC   227
pause  27
Vmean  104.84867944427823
Cmean  115.85342903018443
Vperc  47.17521979258392
Vdev   56.01127218814023   55.70841011005504
Cdev   72.88098719818728   68.80078986700109
varcoV 53.42105640720768   51.96613922075548
varcoC 62.90792409709245   57.70509182739357
Vrpvi  61.97981278237141   58.23123953232434
Crpvi  76.39723221417727   76.17901053843345
Vnpvi  51.743103696607406  49.3484951695647
Cnpvi  60.98061629176426   61.38622691575918
Vcci   27.548826394044156  25.375526987950884
Ccci   39.71993937056671   39.01866803566758
colour #008000
border black
symbol tu
--
FILE   Chinese_chaoyang_ar
intV   157
intC   160
pause  24
Vmean  99.6410318748115
Cmean  93.09827551730169
Vperc  51.224514483116145
Vdev   43.67157367945309   45.19556280209212
Cdev   43.88340808279095   40.52624269342963
varcoV 43.82890547974437   43.48308527106939
varcoC 47.1366497810537    43.029092683826164
Vrpvi  47.79772912278843   54.56480906124127
Crpvi  53.57113258163216   52.08603645203338
Vnpvi  48.02163185689612   52.7120718950414
Cnpvi  57.495229826972604  54.716408132501925
Vcci   36.81707541816237   41.55197613527768
Ccci   35.92672775155663   32.83765247664609
colour #ffffff
border #0000ff
symbol tu
--
FILE   Chinese_hongkong_ar
intV   155
intC   157
pause  23
Vmean  113.7931182472869
Cmean  126.88903276557778
Vperc  46.95996469824065
Vdev   51.7619240486475    52.40148938669644
Cdev   57.33051847817638   60.39348212573153
varcoV 45.487745520921806  43.98005333890944
varcoC 45.181618323225884  48.60068438010151
Vrpvi  57.480006841660064  62.65242200139288
Crpvi  68.59282654091858   72.16597017281977
Vnpvi  47.54732172039167   51.521726489372355
Cnpvi  52.18424500343679   56.91603038149025
Vcci   45.16241171348535   42.31740506318667
Ccci   41.15042764906163   38.74984387130136
colour #ffffff
border #0000ff
symbol tu
--
FILE   Czech_ar
intV   160
intC   163
pause  20
Vmean  99.68085028113907
Cmean  120.05380372381158
```

```
Vperc  44.90418390660829
Vdev   50.81459681351107  52.52518920165548
Cdev   58.20620491238413  54.18528409329724
varcoV 50.977290693442114 50.44080281312639
varcoC 48.483432516881976 44.6295157852612
Vrpvi  50.181031236629686 47.7532730780236
Crpvi  60.67462285416889  60.061560249476194
Vnpvi  45.004005741586184 42.56027108068343
Cnpvi  51.17788975047674  51.70709350995023
Vcci   50.47804349229278  48.2577834306896
Ccci   30.76189731888801  31.798924544656554
colour #c0c0c0
border black
symbol tu
--
FILE   Czech_pm
intV   161
intC   163
pause  20
Vmean  100.7799222444013
Cmean  118.80357417846112
Vperc  45.58953836995485
Vdev   52.83298011136585  54.3594934390792
Cdev   56.84448225726739  53.586365894928065
varcoV 52.42411279423324  51.78934683693253
varcoC 47.84745126596805  44.6707058899146
Vrpvi  50.841575068677656 47.67325490487647
Crpvi  58.890953773309214 58.80551013027518
Vnpvi  44.602858743274524 41.87303007490353
Cnpvi  50.3774696314637   51.374096928239574
Vcci   51.89949012546818  48.67346402664185
Ccci   29.72846319696486  31.26370573280917
colour #c0c0c0
border black
symbol td
--
FILE   Danish_ar
intV   132
intC   137
pause  15
Vmean  85.62370435919341
Cmean  116.2652208743929
Vperc  41.505887912940565
Vdev   39.543668954945446 39.75863272997858
Cdev   60.93772856691652  53.4965871349447
varcoV 46.18308592333128  45.029555906049566
varcoC 52.412688943971105 46.531302972727026
Vrpvi  45.733215740546186 50.50099513591465
Crpvi  66.4244529618174   63.27979366943169
Vnpvi  50.26934187215413  53.73250797303985
Cnpvi  56.669289835901516 55.854490702638074
Vcci   30.33431357544646  32.92892102602869
Ccci   31.731082518969824 29.935961313210232
colour #ffffff
border #00ffff
symbol tu
--
FILE   Dutch_IPA_ar
intV   153
intC   166
pause  19
Vmean  72.99201693926372
Cmean  90.53834732797992
Vperc  42.629755693676955
Vdev   44.91639880805826  46.29096619270412
Cdev   45.62519560319611  46.826108302504856
varcoV 61.53604283250998  60.20860772278783
varcoC 50.39322778658245  50.3267642202385
Vrpvi  53.09554022934119  54.14990768437703
Crpvi  52.912625637773246 55.33936776963548
Vnpvi  67.70567543346453  67.1859367842029
Cnpvi  56.29283681876029  57.22776033339801
Vcci   30.02421250978579  30.470906711540767
Ccci   33.3113356475126   30.864600321552146
colour #ff80ff
```

```
border #0000ff
symbol tu
--
FILE   Dutch_IPA_pm
intV   154
intC   167
pause  19
Vmean  73.48957492348602
Cmean  89.26986365783462
Vperc  43.154224081431394
Vdev   44.66148192020934   45.9975388934719
Cdev   45.11258022892706   46.37283313214383
varcoV 60.772540821890495  59.998601354622224
varcoC 50.53506119583708   50.38582516948217
Vrpvi  53.70198211724736   53.83988654868297
Crpvi  53.04568295210597   55.59510949413121
Vnpvi  68.97340509180847   67.75122457529089
Cnpvi  57.25721425108317   58.24559397956963
Vcci   30.187622519722073  29.21422511505927
Ccci   34.84203823426425   30.585973660499935
colour #ff80ff
border #0000ff
symbol td
--
FILE   Greek_IPA_ar
intV   209
intC   210
pause  12
Vmean  68.48033404706383
Cmean  77.34402567921636
Vperc  46.841959389088025
Vdev   34.41343520498375   35.056633514434424
Cdev   37.16384802973469   37.942009576296456
varcoV 50.25301889055148   49.201129923762096
varcoC 48.0500564890059    48.194621991079025
Vrpvi  37.640381325275705  36.54130975926907
Crpvi  41.9846498908428    44.29192646496179
Vnpvi  52.04625684903008   49.267688177236636
Cnpvi  55.57459177815651   57.19125060599685
Vcci   31.901514090379393  30.077474394027366
Ccci   26.556892139571833  26.862674567919456
colour #ff80ff
border black
symbol tu
--
FILE   Greek_IPA_pm
intV   210
intC   210
pause  11
Vmean  70.53291908512459
Cmean  75.94329405314637
Vperc  48.153155774543926
Vdev   38.329340231828624  39.51773946177551
Cdev   33.7268982056113    33.60630136490787
varcoV 54.342483947913465  53.65944563802201
varcoC 44.4106337842136    44.211211556162986
Vrpvi  41.21752415122962   40.735729891128685
Crpvi  40.40949696457153   41.73174218909708
Vnpvi  54.45881058463915   53.588523463849604
Cnpvi  54.86955488383259   56.26775354727039
Vcci   33.690160838708444  32.7451077298245
Ccci   24.4944265981411    24.589916474695038
colour #ff80ff
border black
symbol td
--
FILE   English_Aus_ar
intV   137
intC   140
pause  12
Vmean  83.80479505054576
Cmean  119.90412279703294
Vperc  40.615976716934966
Vdev   42.710337594061116  44.062518481950846
Cdev   59.65970334701785   61.14378917864621
```

```
varcoV 50.96407379589788   51.51917621395998
varcoC 49.756173478710565  51.565259679950685
Vrpvi  52.082286612367405  56.394382817477556
Crpvi  73.92047757978882   73.13261362745594
Vnpvi  58.315846696934855  60.728587211042466
Cnpvi  62.35933604127948   60.67346987084118
Vcci   45.59105216891864   51.20646690013319
Ccci   39.13216262735044   37.985382562614774
colour #00ff00
border black
symbol tu
--
FILE   English_Aus_pm
intV   137
intC   140
pause  12
Vmean  83.79391867079235
Cmean  120.13507161440377
Vperc  40.566443812868265
Vdev   43.03807899886169   44.626826356873956
Cdev   59.825412423813     61.47361767962581
varcoV 51.36181680194326   52.12259340356624
varcoC 49.79845736957978   51.68268838359979
Vrpvi  52.17650168004063   56.38195945362863
Crpvi  74.55872963687655   74.00436202461346
Vnpvi  58.030891010758026  60.254493653857644
Cnpvi  62.6895885485767    61.13204845209477
Vcci   45.37524236135104   51.175530843902585
Ccci   39.737464348042714  37.83623339550683
colour #00ff00
border black
symbol td
--
FILE   English_GA_ar
intV   134
intC   139
pause  12
Vmean  79.88553133215609
Cmean  108.64824152229959
Vperc  41.480055575609356
Vdev   43.19826721380696   45.026016903547635
Cdev   53.58996638706408   54.687663483742426
varcoV 54.07520798001939   54.223360037969705
varcoC 49.324283243061025  50.07546707278272
Vrpvi  49.105021132373274  48.53478481771054
Crpvi  60.9866647925715    58.81617171210124
Vnpvi  57.775468560496044  55.365228857861716
Cnpvi  57.66127377086846   54.89217888958182
Vcci   33.44364211638657   30.180262258151377
Ccci   33.10176799523614   30.719127065086624
colour #00ff00
border black
symbol tu
--
FILE   English_GA_pm
intV   131
intC   138
pause  12
Vmean  81.51533692809659
Cmean  110.07933941371095
Vperc  41.2784417331425
Vdev   39.61240024928714   40.09864785401721
Cdev   57.48919029834338   59.675174875310915
varcoV 48.595027318881876  49.01731504201415
varcoC 52.225231914121395  52.89694050947226
Vrpvi  46.13111949474402   43.99707852886896
Crpvi  61.549653742901995  60.17285769424527
Vnpvi  54.45019490187495   51.89292813075908
Cnpvi  55.68377093303886   52.2587992039837
Vcci   36.733721854560216  34.79305979355213
Ccci   32.531487965437115  30.78854207091298
colour #00ff00
border black
symbol td
--
```

```
FILE   English_IndE_ar
intV   152
intC   159
pause  17
Vmean  95.63966858024061
Cmean  134.32545616669253
Vperc  40.49934218245582
Vdev   43.505990926712286  41.58265670321217
Cdev   64.89506880474643   62.48319278667646
varcoV 45.48948315333323   42.73843412554874
varcoC 48.311817176495744  46.70784503037955
Vrpvi  47.99229139392463   46.102996949560534
Crpvi  75.77979562825449   76.41977918867188
Vnpvi  49.45396780137248   47.89763729216935
Cnpvi  56.35531299446036   56.76167686340616
Vcci   45.700284355315986  44.889135914087895
Ccci   42.60007991092764   41.41272997977142
colour #00ff00
border black
symbol tu
--
FILE   English_IndE_pm
intV   143
intC   148
pause  15
Vmean  93.99299878500592
Cmean  133.03771959961352
Vperc  40.56976451331555
Vdev   42.09868348912123   43.1139675424377
Cdev   64.69271958171544   62.79505168227585
varcoV 44.78916944166798   43.94569787537353
varcoC 48.62735153339427   46.30642205126359
Vrpvi  48.48090054732116   52.264334327380325
Crpvi  76.15582400886845   76.96727302697255
Vnpvi  51.25977913069677   52.83601742439964
Cnpvi  55.56869719611721   55.47896889050464
Vcci   43.26505613218828   49.24297408258909
Ccci   38.22965406404403   37.71708162350531
colour #00ff00
border black
symbol td
--
FILE   English_NZE_IPA_ar
intV   140
intC   143
pause  12
Vmean  66.76473252049985
Cmean  100.942759044426
Vperc  39.30330021911729
Vdev   36.802343958123714  37.22515222324342
Cdev   45.93932769744719   46.27597451201386
varcoV 55.12243151251104   53.967780180801014
varcoC 45.510275459410416  47.07035398854339
Vrpvi  44.37599404995127   44.70661395684902
Crpvi  53.13476691209686   52.891646248306735
Vnpvi  63.050835594218235  61.76231068947579
Cnpvi  53.34736672151319   53.12346377567981
Vcci   41.960143116019466  41.51079124949668
Ccci   29.934104100201086  28.754122261249275
colour #00ff00
border black
symbol tu
--
FILE   English_NZE_IPA_pm
intV   141
intC   143
pause  12
Vmean  70.80055794328926
Cmean  96.96567489250879
Vperc  41.85874104756668
Vdev   34.960212360043705  35.320764697500366
Cdev   47.48873204077539   47.59814363936908
varcoV 49.37844188748708   48.357879792872495
varcoC 48.97478627712227   50.217821573937734
Vrpvi  43.722875853120705  42.86419148699167
```

