A Rhythm-Based Analysis of Arabic Native and Non-Native Speaking Styles

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***Abstract*—In this paper, we investigate the effect of the mother language (L1) on the rhythm of a second spoken language (L2) uttered by non-native speakers. Rhythm metrics are used to analyze this effect on non-native Arabic language speech data using a Modern Standard Arabic corpus, namely the Linguistic Data Consortium West Point corpus. A common problem with available Arabic corpora is that they usually are not time-labeled because of the time-consuming nature of such a task or because of a lack of resources. This is especially problematic if we are interested in studying rhythm metrics. To cope with this problem, we propose a framework for automatically labeling corpora using parallel processing. Such labeling allows us to perform a quantitative analysis of the rhythm of Arabic. Results show the effectiveness of acoustic rhythm metrics in analyzing variable duration patterns observed in the pronunciation of L1/L2 Arabic.**

***Index Terms*—rhythm, metrics, modern standard arabic, non-native speech, parallel automatic labeling**

I. Introduction

Several investigations suggest that rhythm is a way of objectively referring to the temporal distribution of linguistic information in a language, and as such it can reflect the closeness of relatedness among speech units at different levels. According to the traditional phonetic classification of language rhythm, languages such as English and Swedish are considered stress-timed. This means that their fundamental unit for equal-timed intervals is the stress foot. Syllable-timed languages such as French and Italian, in contrast, have the syllable as the fundamental unit for equal-timed intervals. A third rhythm category that includes mora-timed languages such as Japanese has been proposed by Bloch [1], Han [2], and Ladefoged [3]. Morae are defined as sub-units of syllables consisting of one short vowel and any preceding onset consonants. It is important to note that successive morae are very similar in terms of duration. Therefore, mora-timed languages are closer to syllable-timed languages than to stress-timed languages.

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Ramus *et al*. and Grabe & Low worked separately on quantitative rhythm metrics, and they each proposed approaches for describing the rhythmic structure of languages based on acoustic-phonetic measurements [4] and [5]. Ramus *et al*. suggested a measure based on the percentage of vocalic intervals (%V) and the standard deviation of consonantal intervals ΔC. They showed that these two metrics can be used to classify any language or dialect into one of the three categories mentioned above [5]. If the language is classified as stress-timed, then it has a relatively low %V and high ΔC, but if it is categorized as mora-timed, then it has a high %V and low ΔC. On the other hand, if the language is syllable-timed, then its %V-ΔC values are located between these two extremes. Grabe & Low have proposed the raw and normalized Pairwise Variability Indexes (rPVI, nPVI), which are calculated based on the differences in vocalic and consonantal durations between successive syllables [4].

The organization of the paper is as follows. Section II presents the objective of our study and its relation to prior work. Section III gives an overview of the Arabic language and the characteristics of its rhythm. Section IV gives definitions of the rhythm metrics used in this investigation. The parallel computing framework for the automatic labeling of the test corpus is presented in Section V. The experimental results are reported in Section VI. In Section VII, the paper is concluded.

II. Related Work & Objectives

Recently, numerous approaches based on speech rhythm measures have been proposed to capture the various speech and language typologies related to rhythm. Wiget et al. present an overview of widely used rhythm metrics and made some recommendations about their effectiveness and reliability [6]. They point out, for example, that metrics that deal with vocalic duration are more effective at discriminating between language varieties than those that measure consonantal duration. In fact, the literature shows that these rhythm scores are sensitive to dialect differences in a number of languages, including American English [7], Welsh English, Standard

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Southern British English [8], and Italian [9].A comparison conducted by Hua-Li Jian between the English uttered by Taiwanese speakers and American English using acoustic rhythm showed that Taiwan English is not stress-timed, while American English is [10]. Similarly, Setter showed that the English spoken by Hong-Kong Cantonese native speakers shows considerably less variation than British English [11].

Unanimously, researchers in the field have emphasized the fact that linguistic rhythm is primarily a perceptual phenomenon that requires more research on how rhythm metrics relate to an individual's perception of speech and on the differences between languages, language varieties, and individual speakers [12].

This work has two principle objectives. The first is to investigate specific speech rhythm metrics and their variability depending on the L1 (mother tongue) of the speakers. For this purpose, an internationally referred Modern Standard Arabic (MSA) Arabic corpus [13] is used. This corpus contains data from two groups of speakers: native Arabic speakers and native English speakers uttering Arabic sentences. The second objective of this study is to propose a parallel computing framework that takes as input both the speech signal and its phonetic transcription to perform automatic segmentation and labeling, both of which are essential to the calculation of rhythm metrics.