```
Crpvi  52.33734706807895  49.779444272448174
Vnpvi  59.1257585908029   56.734587435495925
Cnpvi  54.56708333794259  52.019210300714114
Vcci   36.842205966129235 36.810904756966025
Ccci   26.69825551405195  24.344433910022914
colour #00ff00
border black
symbol td
--
FILE   English_RP_IPA_ar
intV   136
intC   139
pause  12
Vmean  77.58686967435825
Cmean  116.22363461487903
Vperc  39.509694042835285
Vdev   48.35227389121337  46.18819732701881
Cdev   59.37175172603828  62.69657469279962
varcoV 62.32017620269239  58.25867881026447
varcoC 51.08406041746475  52.54095608431665
Vrpvi  53.00917005501202  50.410127772135496
Crpvi  69.95275466182463  71.3404580294643
Vnpvi  61.41921308565858  57.348009859210066
Cnpvi  60.374612735767165 61.390108627795264
Vcci   48.4441378778063 2 44.005188420631214
Ccci   43.87063042957515  42.245767025715956
colour #00ff00
border black
symbol tu
--
FILE   English_RP_IPA_pm
intV   136
intC   140
pause  12
Vmean  78.55811631310077
Cmean  114.02745789554696
Vperc  40.093083472078675
Vdev   49.47276651560638  48.30248451885775
Cdev   55.12006417998716  58.2618025260405
varcoV 62.97600914770921  60.12196704974147
varcoC 48.33929055094697  50.36570332513023
Vrpvi  54.93035346379965  53.076860498002084
Crpvi  65.43317052947869  68.43093558190672
Vnpvi  63.31209439018285  61.11796979679134
Cnpvi  57.47575492866749  59.153041300737215
Vcci   44.10846035350281  43.86760981745578
Ccci   36.09242977507904  33.64705532678557
colour #00ff00
border black
symbol td
--
FILE   Estonian_IPA_ar
intV   168
intC   169
pause  19
Vmean  89.60175268267783
Cmean  105.27175258799382
Vperc  45.83206975958909
Vdev   38.80326788189504  40.374727953723415
Cdev   53.560472860183005 51.36346020513333
varcoV 43.30637149399941  40.12209580749224
varcoC 50.87829502545163  47.93916404663122
Vrpvi  42.29866528847245  49.85721597227556
Crpvi  53.32393527473117  48.80925829476
Vnpvi  43.21902962512173  45.497449306637186
Cnpvi  48.81060870123911  45.73579224309237
Vcci   36.71072527610094  37.642377081777525
Ccci   29.435893960703275 28.08565027584204
colour #ffffff
border #00e800
symbol tu
--
FILE   Estonian_IPA_pm
intV   166
intC   170
```

```
pause  16
Vmean  90.0124868685276
Cmean  106.71700409730536
Vperc  45.16409532559567
Vdev   37.880239096819714 41.11441674733809
Cdev   54.80769261020361  53.02329715010627
varcoV 42.08331578722812  40.66863927803253
varcoC 51.35797530469423  49.86845768879365
Vrpvi  41.58921049845218  51.274250209710885
Crpvi  53.65933078744253  50.24524471181216
Vnpvi  42.52187472655331  47.11015472702944
Cnpvi  48.643281736851606 47.487568531996885
Vcci   28.331558755664908 31.596918914964064
Ccci   22.903590251275585 21.29666925483564
colour #ffffff
border #00e800
symbol td
--
FILE   Finnish1_ar
intV   169
intC   173
pause  12
Vmean  96.26535023489875
Cmean  102.59426095292828
Vperc  47.82471320461888
Vdev   44.798042682402986 45.16753823502922
Cdev   46.825102289898155 45.40860698533706
varcoV 46.53599926982087  46.61045748891109
varcoC 45.64105424121354  44.84965641546565
Vrpvi  45.67982697774799  46.135897708074225
Crpvi  55.14527003315632  51.863104001039325
Vnpvi  44.94785502166563  45.18227958663481
Cnpvi  57.31247564519871  54.901420637940106
Vcci   30.415273200354058 31.92899040863049
Ccci   42.12344861143338  40.470769368680294
colour #c17928
border #000000
symbol tu
--
FILE   Finnish1_pm
intV   169
intC   173
pause  12
Vmean  98.18752072498147
Cmean  101.14035278595803
Vperc  48.67473707036773
Vdev   44.418094904822745 44.927706609560296
Cdev   45.80133150323341  44.28846549641572
varcoV 45.23802472743527  45.32951465628833
varcoC 45.28492361516887  44.27742354840763
Vrpvi  45.410384339754856 45.819627321435036
Crpvi  54.3678546011611   51.14475244606835
Vnpvi  44.110143393826576 44.58670123004953
Cnpvi  56.92086408115866  54.29141044607149
Vcci   26.200838728814674 26.73659992791156
Ccci   29.60352681196938  27.819676268521377
colour #c17928
border #000000
symbol td
--
FILE   Finnish2_ar
intV   166
intC   171
pause  18
Vmean  87.15832010738792
Cmean  96.722612807936
Vperc  46.66006222498692
Vdev   48.99043231326925  44.483509026451976
Cdev   43.10358790046906  42.19862876486127
varcoV 56.20855502137725  48.77306331339941
varcoC 44.56412688732955  43.40311893449882
Vrpvi  48.94438739480219  50.71501689896006
Crpvi  48.79850362327251  47.8756682510939
Vnpvi  50.88739213553605  51.12003568294451
Cnpvi  52.524914941780466 51.253048624332195
```

```
Vcci   40.762251811742445  43.10371732706063
Ccci   35.41442084906453   37.25259305850965
colour #c17928
border #000000
symbol tu
--
FILE   Finnish2_pm
intV   166
intC   171
pause  18
Vmean  89.16233224281811
Cmean  95.00511115949402
Vperc  47.67298743969282
Vdev   48.606720541868796  44.803251383742605
Cdev   42.212589863626775  42.35657315516974
varcoV 54.51485994051484   48.269924739087514
varcoC 44.431914608005165  44.44047831937604
Vrpvi  49.35824947497896   50.83662889542953
Crpvi  47.90695170068412   47.778036580410735
Vnpvi  50.78659466710902   50.469474957917484
Cnpvi  52.05840026844856   51.69808719617203
Vcci   25.653975259077693  25.38645287205219
Ccci   28.651061066581892  28.52022202872506
colour #c17928
border #000000
symbol td
--
FILE   French_canadian1_ar
intV   165
intC   164
pause  23
Vmean  103.12557714372231
Cmean  99.05379300494747
Vperc  51.15887794218404
Vdev   46.510997991732495  45.57556067630205
Cdev   47.57208574045189   40.43421291391521
varcoV 45.10132139858168   41.24371742850928
varcoC 48.026515994269694  39.74680969629114
Vrpvi  51.781395836704135  52.1864327504423
Crpvi  50.81570360381441   47.32889887450178
Vnpvi  46.69912924690057   45.59229521234551
Cnpvi  50.38172447425786   47.973399793839256
Vcci   43.48524541300082   42.85780977215406
Ccci   41.80864070569796   41.455528284091415
colour #ff8000
border black
symbol tu
--
FILE   French_canadian1_pm
intV   159
intC   159
pause  22
Vmean  107.88632818337884
Cmean  95.18813153835197
Vperc  53.12648785633285
Vdev   48.53201306625618   51.09636189687059
Cdev   39.57283048321416   37.16362239083149
varcoV 44.98439596884261   43.328719428312425
varcoC 41.573282134727044  37.92533644341819
Vrpvi  53.250679106075985  59.791438281775136
Crpvi  46.607047332645486  45.664661245600506
Vnpvi  44.62175744146854   47.95705882639621
Cnpvi  48.866968831959596  47.944602326287246
Vcci   43.292606434001264  46.06339027756656
Ccci   38.16566928931578   37.42069643628213
colour #ff8000
border black
symbol td
--
FILE   French_IPA_ar
intV   152
intC   147
pause  15
Vmean  89.65155913638597
Cmean  98.24325716612074
```

```
Vperc  48.54870543659568
Vdev   40.15810446948856   42.35230534425519
Cdev   40.187816715151094  36.84490284525493
varcoV 44.79353717473721   44.95228185344565
varcoC 40.90643762675439   37.10154188104412
Vrpvi  43.99462917070564   42.53157858148581
Crpvi  44.23382405522516   44.71636944041687
Vnpvi  44.89003060957618   44.07698058468937
Cnpvi  47.02202956167576   48.661978334652716
Vcci   36.57106454801881   35.396705552324
Ccci   38.22235543769925   37.54101908572155
colour #ff8000
border black
symbol tu
--
FILE   French_IPA_pm
intV   151
intC   147
pause  14
Vmean  91.82262485445592
Cmean  96.56640871997465
Vperc  49.411902884016015
Vdev   42.35492201418722   45.54377115530659
Cdev   42.56527442722518   41.417277189408644
varcoV 46.126890928376504  48.19177991734656
varcoC 44.07875884735123   41.28275878428803
Vrpvi  47.33654270674053   45.95735728609675
Crpvi  46.15989938113067   50.31664442901221
Vnpvi  47.06038023895268   47.20469715336518
Cnpvi  48.7971172776731    53.067805538390644
Vcci   38.57216830577835   38.049584436887336
Ccci   37.122776404040685  37.04217597581681
colour #ff8000
border black
symbol td
--
FILE   German1_ar
intV   167
intC   168
pause  16
Vmean  95.07465465294844
Cmean  110.3327525972704
Vperc  46.13749666542734
Vdev   53.662424717705576  52.32075007600697
Cdev   65.92949978334192   61.11198032026265
varcoV 56.442408246014494  53.20318803453013
varcoC 59.755148159852034  54.358153486818395
Vrpvi  59.43004984398619   54.92810049072377
Crpvi  64.69806779631102   60.18061669342096
Vnpvi  57.885910092034564  54.04230869751597
Cnpvi  56.99006724383795   52.230685992486855
Vcci   51.25056678567742   45.534126935977795
Ccci   31.340503836889038  30.215434216085455
colour #00ffff
border black
symbol tu
--
FILE   German1_pm
intV   174
intC   177
pause  19
Vmean  88.11729813419076
Cmean  109.1178262686063 8
Vperc  44.25414924257801
Vdev   42.67220523494236   44.16578776059714
Cdev   59.72588319224266   58.52745575908424
varcoV 48.42659289207704   49.73881669834122
varcoC 54.73522084761876   53.77571523390565
Vrpvi  51.27990855039527   47.88425006569925
Crpvi  67.51348782869741   66.28705895270005
Vnpvi  57.26047711013468   55.08892275046879
Cnpvi  62.95708704005821   62.80441158535594
Vcci   40.07187136162802   35.25617243674631
Ccci   30.501029333827173  28.702901533007118
colour #00ffff
```

```
border black
symbol td
--
FILE   German2_ar
intV   154
intC   157
pause  15
Vmean  89.20258575127878
Cmean  117.14715709283101
Vperc  42.755981009457436
Vdev   47.30402500437111   46.88185312827805
Cdev   69.8519860887582    65.4665835679601
varcoV 53.02988092325898   51.86521764722612
varcoC 59.62755547998944   55.51904824426928
Vrpvi  53.07029742653888   49.51370287746123
Crpvi  71.57245128043388   68.70043101106573
Vnpvi  56.635004787922405  55.289232551001874
Cnpvi  59.624031830602405  57.221077387380866
Vcci   51.32216709253293   48.48372902036306
Ccci   28.433719272456546  28.12592249228691
colour #00ffff
border black
symbol tu
--
FILE   German2_pm
intV   165
intC   169
pause  16
Vmean  91.58712263156215
Cmean  101.32597216764307
Vperc  46.87892996001777
Vdev   50.730098265511764  48.95834673606745
Cdev   54.00663348872089   51.637189410866306
varcoV 55.38999021684462   52.14773419218138
varcoC 53.29989175861773   49.794475654823714
Vrpvi  53.02100726411072   47.65437630122638
Crpvi  58.00380971601656   55.057335837621814
Vnpvi  53.14160008733706   49.417743091359135
Cnpvi  56.82636083627906   53.421712690611976
Vcci   46.05135137263825   41.60439200910549
Ccci   26.151441770561934  23.290263182084043
colour #00ffff
border black
symbol td
--
FILE   Icelandic01
intV   0
intC   0
pause  0
Vmean  0
Cmean  0
Vperc  40.23
Vdev   33.24  33.24
Cdev   59.66  59.66
varcoV 45.34  45.34
varcoC 56.35  56.35
Vrpvi  0      0
Crpvi  63.15  63.15
Vnpvi  44.58  58
Cnpvi  0      0
Vcci   31.47  31.47
Ccci   43.35  43.35
colour #ffffff
border #c0c0c0
symbol td
--
FILE   Icelandic02
intV   0
intC   0
pause  0
Vmean  0
Cmean  0
Vperc  41.88
Vdev   36.80  36.80
Cdev   62.01  62.01
```

```
varcoV 44.97  44.97
varcoC 52.63  52.63
Vrpvi  0      0
Crpvi  64.29  64.29
Vnpvi  52.60  52.60
Cnpvi  0      0
Vcci   44.67  44.67
Ccci   44.24  44.24
colour #ffffff
border #c0c0c0
symbol td
--
FILE   Icelandic03
intV   0
intC   0
pause  0
Vmean  0
Cmean  0
Vperc  41.18
Vdev   39.67  39.67
Cdev   60.85  60.85
varcoV 53.10  53.10
varcoC 58.85  58.85
Vrpvi  0      0
Crpvi  65.11  65.11
Vnpvi  53.60  53.60
Cnpvi  0      0
Vcci   37.99  37.99
Ccci   42.94  42.94
colour #ffffff
border #c0c0c0
symbol td
--
FILE   Icelandic04
intV   0
intC   0
pause  0
Vmean  0
Cmean  0
Vperc  46.53
Vdev   38.27  38.27
Cdev   46.40  46.40
varcoV 48.59  48.59
varcoC 50.89  50.89
Vrpvi  0      0
Crpvi  47.21  47.21
Vnpvi  54.01  54.01
Cnpvi  0      0
Vcci   36.32  36.32
Ccci   36.47  36.47
colour #ffffff
border #c0c0c0
symbol td
--
FILE   Icelandic05
intV   0
intC   0
pause  0
Vmean  0
Cmean  0
Vperc  44.94
Vdev   49.22  49.22
Cdev   63.86  63.86
varcoV 49.58  49.58
varcoC 54.02  54.02
Vrpvi  0      0
Crpvi  66.11  66.11
Vnpvi  46.64  46.64
Cnpvi  0      0
Vcci   44.21  44.21
Ccci   45.24  45.24
colour #ffffff
border #c0c0c0
symbol td
--
```

```
FILE   Icelandic06
intV   0
intC   0
pause  0
Vmean  0
Cmean  0
Vperc  44.14
Vdev   35.78  35.78
Cdev   57.75  57.75
varcoV 44.99  44.99
varcoC 55.52  55.52
Vrpvi  0      0
Crpvi  54.38  54.38
Vnpvi  48.20  48.20
Cnpvi  0      0
Vcci   35.19  35.19
Ccci   38.47  38.47
colour #ffffff
border #c0c0c0
symbol td
--
FILE   Icelandic07
intV   0
intC   0
pause  0
Vmean  0
Cmean  0
Vperc  46.18
Vdev   44.38  44.38
Cdev   56.93  56.93
varcoV 48.93  48.93
varcoC 54.58  54.58
Vrpvi  0      0
Crpvi  64.31  64.31
Vnpvi  50.24  50.24
Cnpvi  0      0
Vcci   43.23  43.23
Ccci   39.86  39.86
colour #ffffff
border #c0c0c0
symbol td
--
FILE   Icelandic08
intV   0
intC   0
pause  0
Vmean  0
Cmean  0
Vperc  44.08
Vdev   52.18  52.18
Cdev   73.93  73.93
varcoV 49.19  49.19
varcoC 55.36  55.36
Vrpvi  0      0
Crpvi  77.65  77.65
Vnpvi  48.80  48.80
Cnpvi  0      0
Vcci   50.43  50.43
Ccci   49.96  49.96
colour #ffffff
border #c0c0c0
symbol td
--
FILE   Icelandic09
intV   0
intC   0
pause  0
Vmean  0
Cmean  0
Vperc  43.32
Vdev   39.47  39.47
Cdev   65.05  65.05
varcoV 49.04  49.04
varcoC 44.61  44.61
Vrpvi  0      0
```

```
Crpvi  51.18  51.18
Vnpvi  49.81  49.81
Cnpvi  0      0
Vcci   50.43  50.43
Ccci   49.96  49.96
colour #ffffff
border #c0c0c0
symbol td
--
FILE   Icelandic10
intV   0
intC   0
pause  0
Vmean  0
Cmean  0
Vperc  45.38
Vdev   37.87  37.87
Cdev   46.40  46.40
varcoV 47.52  47.52
varcoC 51.02  51.02
Vrpvi  0      0
Crpvi  60.86  60.86
Vnpvi  49.65  49.65
Cnpvi  0      0
Vcci   38.48  38.48
Ccci   41.40  41.40
colour #ffffff
border #c0c0c0
symbol td
--
FILE   Italian01_Antonio_ar
intV   219
intC   213
pause  14
Vmean  69.3424557522141
Cmean  85.5167660707745
Vperc  45.4656041624003З
Vdev   28.957929516804423  30.51696484364637
Cdev   41.7076139142253l   41.28635260731086
varcoV 41.760749893660645  41.67459266261421
varcoC 48.771271214473025  47.65182546333696
Vrpvi  29.569087200857282  33.45831138791384
Crpvi  51.642631913096594  51.401158623574005
Vnpvi  39.38241223782578   42.57875244469126
Cnpvi  62.835878904734855  60.77849933344085
Vcci   28.815479866866877  32.31156844985383
Ccci   30.289583300971962  31.18780703353285
colour #ffff00
border black
symbol tu
--
FILE   Italian01_Antonio_pm
intV   219
intC   212
pause  15
Vmean  73.18779861918765
Cmean  82.32710263948013
Vperc  47.87163212025704
Vdev   29.954217211499785  30.568393663843544
Cdev   37.72533602886081   36.993140447682286
varcoV 40.92788385036449   39.10379642137391
varcoC 45.82371396460337   44.96251240871027
Vrpvi  29.24219634244279   32.28799533985129
Crpvi  47.07534194742961   46.60993911121017
Vnpvi  37.25062990889835   39.32231887876096
Cnpvi  59.077494273247844  57.664507980700314
Vcci   30.02591278266812   33.021801183516835
Ccci   22.567108877532657  22.629623788522455
colour #ffff00
border black
symbol td
--
FILE   Italian02_Canepari_ar
intV   213
intC   202
```

```
pause  26
Vmean  78.66310070472018
Cmean  94.32507034046913
Vperc  46.79070920967226
Vdev   35.90788206602431   33.73411708428573
Cdev   47.04328209401284   52.02137315943209
varcoV 45.64768200634844   41.371352434601874
varcoC 49.87357223716741   52.93379841335935
Vrpvi  37.399514906000576  40.838509489590635
Crpvi  57.44710802344098   66.50934193153105
Vnpvi  43.570799462460215  44.521780335968245
Cnpvi  61.07319306827902   66.99502714165601
Vcci   39.77147912170352   45.01631347770219
Ccci   23.86239626231375   27.095992584814212
colour #ffff00
border black
symbol tu
--
FILE   Italian02_Canepari_pm
intV   212
intC   201
pause  25
Vmean  80.31001755919029
Cmean  93.83355924044967
Vperc  47.44356026793772
Vdev   37.539265185792324  35.17832918289625
Cdev   46.3221920299022 4  49.94356490499856
varcoV 46.742942321143246  42.288276800233895
varcoC 49.36633801900346   51.80037884870898
Vrpvi  39.261125705014045  42.006282093514976
Crpvi  56.76584229792415   63.89448309647452
Vnpvi  44.78416144288508   45.08164531479638
Cnpvi  60.848586159703125  66.23124292929688
Vcci   39.306756465496036  44.16824067734342
Ccci   23.091014118152074  24.749751204217745
colour #ffff00
border black
symbol td
--
FILE   Italian03_lazio_ar
intV   210
intC   205
pause  15
Vmean  77.64890272112198
Cmean  92.25495755822716
Vperc  46.300248344286985
Vdev   39.615266612910105  40.59683551451825
Cdev   48.6454581214836    51.58362007112845
varcoV 51.01845000333017   49.61614081905338
varcoC 52.729370224663306  54.278559324346396
Vrpvi  41.01212932673158   43.8231390823135
Crpvi  58.33080481526437   61.993024642402986
Vnpvi  48.69934775659977   49.179365080938354
Cnpvi  65.09603869859578   66.74468894043417
Vcci   39.03762711946384   41.3798259703237
Ccci   23.805550168270248  22.530835278472985
colour #ffff00
border black
symbol tu
--
FILE   Italian03_lazio_pm
intV   209
intC   203
pause  15
Vmean  82.94436302006689
Cmean  89.48312105248773
Vperc  48.83142071590342
Vdev   43.23340665708912   44.07775834739213
Cdev   47.33175368480325   50.10065414755631
varcoV 52.123381364240004  50.61515015099838
varcoC 52.894616468551725  55.112609979786626
Vrpvi  42.08908837692474   45.0046090915925
Crpvi  56.92892860043668   61.665891942276794
Vnpvi  46.190917551436804  46.89143576920909
Cnpvi  65.47106826098063   69.08987016666865
```

```
Vcci   41.212217790272376  43.79578747904848
Ccci   23.39697667166889   22.46999419441394
colour #ffff00
border black
symbol td
--
FILE   Italian04_00mp_ar
intV   186
intC   174
pause  23
Vmean  70.55396900968178
Cmean  103.37872992380213
Vperc  42.181430065873506
Vdev   30.61827903754623   30.913673359673428
Cdev   52.14060016819906   54.935060400041834
varcoV 43.39696188225021   41.07590488778273
varcoC 50.43648747341991   50.68704369241909
Vrpvi  28.996399001682295  32.150881393390186
Crpvi  60.513762599899565  70.26874423239423
Vnpvi  38.524576213647215  40.17287442916294
Cnpvi  62.47721080365849   66.96324505561267
Vcci   24.911857435912584  29.188083028584227
Ccci   30.922553875853772  39.5918929371897
colour #ffff00
border black
symbol tu
--
FILE   Italian04_00mp_pm
intV   186
intC   172
pause  23
Vmean  74.46013991201394
Cmean  101.40768321181696
Vperc  44.259604585884084
Vdev   30.459310928720303  30.27793805850411
Cdev   50.54457142355324   52.21867903738691
varcoV 40.90686770762537   38.329659763007605
varcoC 49.84294071483464   49.39397576902259
Vrpvi  28.00516314934199   31.372994066285173
Crpvi  57.97700735096901   66.06016950543318
Vnpvi  35.20900736192189   37.55900655405445
Cnpvi  60.94221386417622   64.56463435674948
Vcci   24.99173647566174   29.911084243815694
Ccci   25.352865179296693  26.581630391216617
colour #ffff00
border black
symbol td
--
FILE   Italian05_IPA_ar
intV   175
intC   167
pause  22
Vmean  83.64165445916619
Cmean  111.12055477269926
Vperc  44.095629838443045
Vdev   44.17778921874151   43.1753110469118
Cdev   53.913920873821056  57.76286779411136
varcoV 52.81792846446991   45.591318513638356
varcoC 48.51840506385497   50.38972028556759
Vrpvi  44.55042436262723   51.63630112638489
Crpvi  62.375920942483376  68.83224267794999
Vnpvi  47.53262584801243   49.72210225362104
Cnpvi  60.253509383096294  61.350834870348194
Vcci   39.8617728694122    39.323100696815594
Ccci   37.20966186755655   38.360017982702566
colour #ffff00
border black
symbol tu
--
FILE   Italian05_IPA_pm
intV   174
intC   168
pause  23
Vmean  89.81549527566054
Cmean  108.76828201574641
```

```
Vperc  46.098673000610745
Vdev   48.006880689026154  35.171726921312924
Cdev   51.725130883813094  54.23866252173843
varcoV 53.45055498684728   40.06393172997143
varcoC 47.55534419153999   48.980716181222384
Vrpvi  47.27804227911301   40.02539971654943
Crpvi  59.970169817407545  63.655001190697746
Vnpvi  47.64476732398259   43.3355071170108
Cnpvi  58.07505406519908   59.715605736824934
Vcci   42.57634166338038   42.31395523484219
Ccci   29.73036878120449   29.747729615360317
colour #ffff00
border black
symbol td
--
FILE   Italian06_Michela_ar
intV   216
intC   212
pause  9
Vmean  64.92074761738297
Cmean  90.2169181164771
Vperc  42.30274600035516
Vdev   28.976885891855304  27.36051675259338
Cdev   44.45823209950234   43.35808885185855
varcoV 44.63424553061762   41.84962536030757
varcoC 49.27926272332123   48.328943882952274
Vrpvi  27.221557767053223  26.365316286174654
Crpvi  52.33308420341009   51.44345874280418
Vnpvi  38.833418481201996  37.675113239501506
Cnpvi  59.203326533511635  59.59629746907733
Vcci   30.23142863902856   29.236711408781503
Ccci   28.803673267412226  28.20308632754246
colour #ffff00
border black
symbol tu
--
FILE   Italian06_Michela_pm
intV   216
intC   213
pause  10
Vmean  67.49232196313675
Cmean  87.77970001397269
Vperc  43.811145208408405
Vdev   32.73774498365838   30.601000404123567
Cdev   41.927600700251176  39.92703883581369
varcoV 48.50588041931529   45.32935490989977
varcoC 47.76457505958346   46.249137964259496
Vrpvi  31.147283604643597  31.137164285391204
Crpvi  49.832531101909     45.7580643719967
Vnpvi  42.37745502932878   42.318768446999265
Cnpvi  56.48271593166548   53.521353889302986
Vcci   30.822345800462887  29.66242387579943
Ccci   25.831353947927578  25.578859340760314
colour #ffff00
border black
symbol td
--
FILE   Italian07_Paolo_ar
intV   218
intC   213
pause  15
Vmean  73.28579263078484
Cmean  87.1893861613963
Vperc  46.2442640001025
Vdev   32.05710688477052   33.56087692358904
Cdev   39.0165375462935    39.920657373500426
varcoV 43.74259421096093   44.61117335644917
varcoC 44.74918251410782   44.40483286916571
Vrpvi  31.978055386666323  35.03522893158629
Crpvi  50.84565760962115   51.77260274434663
Vnpvi  39.195509622257745  40.69787929233571
Cnpvi  59.792851512907795  58.95949147148177
Vcci   34.916037074952456  38.86071258137095
Ccci   27.35415200559196   27.79548015844751
colour #ffff00
```

```
border black
symbol tu
--
FILE   Italian07_Paolo_pm
intV   216
intC   212
pause  15
Vmean  72.8632122417797
Cmean  90.12186668008789
Vperc  45.167957314520656
Vdev   32.19431357398436   33.02355659370654
Cdev   39.091024482613086  39.45232174829556
varcoV 44.18459272308086   44.31958743446182
varcoC 43.37573767904445   42.454883654983725
Vrpvi  31.714402521698258  33.93483802849649
Crpvi  49.60061211817501   50.41484362325735
Vnpvi  39.96905833521601   40.99721086857569
Cnpvi  54.416602741465994  53.56435860156726
Vcci   32.09290728824333   35.30086525229448
Ccci   20.9226500329548    20.667813360648832
colour #ffff00
border black
symbol td
--
FILE   Italian08_Claudia_pm
intV   216
intC   210
pause  12
Vmean  74.60380087694593
Cmean  94.59319755122537
Vperc  44.78841646424051
Vdev   34.94180771871385   36.363586510961824
Cdev   45.65233522973976   47.76641648555264
varcoV 46.83649801750459   47.87898872286276
varcoC 48.26175286549279   49.72078071985118
Vrpvi  34.909153799367175  36.388112116881764
Crpvi  52.67988294230476   55.60139394581966
Vnpvi  44.184272539127804  45.534079811773715
Cnpvi  57.14541603347369   59.93568729471983
Vcci   34.504084850660675  34.96907457044884
Ccci   26.62753348577412   26.50774690363901
colour #ffff00
border black
symbol td
--
FILE   Italian09_mazara_pm
intV   184
intC   180
pause  8
Vmean  73.03953842415355
Cmean  90.50916823024545
Vperc  45.20301642535804
Vdev   33.790719434570825  33.30451588459044
Cdev   46.20744285151275   46.07037068403383
varcoV 46.26359936496603   45.09461015050976
varcoC 51.052775928694935  50.82497677965021
Vrpvi  29.16738399551481   28.78542305212621
Crpvi  50.74931878629317   48.40776488173622
Vnpvi  36.26723113129853   35.83081517834973
Cnpvi  58.262465601699745  56.81343832281731
Vcci   28.50501410422417   28.100019408759795
Ccci   18.86718826931001   17.367122864107014
colour #ffff00
border black
symbol td
--
FILE   Italian10_bitonto_pm
intV   209
intC   189
pause  30
Vmean  84.4580298051313
Cmean  102.35611437083689
Vperc  47.71119842485954
Vdev   42.54751921855831   41.29718569909101
Cdev   49.819772271645384  52.1429661722716 2
```

```
varcoV 50.3771154936097    47.21364744616284
varcoC 48.67298116763989   50.27625551128993
Vrpvi  39.95764739862918   41.33716600862788
Crpvi  56.76929733756047   66.107031721573
Vnpvi  44.41664859701507   44.11349126002969
Cnpvi  58.38451895450727   64.69501925709586
Vcci   36.98992234519241   39.95568690120745
Ccci   27.041699911635774  29.93498902283976
colour #ffff00
border black
symbol td
--
FILE   Italian11_vazzano_pm
intV   182
intC   178
pause  11
Vmean  69.93155295966865
Cmean  86.04984598763733
Vperc  45.38351945224115
Vdev   31.422289210301994  28.695591497227554
Cdev   38.86066985057405   38.96159140844448
varcoV 44.93292066375824   40.79138025561132
varcoC 45.16065009129373   45.00785715855712
Vrpvi  30.41658043226776   29.09500447507015
Crpvi  44.95084267614729   43.178398674930044
Vnpvi  41.302403800640136  40.130097075871305
Cnpvi  54.717716334623645  52.6526727804024
Vcci   28.108639286627294  26.298998673228425
Ccci   21.129558729589363  21.64619354365528
colour #ffff00
border black
symbol td
--
FILE   Italian12_nuragus_pm
intV   184
intC   175
pause  16
Vmean  77.24565679101312
Cmean  92.86984109009082
Vperc  46.65354828895464
Vdev   33.5372400231459    34.19762051322103
Cdev   37.623869153752665  36.34806309099403
varcoV 43.41634392970515   43.283906139384136
varcoC 40.51247284600675   39.70843670302089
Vrpvi  31.744972023807687  33.05226019459462
Crpvi  42.996791431111326  43.939935711660645
Vnpvi  37.109870459303906  37.31054658539476
Cnpvi  49.61154658985211   50.462810433207345
Vcci   28.305458362906798  30.713364119521998
Ccci   25.052556289717707  22.6527363243979
colour #ffff00
border black
symbol td
--
FILE   Italian13_tramonti_pm
intV   186
intC   180
pause  13
Vmean  77.90586139234333
Cmean  95.83793592800005
Vperc  45.65182172270577
Vdev   36.77582621365092   34.17581054015073
Cdev   47.944051023101046  50.19424535178806
varcoV 47.20546767135199   43.412443511594006
varcoC 50.02617236990565   51.84626425877659
Vrpvi  33.00487102460203   31.822506357273607
Crpvi  54.044090404825184  57.41954673137221
Vnpvi  38.969202192170265  37.7825047927272
Cnpvi  59.997792219788046  64.82924364622926
Vcci   29.445361493517115  30.264401295951995
Ccci   20.76696781994052   21.68943954378339
colour #ffff00
border black
symbol td
--
```

```
FILE   Italian14_treviso_pm
intV   182
intC   178
pause  13
Vmean  97.893567674732
Cmean  104.46860070787719
Vperc  48.93059877446055
Vdev   48.46383039443288   45.566367061108934
Cdev   51.78605952346053   55.63395933380938
varcoV 49.50665456944239   44.251370008065834
varcoC 49.57093248359718   52.75506705761912
Vrpvi  44.10597326109259   42.188372296039795
Crpvi  62.01346978034345   66.36234471384887
Vnpvi  41.8132743608915    39.617507602161616
Cnpvi  62.37574583868767   66.2624221978922
Vcci   38.933995287775055  37.0352504932801
Ccci   31.919591537733105  30.9675235326447
colour #ffff00
border black
symbol td
--
FILE   Italian15_torinorfstd_pm
intV   185
intC   179
pause  12
Vmean  71.64176448400777
Cmean  86.60387022023053
Vperc  46.09058896162323
Vdev   33.94477560481491   30.570706989480687
Cdev   39.52467691777299   36.63066520160751
varcoV 47.38126684804397   42.422050516110374
varcoC 45.638464906086945  42.10802876043337
Vrpvi  27.66501522500965   26.28303917243272
Crpvi  46.36726220467247   43.905745577900966
Vnpvi  35.91112326355702   34.945518314700074
Cnpvi  56.60463398377629   53.81611731279133
Vcci   25.759290844764607  24.73028171016165
Ccci   19.46278758368615   17.51346122370952
colour #ffff00
border black
symbol td
--
FILE   Japanese_phl_pm
intV   212
intC   210
pause  18
Vmean  83.29460136594182
Cmean  79.7892238222566
Vperc  51.31154971471287
Vdev   40.731153912056044  33.94644411413219
Cdev   32.22799524001282   28.149861515721412
varcoV 48.90011266529758   39.86161633245033
varcoC 40.39141339663347   35.19489108952554
Vrpvi  38.17209276557493   33.431077552255445
Crpvi  33.40673095389991   33.52122211763805
Vnpvi  44.74085411550362   38.404661297790085
Cnpvi  41.27357678796416   42.86263472451292
Vcci   30.74519955081613   27.668223140750257
Ccci   28.438259355353733  30.206908081747724
colour #ffffff
border #ff0000
symbol td
--
FILE   Japanese_phn_ar
intV   186
intC   184
pause  18
Vmean  88.79876313510084
Cmean  97.18889148366951
Vperc  48.01422549555959
Vdev   39.37763873075961   32.16177618760312
Cdev   55.9295628786883    51.334023826965
varcoV 44.344805423527575  35.387500039442195
varcoC 57.547279349395666  53.52962511376319
Vrpvi  35.21079652234537   30.532446340534715
```

```
Crpvi  60.26276481207018   54.27513298723366
Vnpvi  36.79232489428386   31.63806915089149
Cnpvi  58.05478399614456   55.88188533785265
Vcci   23.87949835727853   22.185113263226484
Ccci   31.597089078738428  32.34770879770544
colour #ffffff
border #ff0000
symbol tu
--
FILE   Japanese_phl_ar
intV   214
intC   211
pause  19
Vmean  82.93205037862208
Cmean  78.64327041290834
Vperc  51.67980312117183
Vdev   39.30473945875299   32.915868841147045
Cdev   31.391594419032028  27.766899935469993
varcoV 47.39390775859175   39.128815743894876
varcoC 39.91644072558748   35.35378174983338
Vrpvi  36.644929949447196  31.818579495865208
Crpvi  32.347715462436575  32.65130364941389
Vnpvi  42.49186703106479   36.963781787469436
Cnpvi  40.845086110336766  42.49359305927674
Vcci   26.706762586817582  24.584429094897224
Ccci   28.7837574362905    30.353671649610558
colour #ffffff
border #ff0000
symbol tu
--
FILE   Japanese_phn_pm
intV   186
intC   184
pause  18
Vmean  89.38757370871872
Cmean  96.67447707843408
Vperc  48.31172114110805
Vdev   39.61915026611358   32.608318761575894
Cdev   54.698377698947375  50.29984480899646
varcoV 44.32288362051066   35.600724787851924
varcoC 56.579957142741414  52.56633293892352
Vrpvi  35.46550582109242   30.903119578630047
Crpvi  58.29805884648838   52.87901362979658
Vnpvi  36.70264692718096   31.739018803319208
Cnpvi  56.618150832351375  54.99387463515671
Vcci   27.01499628031619   24.873729402434293
Ccci   28.38746412188199   30.143802323580676
colour #ffffff
border #ff0000
symbol td
--
FILE   Polish_IPA_ar
intV   158
intC   164
pause  15
Vmean  77.68281441479469
Cmean  134.42481552158236
Vperc  35.76353156055076
Vdev   32.08524100299366   27.84108087085223
Cdev   65.89284742349562   61.29466310799533
varcoV 41.30288178241265   35.28535488308908
varcoC 49.01836552114614   46.444276673055256
Vrpvi  32.14555176453511   29.599613817915124
Crpvi  72.39261631221315   69.89452145744674
Vnpvi  40.658542116977884  37.638027128808574
Cnpvi  55.4456799481717    54.78119190064583
Vcci   27.012067263316577  24.862948938990048
Ccci   43.02379389705914   40.86885996979048
colour #ffffff
border black
symbol tu
--
FILE   Polish_IPA_pm
intV   160
intC   165
```

```
pause  14
Vmean  78.85833462704832
Cmean  132.3311584230415
Vperc  36.622961840282755
Vdev   32.70986387680613  29.66746015114169
Cdev   70.01215609361535  63.75961042073766
varcoV 41.479272966521265 36.55895921964797
varcoC 52.90678093348031  48.46501536863757
Vrpvi  32.38780272428115  31.291171028606307
Crpvi  77.2591656724486   74.95909059108948
Vnpvi  39.29760933386811  38.84887872481133
Cnpvi  58.466699442360614 57.22657247838658
Vcci   26.052844989550927 25.594323302452672
Ccci   36.11718944864734  35.599243420213185
colour #ffffff
border black
symbol td
--
FILE   Portuguese_manaus_ar
intV   164
intC   160
pause  21
Vmean  114.45532200721969
Cmean  120.63150036383963
Vperc  49.30346284802374
Vdev   55.34025775207122  56.96707049048419
Cdev   53.574406277237145 48.44206453707678
varcoV 48.35096942768675  47.60296880239966
varcoC 44.41162226752553  38.510674857608564
Vrpvi  66.24924456952499  70.13631165668227
Crpvi  56.43454290411068  53.15532082340069
Vnpvi  56.93580809578065  58.690101787697145
Cnpvi  46.84071128511291  43.32896219173523
Vcci   50.70472487250472  54.03687837869711
Ccci   40.81723008896643  38.19537720213249
colour #0000ff
border black
symbol tu
--
FILE   Portuguese_manaus_pm
intV   164
intC   159
pause  21
Vmean  119.56380658618578
Cmean  119.29661017709834
Vperc  50.82991093314241
Vdev   62.37432751372985  68.05136229427755
Cdev   53.98049674184157  48.63659388229077
varcoV 52.168234932172595 50.98332345996149
varcoC 45.24897787263727  39.430662048107884
Vrpvi  73.80969823017409  85.29726159428051
Crpvi  57.3268674376657   54.15664486729973
Vnpvi  59.815514295896946 63.45443261173132
Cnpvi  47.49067158093844  44.86711471642803
Vcci   54.31924387920861  57.97273308927976
Ccci   41.34488395039042  39.93412617212125
colour #0000ff
border black
symbol td
--
FILE   Romanian_brasov_ar
intV   194
intC   198
pause  22
Vmean  90.64310262618477
Cmean  102.71581227352779
Vperc  46.37026903851032
Vdev   48.479416001049366 47.54388824910096
Cdev   41.499271824855924 41.6922950156931
varcoV 53.48384443654817  49.97819654348041
varcoC 40.40202857408667  40.37049985087077
Vrpvi  51.64700603331115  53.74605667576475
Crpvi  47.6668087602596   51.60336532398311
Vnpvi  52.81858216864491  52.72510391605423
Cnpvi  45.620502226751036 47.840128484224564
```

```
Vcci   31.32182985357846  28.61235336327011
Ccci   32.34527890310645  31.047789836078717
colour #aa00aa
border black
symbol tu
--
FILE   Romanian_brasov_pm
intV   195
intC   197
pause  20
Vmean  90.71564210889268
Cmean  103.25657770935332
Vperc  46.51338526226603
Vdev   51.03178363700195  54.60816556028061
Cdev   40.83016312352775  42.26286314317476
varcoV 56.25466837984207  53.032793751628674
varcoC 39.542433062672785 39.50412105158487
Vrpvi  53.72088994291564  62.64991251086949
Crpvi  45.44926719347183  50.036560898608954
Vnpvi  54.653788562116745 55.96618451510798
Cnpvi  44.000800662226425 45.59819163143459
Vcci   31.82311691239001  27.630202940047656
Ccci   32.768589706960576 30.859336326985623
colour #aa00aa
border black
symbol td
--
FILE   Romanian_bucharest_ar
intV   201
intC   199
pause  20
Vmean  100.56499722893405
Cmean  115.06850819224195
Vperc  46.885952423699855
Vdev   48.570920066341756 51.37660225120853
Cdev   59.66372587026871  52.72997412786821
varcoV 48.29803749287747  48.11326859542434
varcoC 51.850612133243345 45.067744988741794
Vrpvi  49.25189754065848  54.129662647172324
Crpvi  62.07257642417116  59.93216745946566
Vnpvi  45.25297351704499  47.01546297771315
Cnpvi  52.91635247788881  51.665792592586335
Vcci   33.546477776316394 33.3968829564933
Ccci   41.73155874756905  43.20209813018427
colour #aa00aa
border black
symbol tu
--
FILE   Romanian_bucharest_pm
intV   199
intC   197
pause  20
Vmean  109.24902276038414
Cmean  110.38453496520106
Vperc  49.99402356861555
Vdev   61.07974217457555  64.73347795502438
Cdev   55.659272878186364 49.668506939596256
varcoV 55.90873092617198  55.62679325257056
varcoC 50.42307139830145  44.62310934359297
Vrpvi  62.76266315313038  69.95161749625241
Crpvi  60.13132058345864  58.515269187903364
Vnpvi  52.86089313246089  56.88263789696342
Cnpvi  55.559569328362336 53.66170452309007
Vcci   40.10094970195722  39.12967195125326
Ccci   43.973902448618986 44.51474822458667
colour #aa00aa
border black
symbol td
--
FILE   Romanian_bucovina_ar
intV   203
intC   201
pause  17
Vmean  81.9153609757973
Cmean  84.92768529115041
```

```
Vperc  49.34472424064453
Vdev   35.80307190048414   36.92203315373035
Cdev   36.165295256402274  33.86133981470167
varcoV 43.70739684717072   40.210707351233204
varcoC 42.583634691584784  39.77950244757489
Vrpvi  34.78632883020416   39.969320861834085
Crpvi  40.73664498314597   38.06736598574737
Vnpvi  38.955449310552545  40.04499031753832
Cnpvi  51.411327949086385  47.84491689971803
Vcci   20.37817834135273   21.169964307763593
Ccci   33.21502133589963   32.370529972831825
colour #aa00aa
border black
symbol tu
--
FILE   Romanian_bucovina_pm
intV   201
intC   200
pause  16
Vmean  84.51367806975267
Cmean  84.58420075152782
Vperc  50.10383576564487
Vdev   41.87801699362005   39.13087727540895
Cdev   36.73350583553216   34.3094435878664
varcoV 49.5517624485073    44.53490491362393
varcoC 43.42833000626143   40.288652102653224
Vrpvi  40.56598988850253   40.4092702744872
Crpvi  40.52683767480579   37.95556702679769
Vnpvi  43.9379329970122    42.74548235270227
Cnpvi  52.69688452005275   49.162748770949996
Vcci   22.30588620487533   22.391876740152284
Ccci   35.44545196294452   34.38216402611619
colour #9d16de
border black
symbol td
--
FILE   Romanian_moldavian_ar
intV   186
intC   186
pause  9
Vmean  74.74669463208134
Cmean  95.55075801261107
Vperc  43.8918453983175
Vdev   40.94272401364441   44.86326702750932
Cdev   47.73424675487276   42.123115142080394
varcoV 54.77529704179288   52.440030181526716
varcoC 49.95695245931241   44.29331123171506
Vrpvi  42.090078551941104  51.809208270922795
Crpvi  52.197224777379695  45.37463599582945
Vnpvi  51.620544778739955  55.80691620811605
Cnpvi  54.10967234329719   48.66576864839299
Vcci   23.132834820735958  23.596643803497994
Ccci   36.71250382778991   37.508291928984896
colour #aa00aa
border black
symbol tu
--
FILE   Romanian_moldavian_pm
intV   178
intC   178
pause  7
Vmean  72.2355691406971
Cmean  94.25124616494811
Vperc  43.38816200435047
Vdev   38.19503747385319   40.294440085164354
Cdev   48.88066994819687   47.443589907919794
varcoV 52.87566489503068   51.70744002428173
varcoC 51.86209406998324   49.3644767429121
Vrpvi  40.46676349756715   44.643577237301905
Crpvi  53.14270115229604   52.166240024256446
Vnpvi  53.6201239094845    54.79463351673329
Cnpvi  55.86679164978315   54.79050928961663
Vcci   39.604074273546246  42.9166651049826
Ccci   34.88312435807211   36.11178579576258
colour #aa00aa
```

```
border black
symbol td
--
FILE   Romanian_muntenian_ar
intV   189
intC   190
pause  21
Vmean  60.944402300096506
Cmean  90.21685466774922
Vperc  40.19056122957424
Vdev   30.749122781214343  31.456797845847394
Cdev   45.02851239292064   41.58223477708734
varcoV 50.454384029894165  46.682332385356105
varcoC 49.91141905661832   44.78530768800086
Vrpvi  31.867297793803374  34.09918789846107
Crpvi  49.38276953432634   49.55588620732935
Vnpvi  52.038061258429835  50.56350092452248
Cnpvi  57.08966768341851   54.558557274258135
Vcci   31.913776967653174  34.12649441309783
Ccci   34.342367321283284  33.85608246498844
colour #9d16de
border black
symbol tu
--
FILE   Romanian_muntenian_pm
intV   179
intC   180
pause  19
Vmean  60.58626123932914
Cmean  88.90745034933519
Vperc  40.3934256673906
Vdev   31.227489451595165  32.70011912717695
Cdev   45.16518633060256   41.460919521797955
varcoV 51.54219589196909   48.49603852720002
varcoC 50.80022669994414   45.2331166742617
Vrpvi  31.795234331089233  34.026515125321765
Crpvi  49.0718420197451    49.15631399883024
Vnpvi  52.33304091111064   50.93372964107818
Cnpvi  57.555234529646086  55.00565609623976
Vcci   32.50176197135167   34.556196012810375
Ccci   34.814701807781645  34.355146474021836
colour #9d16de
border black
symbol td
--
FILE   Romanian_oltenian_ar
intV   199
intC   198
pause  18
Vmean  119.25152170939269
Cmean  118.18141886137444
Vperc  50.35128903482907
Vdev   61.61569352895423   59.52150981784743
Cdev   51.36122218815213   47.80834485244338
varcoV 51.66868535154395   48.8980783446063
varcoC 43.45964254194502   40.25921591679274
Vrpvi  63.922436191480806  66.15649786777921
Crpvi  58.024653438635255  52.81617539302263
Vnpvi  47.88856224458527   48.90565612105101
Cnpvi  50.46269499591334   46.11617798484887
Vcci   58.65734091489904   60.1531092340645
Ccci   44.36503990731258   41.51597426364943
colour #9d16de
border black
symbol tu
--
FILE   Romanian_oltenian_pm
intV   186
intC   184
pause  17
Vmean  119.48943435353192
Cmean  118.39287029669973
Vperc  50.50074237215807
Vdev   63.044316298297794  59.560258825560815
Cdev   54.61709313215443   49.341892791686014
```

```
varcoV 52.76141496474855   49.94848880221439
varcoC 46.13207957141395   41.42905938475505
Vrpvi  66.805596837662     66.24449842218847
Crpvi  60.9982400467413    55.169620728500604
Vnpvi  49.92557713186258   50.57611142245323
Cnpvi  52.44352067159418   47.71111106273155
Vcci   62.727476890631756  64.48907697104451
Ccci   45.62373234778402   42.04713127863612
colour #9d16de
border black
symbol td
--
FILE   Portuguese_lisbon_ar
intV   135
intC   132
pause  14
Vmean  86.81166790906997
Cmean  113.28576394439247
Vperc  43.93748400662826
Vdev   36.60374899440246   37.63573748389804
Cdev   60.76629076911973   60.32960623280141
varcoV 42.164549853762395  42.51535700545488
varcoC 53.63982962497169   50.21240446298792
Vrpvi  44.19473254318312   45.40367867349021
Crpvi  59.97701922687909   61.92046874089088
Vnpvi  52.32485951004173   52.847524852350865
Cnpvi  54.860495414357246  54.96620331052126
Vcci   36.15150820497482   36.950420130478406
Ccci   31.382774730260813  32.852140143415916
colour #0000ff
border black
symbol tu
--
FILE   Portuguese_lisbon_pm
intV   135
intC   132
pause  14
Vmean  87.337018147916
Cmean  113.05726893954588
Vperc  44.135929904026206
Vdev   37.675199559677395  38.523278297579324
Cdev   61.07128898755888   58.54781835586839
varcoV 43.13772139079652   43.234666357053975
varcoC 54.01801189821328   48.532330825307966
Vrpvi  44.64534532740879   45.563671866211834
Crpvi  61.39598971606641   60.10239571926874
Vnpvi  52.429601656777926  52.75103766164243
Cnpvi  55.832201989096816  53.190959821477094
Vcci   36.315266387434896  38.10476467520944
Ccci   29.534607661059642  27.90800668847583
colour #0000ff
border black
symbol td
--
FILE   Portuguese_saoPaulo_ar
intV   158
intC   154
pause  11
Vmean  96.28429583312244
Cmean  102.13351155242842
Vperc  49.16674631364098
Vdev   46.95528302636106   46.54318495929374
Cdev   50.38512529722623   48.15800532507962
varcoV 48.767332844956144  46.99188671311375
varcoC 49.33260839794187   46.23625904936922
Vrpvi  54.39073037747987   57.00794930926328
Crpvi  54.023928251772816  54.50604124721722
Vnpvi  55.97017247799939   56.19809804799767
Cnpvi  51.75481242982659   51.21127681977297
Vcci   44.832417059840594  48.67664098825995
Ccci   34.791816395883906  33.58020786441748
colour #0000ff
border black
symbol tu
--
```

```
FILE   Portuguese_saoPaulo_pm
intV   158
intC   154
pause  11
Vmean  97.95674628678923
Cmean  100.42795674978542
Vperc  50.01819563053995
Vdev   47.91979244653272   48.06880531860939
Cdev   49.84145491778849   47.992895445430555
varcoV 48.91933864997652   47.653964501812915
varcoC 49.62906398859398   46.77933828056486
Vrpvi  55.67909363649826   58.80834863769837
Crpvi  53.82097291723188   54.83129646622226
Vnpvi  56.02836819593462   56.40520038097956
Cnpvi  51.890624750162075  51.93026787642263
Vcci   46.1906132290045    51.393380717159516
Ccci   34.870442053664746  34.32626840447903
colour #0000ff
border black
symbol td
--
FILE   Russian_gs_ar
intV   175
intC   179
pause  11
Vmean  79.23956669029302
Cmean  113.84205660997526
Vperc  40.49369240985652
Vdev   33.85025000969529   32.18513511153391
Cdev   54.86019969145939   50.876537420906025
varcoV 42.71887318869198   40.53189037498117
varcoC 48.18974755472956   45.91521818414914
Vrpvi  38.15285113126302   36.27192423734597
Crpvi  62.675585520459045  60.16436089360859
Vnpvi  44.943694149910456  43.034870995083004
Cnpvi  55.56382884080199   54.82331916255019
Vcci   28.58638037646266   27.42435319886409
Ccci   35.53713851986736   34.46857660236302
colour #f7c109
border black
symbol tu
--
FILE   Russian_gs_pm
intV   182
intC   186
pause  11
Vmean  79.10720355275635
Cmean  106.95941062567586
Vperc  41.98509052606885
Vdev   33.12758288675832   31.634555607154063
Cdev   48.35976043190399   47.1756960561775
varcoV 41.87682208316925   39.74463065865806
varcoC 45.2131889555262    45.11885186429301
Vrpvi  36.73975357453552   35.22698809497796
Crpvi  54.35577592456517   52.90746399219127
Vnpvi  43.888698019913136  42.292064417456245
Cnpvi  51.52397464834826   50.874342077389244
Vcci   31.853089521449384  31.45726855231651
Ccci   29.715986096016756  28.278131649301514
colour #fecb01
border black
symbol td
--
FILE   Russian_ss_ar
intV   174
intC   177
pause  17
Vmean  78.00773586189523
Cmean  123.67301935815395
Vperc  38.274161726061315
Vdev   36.23256713225476   37.80584692315388
Cdev   57.923156861650874  54.90722917463583
varcoV 46.44740259658457   43.92850870307808
varcoC 46.8357263065656    44.29127274399847
Vrpvi  37.87215575215725   42.80919623661539
```

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Crpvi  65.24290252445456   62.94226176665938
Vnpvi  46.958401961484924  49.2093300647478
Cnpvi  54.72322953125756   53.5304556418685
Vcci   34.31662033835754   35.690617736896456
Ccci   40.45879992181798   43.65707997392145
colour #f7c109
border black
symbol tu
--
FILE   Russian_ss_pm
intV   175
intC   179
pause  17
Vmean  78.96126168963193
Cmean  121.66893610651427
Vperc  38.8185414047251
Vdev   38.45111724844714   39.54883034720778
Cdev   55.20837352232766   53.184752892547806
varcoV 48.69617889286589   44.9684816686361
varcoC 45.37589896733859   43.6178139084747
Vrpvi  38.190041235159406  42.97422044740744
Crpvi  63.04716828632986   60.27842993477008
Vnpvi  46.30674831427909   48.4345695785036
Cnpvi  53.49030604834872   51.974898131859284
Vcci   33.339724660075255  33.35627535818072
Ccci   38.70934807546905   40.68483827287438
colour #fecb01
border black
symbol td
--
FILE   Spanish_bogota_ar
intV   157
intC   154
pause  19
Vmean  72.35528189297948
Cmean  96.85492007206696
Vperc  43.23345518307142
Vdev   34.7828489271357    32.752460520981444
Cdev   46.39919193246093   46.149500175631346
varcoV 48.07230103613297   42.88109113301242
varcoC 47.90586982874657   46.68421866436047
Vrpvi  36.33641031878884   37.35589781669293
Crpvi  56.75667658866066   57.60966321073218
Vnpvi  46.57731504342108   47.51101748033804
Cnpvi  60.182227488702566  59.282573029386995
Vcci   27.36296789517043   26.95302261635581
Ccci   27.86178644621503   25.577643501908735
colour #ff0000
border black
symbol tu
--
FILE   Spanish_bogota_pm
intV   161
intC   158
pause  19
Vmean  74.98089889309256
Cmean  92.54065394472045
Vperc  45.22446828855111
Vdev   29.09357267491019   25.604697086338362
Cdev   43.30929996252935   42.712506536963915
varcoV 38.801312206715046  34.421714735989944
varcoC 46.800295995747284  45.24748817855949
Vrpvi  32.06195114984841   28.80176161010774
Crpvi  51.32921329926918   51.9454161074592
Vnpvi  41.20515827131481   38.72787017462656
Cnpvi  57.25007758923295   55.79679620061273
Vcci   28.923814076179184  28.137666321624923
Ccci   28.451414199850255  25.534850917525823
colour #ff0000
border black
symbol td
--
FILE   Spanish_caracas_ar
intV   155
intC   156
```

```
pause  17
Vmean  61.551273453424756
Cmean  88.21230878315957
Vperc  40.94337156749738
Vdev   28.855752266087336  29.130724141198687
Cdev   40.968802934040475  39.07536297769295
varcoV 46.88083714128547   43.64663805022232
varcoC 46.443408521081295  44.80876142651439
Vrpvi  27.757391497830945  31.536676371968213
Crpvi  47.01333670136085   49.66234703245115
Vnpvi  42.42618622971178   44.67418627711227
Cnpvi  54.97503011841243   55.270776646158644
Vcci   23.140292517652842  21.98869083442424
Ccci   24.02891424905356   24.69513698765942
colour #ff0000
border black
symbol tu
--
FILE   Spanish_caracas_pm
intV   156
intC   154
pause  16
Vmean  65.18279590929804
Cmean  85.20535558254896
Vperc  43.66017447509747
Vdev   23.720275124021367  22.774266056630015
Cdev   36.505517593271094  32.53986013634101
varcoV 36.390392270113985  33.603599675174365
varcoC 42.84415849647348   38.87189985380579
Vrpvi  24.874195972897756  25.242230805508406
Crpvi  41.081382820811605  41.91621185864005
Vnpvi  36.878264535428755  35.883386260333495
Cnpvi  47.91542767789988   47.38589434360223
Vcci   24.089868176218683  22.798518219866814
Ccci   22.125057300521796  19.521289466831888
colour #ff0000
border black
symbol td
--
FILE   Spanish_granada_ar
intV   165
intC   162
pause  16
Vmean  67.25052584242421
Cmean  84.98924626543216
Vperc  44.62705672937064
Vdev   22.497932029248073  23.13194775796735
Cdev   46.47694381510287   46.49980935596266
varcoV 33.4539124377456    33.56929329448244
varcoC 54.68567596181463   53.18126232740229
Vrpvi  24.729144189024446  25.849474966615684
Crpvi  55.979548577639875  60.527829473881624
Vnpvi  36.837549747125266  37.4106209846264
Cnpvi  68.0129299862016    70.54808788530038
Vcci   23.8613543841464    23.426389855504585
Ccci   33.63030512008287   31.316667106681905
colour #ff0000
border black
symbol tu
--
FILE   Spanish_granada_pm
intV   161
intC   159
pause  16
Vmean  68.81708109688834
Cmean  87.57673044445247
Vperc  44.31066706335409
Vdev   23.847598509026927  23.7052862187883
Cdev   47.156586359362635  46.230993409702755
varcoV 34.65360362415200 5 33.090505452139226
varcoC 53.846022933309634  51.153518415096
Vrpvi  23.194150306121305  23.51610829563192
Crpvi  56.635992947913294  60.8528756570044
Vnpvi  32.930317541626884  32.27254246411719
Cnpvi  67.78447367808475   69.48335038302395
```

```
Vcci   21.46967096861252  21.075521213971836
Ccci   31.63357827121847  28.576739139629943
colour #ff0000
border black
symbol td
--
FILE   Spanish_IPA_ar
intV   164
intC   162
pause  13
Vmean  71.20441839516616
Cmean  99.37284848013111
Vperc  42.041891194304434
Vdev   30.070779562728855 33.63534530691724
Cdev   52.30973236533942  48.99958626142094
varcoV 42.231620228738876 45.4097368230649
varcoC 52.63986407292972  49.00915461157334
Vrpvi  31.66939801119255  34.58080703373354
Crpvi  59.48718221307275  63.5222751675023
Vnpvi  41.6191459645734   45.06648929609983
Cnpvi  60.820311508138225 62.76656351120989
Vcci   26.341149108260435 29.829788395509212
Ccci   32.62775936602838  34.79382494277831
colour #ff0000
border black
symbol tu
--
FILE   Spanish_IPA_pm
intV   163
intC   161
pause  13
Vmean  74.75581609635226
Cmean  99.5274205850065
Vperc  43.19596343538248
Vdev   33.85165166570099  37.12816641953708
Cdev   51.70747504167457  48.875960542260856
varcoV 45.28296717685461  47.826272384381355
varcoC 51.952994197725786 48.90950269343214
Vrpvi  31.258745241600703 32.22766148648249
Crpvi  57.254522177357146 62.04175437936107
Vnpvi  38.155769187080026 40.17237409187338
Cnpvi  59.945389188001705 63.4372727253615б
Vcci   29.257802112117616 30.59483730341013
Ccci   32.66958287673966  30.629936266772486
colour #ff0000
border black
symbol td
--
FILE   Spanish_lima_ar
intV   172
intC   172
pause  23
Vmean  76.91261963021269
Cmean  84.22826101601434
Vperc  47.73004796906174
Vdev   35.48581323027807  32.511678931322564
Cdev   37.597461422060015 35.44783015704988
varcoV 46.1378293976852   38.68598613479965
varcoC 44.637584782750764 42.501957439459595
Vrpvi  33.41288174052672  35.3040511837775
Crpvi  44.004557401645044 43.12189371159943
Vnpvi  39.94239191636248  40.662973803791154
Cnpvi  57.09417366871914  54.81187630217617
Vcci   22.80225625196563  21.95501672300476
Ccci   26.137598264466266 23.906061197447784
colour #ff0000
border black
symbol tu
--
FILE   Spanish_lima_pm
intV   158
intC   157
pause  21
Vmean  73.26461417975007
Cmean  88.11295705668206
```

```
Vperc  45.556934670192064
Vdev   25.761760373741172  24.679717196929943
Cdev   36.869773765841224  35.7228238634609
varcoV 35.16262340580452   31.402983913866183
varcoC 41.84375941681689   39.78345177579403
Vrpvi  25.13475635103389   25.549788260284863
Crpvi  44.11441457276916   46.09248745040499
Vnpvi  32.322524511220834  31.910251643681768
Cnpvi  51.89929109276624   52.418885191769654
Vcci   22.758055103107644  20.65633265514097
Ccci   26.18698548038082   25.229280142993048
colour #ff0000
border black
symbol td
--
FILE   Swedish_IPA_ar
intV   160
intC   164
pause  15
Vmean  92.02348495976844
Cmean  114.1792381098518
Vperc  44.01832761042909
Vdev   35.805234522877065  36.59186057833848
Cdev   54.74927740796527   52.2714688738541
varcoV 38.908800876787794  39.184828456410266
varcoC 47.9502914140056    47.1110377875044
Vrpvi  42.06931769767066   42.790291455621364
Crpvi  68.11331260264166   63.72154898945452
Vnpvi  45.26058476189414   45.07106415570816
Cnpvi  60.49140863660416   56.97984770435922
Vcci   31.695124141273237  31.000544876893315
Ccci   30.60082372107569   29.5787112400012
colour #b35900
border black
symbol tu
--
FILE   Turkish_ar
intV   163
intC   169
pause  16
Vmean  87.77415070550994
Cmean  103.97499035331374
Vperc  44.879715631566775
Vdev   37.96009756046363   37.759943692715424
Cdev   57.49794998762647   53.28041936509227
varcoV 43.24746779700908   41.649353515539666
varcoC 55.29978872058051   50.76838580492096
Vrpvi  40.976826882311734  40.796125008751474
Crpvi  67.2258252140195    65.13028111702876
Vnpvi  46.0729495081369    44.86816107777714
Cnpvi  61.95452946659324   60.50233190119441
Vcci   40.79394040294805   40.35836668199842
Ccci   40.48123132158842   39.2430728233207
colour #ffd9ff
border #ff00ff
symbol tu
--
```

Appendix 3: Tcl implementations

Key Tcl implementations are reported below. However, this is merely a fraction of the entire program, which contains more than 4000 lines of code (which can be consulted directly from the sources, available at the following internet address: http://www.lfsag.unito.it/correlatore/download_en.html).

Appendix 3a: Tcl implementation of the metrics

The procedures (proc) of *Correlatore* implementing the calculation of the rhythm metrics are reported below. All take a numerical list as argument (consonantal or vocalic durations), except for the CCI, which take 2 lists as arguments (the first being a numerical list containing the duration of consonantal or vocalic intervals, the second being a string list containing the segments composing each interval).

```
# Tcl implementation of the delta (standard deviation)
proc stdev {lista} {
	set media [mean $lista]
	foreach item $lista {
		lappend provvisorie [expr pow(($item - $media), 2)]
	}
	return   [expr   sqrt(   ([join   $provvisorie   +])   /   ([llength
$provvisorie].0 - 1) )]
}

# Tcl implementation of the varco
proc varco {lista} {
	return [expr [stdev $lista] / [mean $lista] * 100]
}

# Tcl implementation of the rPVI
roc rpvi {valori} {
	set volte 0
	foreach v $valori {
		if {$volte > 0} {
			set prec [lindex $valori [expr $volte - 1]]
			lappend rpvi [expr abs($v - $prec)]
		}
		incr volte
	}
	return [mean $rpvi]
}

# Tcl implementation of the nPVI
proc npvi {valori} {
	set volte 0
	foreach v $valori {
		if {$volte > 0} {
			set prec [lindex $valori [expr $volte - 1]]
			lappend npvi [expr (abs($v - $prec)) / (($v + $prec) /
2.0)]
		}
		incr volte
	}
	return [expr 100 * [mean $npvi]]
}

# Tcl implementation of the CCI
proc cci {durate segmenti} {
	set volte 0
	foreach durata $durate {
		lappend  differenze  [expr  $durata  /  [string  length  [lindex
$segmenti $volte]].0]
		incr volte
```

```
        }
        set volte 0
        foreach v $differenze {
                if {$volte > 0} {
                        set prec [lindex $differenze [expr $volte - 1]]
                        lappend cci [expr abs($v - $prec)]
                }
                incr volte
        }
        return [mean $cci]
}
```

Appendix 3b: reading CV and SAMPA segmentations with a foreach cycle.

```
foreach item $contenuto($scelto) {

        #----- correct characters that may interfer with Tcl -----
        set item [string map {\" ""} $item]
        set item [string map {\[ \\\[} $item]
        set item [string map {\] \\\]} $item]
        set item [string map {\{ \\\{} $item]
        set item [string map {\} \\\}} $item]

        #----- a = fono ; b = durata -----
        incr n_intervallo
        set a [lindex $item 0]
        set b [lindex $item 1]
        if {$a eq ""} {set a "#"}

        #----- if annotation is in CV, put it in $pronto_cci -----
        if {$tipo($scelto) eq "CV"} {
                if {![string match -nocase "*c*" $a] && ![string match -nocase
"*v*" $a] && ![string match -nocase "#" $a]} {
                        lappend   log   [errore_segmento   $scelto   $n_intervallo
$item]
                } else {
                        lappend pronto_cci "$a\t$b"
                }
        }

        #----- if annotation is in SAMPA, convert SAMPA in CV -----
        if {$tipo($scelto) eq "SAMPA"} {
                if {[string match "*#*" $a]} {
                        set a "#"
                } elseif {[string match $var_sost $a]} {
                        set a v
                } else {
                        set a c
                }
        }

        #----- compute durations for #, V and C intervals -----
        if {[regexp {^\#+$} $a]} {
                if {($precedente eq "#") || ($precedente eq "null")} {
                        append intervallo $a
                        set durata [expr $durata + $b]
                } elseif {($precedente eq "v") || ($precedente eq "c")} {
                        lappend pronto "$intervallo\t$durata"
                        set intervallo $a
                        set durata $b
                }
                set precedente "#"

        } elseif {[regexp {^[vV]+$} $a]} {
                if {$precedente eq "v" || ($precedente eq "null")} {
```

```
				append intervallo $a
				set durata [expr $durata + $b]
			} elseif {($precedente eq "c") || ($precedente eq "#")} {
				lappend pronto "$intervallo\t$durata"
				set intervallo $a
				set durata $b
			}
			set precedente "v"

		} elseif {[regexp {^[cC]+$} $a]} {
			if {$precedente eq "c" || ($precedente eq "null")} {
				append intervallo $a
				set durata [expr $durata + $b]
			} elseif {($precedente eq "v") || ($precedente eq "#")} {
				lappend pronto "$intervallo\t$durata"
				set intervallo $a
				set durata $b
			}
			set precedente "c"
		}
	}
```

Appendix 4: sample log file of a perceptive test

A sample log file of a perceptive test is reported below. The original name and surname of the participant have of course neen removed for privacy reasons. “False” and “True” are the Boolean values returned by checkboxes in the preliminary phase (each “true” indicate that the participant marked a stress on the corresponding syllable). Below, “is” indicates the choice “Spanish, French or similar”; “ia” indicates the choice “English, German or similar”; “al” indicates the choice “other”; “no” indicates the choice “I don’t know”. Details on the test can be found in chapter 6.

```
Nome Cognome
età: 25
titolo: Laurea triennale
CFUfon: 0
CFUling: 12
madrelingua: Italiano
inglese: C1
francese: C1
tedesco: B1
spagnolo: no
altro(specificare): no
altro(specificare): no
true false false false true false false false false false false false true
false false false false false false false false false true false true false
false false false true false false false true false false true false false
false false true false false true false false true true false false true
false true false false false false undefined undefined undefined
true false false false false false false false true false false false true
false true false false true false false false true false false false false
false false false false true false false false true false false false true
false false false false false false false false false false true true false
true false false false undefined undefined undefined
true false true false false false false true false false false false true
false false false false false false false false false false true false
false false false false false false false false false false false true
false true false false true false false false false true false true false
true false false false true false false true false false false false true
false false true false false undefined undefined undefined
true false true false false false false false false false false false false
false false false false false true false false true false false false false
false false false false true false false true false true false true false
true false false false true false false false false false false false true
false false true false false true false false true false false true false
false undefined undefined undefined
true false false true false false true false false false false false false
false false false true false true false false false false false false false
true false false true false false true false true false false true true
false false false true false true false false false true false false false
undefined undefined undefined
1: is
2: is
3: ia
4: ia
5: is
6: is
7: is
8: ia
9: ia
10: is
11: ia
12: al
13: al
14: is
15: al
1: en
2: en
```

```
3: fr
4: en
5: jp
6: fr
7: jp
8: en
9: fr
10: en
11: jp
12: jp
13: fr
14: en
15: jp
slider1: 66.66666666666667
slider2: 70.70707070707071
slider3: 60.60606060606061
slider4: 34.343434343434346
slider5: 19.19191919191919
slider6: 3.0303030303030303
slider7: 8.080808080808081
slider1: 19.19191919191919
slider2: 61.61616161616162
slider3: 70.70707070707071
slider4: 29.292929292929294
slider5: 24.242424242424242
slider6: 9.090909090909092
slider7: 70.70707070707071
slider1: 71.71717171717172
slider2: 34.343434343434346
slider3: 19.19191919191919
slider4: 40.4040404040404
slider5: 71.71717171717172
slider6: 8.080808080808081
slider7: 40.4040404040404
```

Appendix 5: Results of the perceptive test by best performers in the preliminary phase.

Here I report the results of the perceptive tests by exclusively participants who performed better in the preliminary phase. Their performance in the preliminary phase has been evaluated in terms of correlation with model answers. I have selected those participants whose score was higher than or equal to the median (hence 22 out of 43). The results are reproduced in charts equivalent to those presented in chapter 6 for all participants.

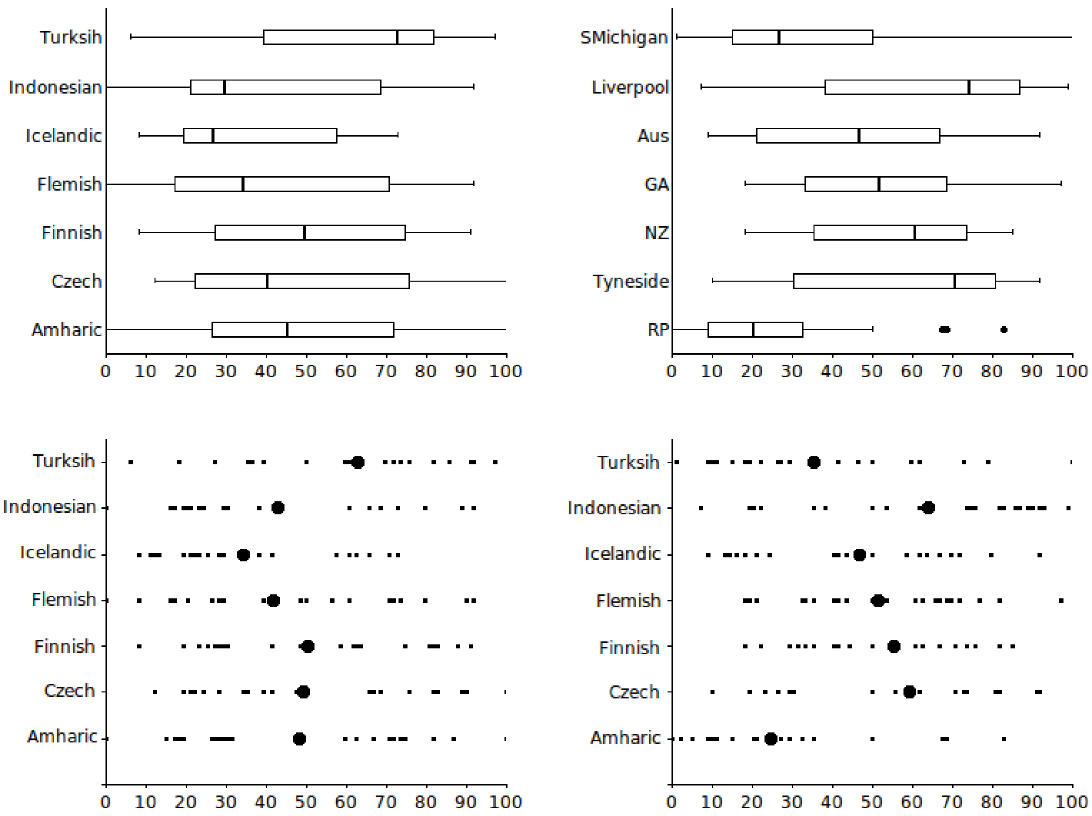

Figura 9.1. Results of the final part of the test, asking for a scalar categorisation of 7 samples of unknown languages (on the left) and 7 regional varieties of English (on the right). Data is presented on box-plots above and on scatter-plots below. 0 corresponds to A (synthesised RP English sample) and 100 corresponds to B (synthesised French sample). Cf. figure 6.9.

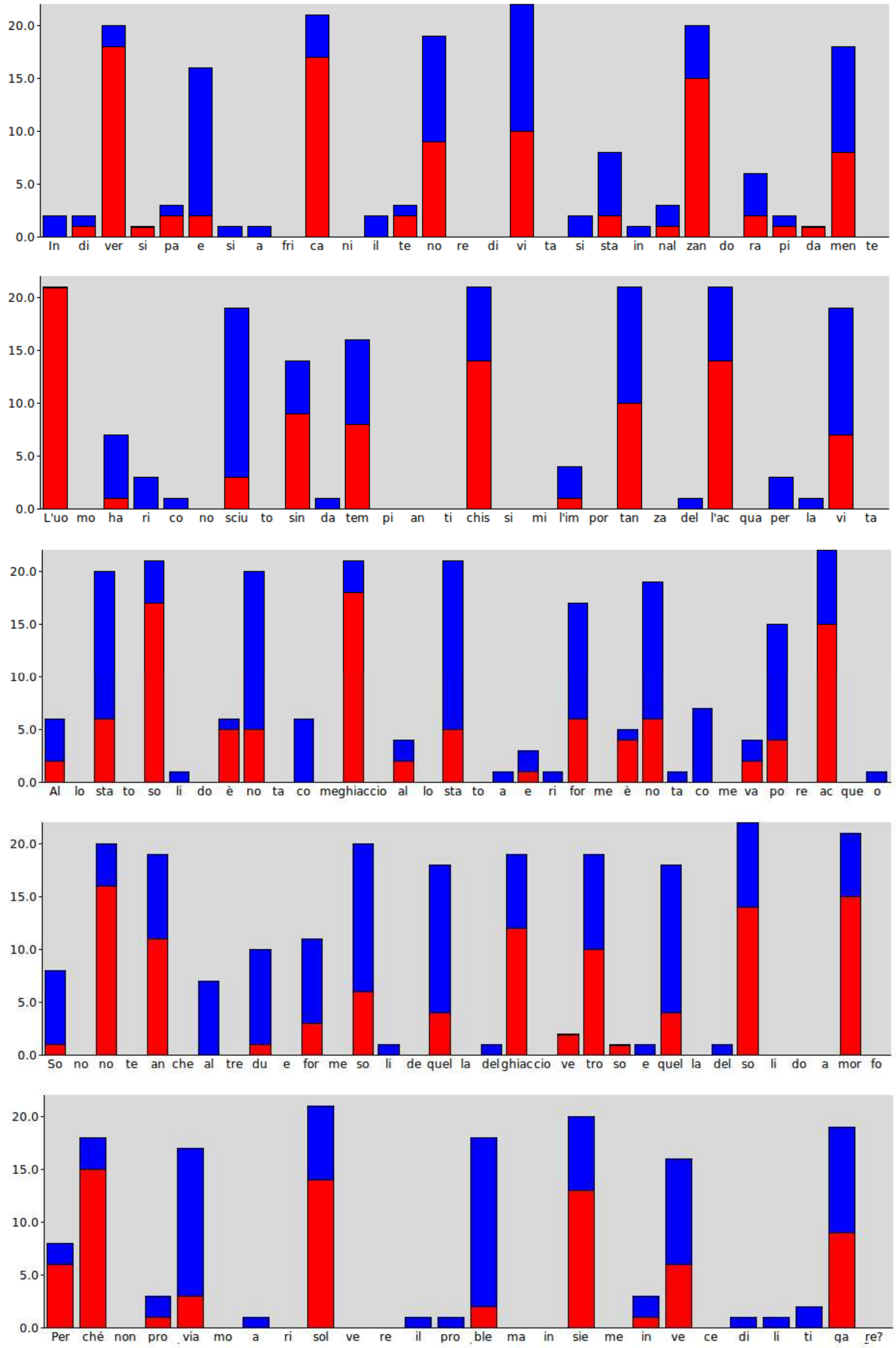

Figure 9.2. Histograms representing the answers given to the preliminary phase of the test. Syllables are shown in the x-axis, the y-axis represents the number of people who marked a stress on each syllable (first level stresses in blue, second level stresses in red). Cf. figure. 6.3.

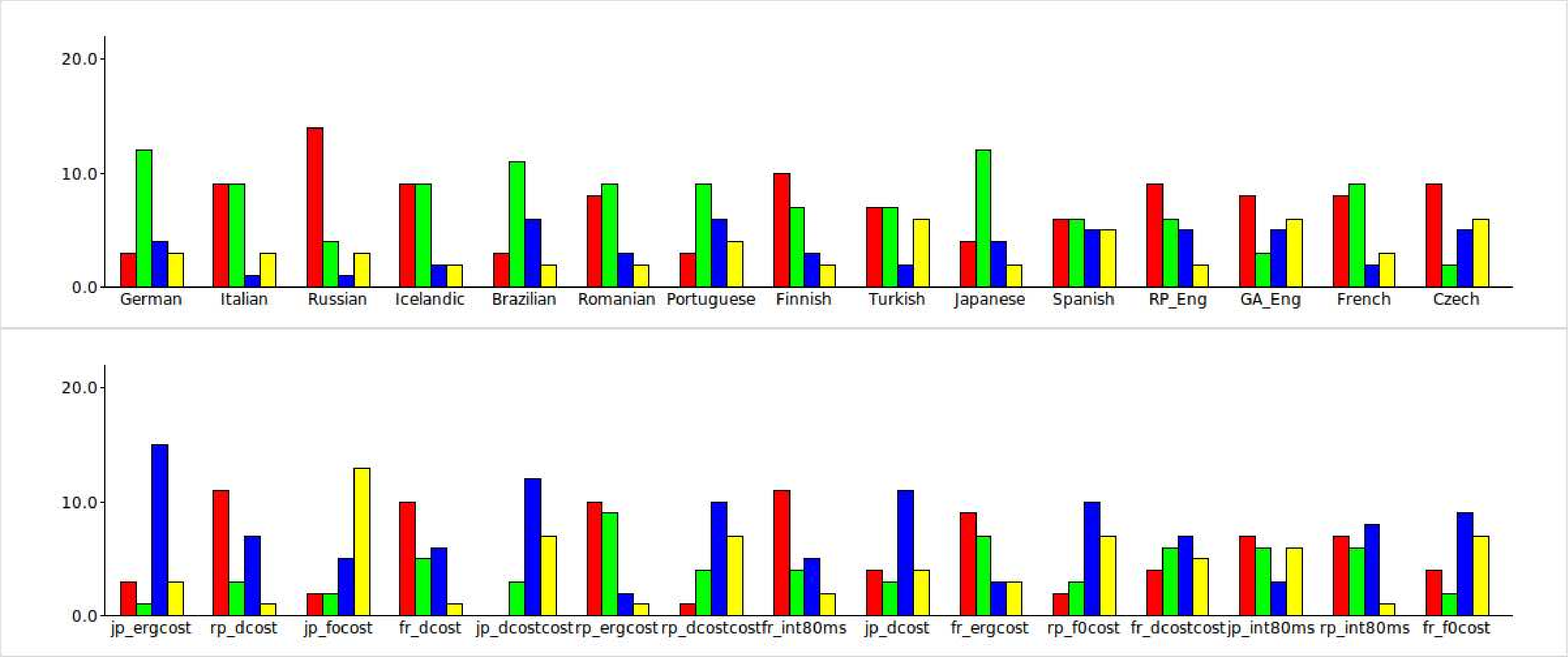

Figure 9.3. Answers given by the 43 participants for each audio sample. For the first task (above), red bars indicate ratings for "English, German or similar", green bars indicate ratings for "French, Spanish or similar", blue bars indicate rating for "Other", while yellow bars indicate ratings for "I don't know". For the second task (below), red bars indicate ratings for "English", green bars indicate ratings for "French", blue bars indicate rating for "Japanese", while yellow bars indicate ratings for "I don't know". Cf. figure 6.7.

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2011