III. Arabic Language & Rhythm

Preliminary evidence from our listening experiments [14] and [15] shows noticeable perceptual differences between native and non-native Arabic speakers in terms of speaking rate and vowel and consonant length. Arabic speech has been observed by linguists to have a temporal rhythm that can be characterized by placing a perceptual "beat" around successive syllables [16]. This periodic speech rhythm provides a syllable-level characterization of the speech signal that approximates the number of segmental elements in the utterance. Al-Haj et al. investigated the speech rhythms of different Arabic dialects that have been consistently described heretofore as stress-timed when compared with other languages belonging to different rhythm categories [17]. In their work, Algerian, Moroccan, and Tunisian dialects are compared with Egyptian, Syrian, and Jordanian dialects in an attempt to elucidate the factors of the language that give human listeners the ability to perceptually distinguish between these dialects. An acoustic investigation based on duration measurements, namely the duration of %V and the standard deviation of consonantal intervals, was carried out.

IV. Rhythm Metrics

Researchers have developed a number of metrics that quantify rhythm in languages. These rhythm metrics are based on acoustic measures of the duration of vocalic and consonantal intervals in continuous speech; they take into account variability in the durations, and they are calculated in both raw and rate-normalized forms:

- (ΔV, ΔC): standard deviation of the duration of vocalic and consonantal intervals, respectively [5];
- %V: percentage of duration utterance composed of vocalic intervals [5];
- (nPVI-V, nPVI-C): normalized index of variability between the duration of successive vocalic and consonantal intervals, respectively [4];
- nPVIVC: mean of the difference between successive vocalic and consonantal durations divided by their sum and multiplied by 100;
- (rPVI-V, rPVI-C): mean difference between the successive durations of vocalic and consonantal intervals, respectively;
- (VarcoV, VarcoC): standard deviation of vocalic and consonantal interval durations, respectively, divided bythe mean vocalic (resp. consonantal) interval duration, multiplied by 100 [18];
- VarcoVC: coefficient of variation of vocalic and consonantal interval durations.

While these metrics provide only a partial picture of the general notion of rhythm in language, as noted by a number of researchers [19], they have contributed new insights to the quantitative discrimination of rhythmic differences both across and within languages.

V. Parallel Framework for Labeling

As previously mentioned, one problem with Arabic corpora, or the corpora of under-resourced languages in general, is that they generally lack proper manual time-aligned labels. This is particularly problematic when we are interested in studying the rhythmic properties of a language because the measures are directly related to phonemic/syllabic length and rate. To deal with this challenge in a time-efficient manner, we exploited the HTK [20] Toolkit parallel accumulator ability of the HERest tool for HMM re-estimation, in combination with GNU parallel powerful parallelization capabilities [21]. The master label file was divided into N parts to enable parallel time-alignment with the HVite tool. To determine if our portable framework effectively cut processing time and scaled well with the number of processors, we evaluated it on a Linux virtual machine using 8 GB of RAM and 10 cores from a dual Intel Xeon5650 system clocked at 2.66 GHz. Serving as a baseline, one iteration of HERest on one core took 175.13 seconds to complete.

TABLE I. HMM Model Re-Estimation Computation Time with Respect to the Number of Cores Available for Processing

N cores	Time(seconds)	Speed-up
1	175.13	1
2	88.71	1.97
4	55.17	3.17
6	37.5	4.67
8	33.34	5.25
10	29.5	5.94

Table I shows the resulting scaling. We see that by using two cores, the speed-up is nearly linear at 1.97 over a single core. However, as we progress up the scale, we observe that the speed-up is more related to a power curve than a linear one, with speed-ups of 5.25 and 5.94 for 8 and 10 cores, respectively.

TABLE II. LABEL ALIGNMENT COMPUTATION TIMES WITH RESPECT TO THE NUMBER OF CORES AVAILABLE FOR PROCESSING

N cores	Time(seconds)	Speed-up
1	68.92	1.00
2	33.7	2.05
4	18.6	3.71
6	12.62	5.46
8	12.15	5.67
10	11.15	6.18

As illustrated in Table II, the parallel time alignment of the labels scales a bit better than the parameter re-estimations. With two cores, we obtain a speed-up of 2.05, and then up to a speed-up of 6.18 when running on 10 cores. Although not completely linear, this still represents a considerable speed-up and enables us to obtain precisely aligned time labels (the obtained labels were verified and validated by an external team of experts) much more rapidly.

VI. EXPERIMENTS AND RESULTS

We examined the effectiveness of rhythm metrics in distinguishing between variable duration patterns observed in the pronunciation of Arabic by native and non-native speakers. Our experiments focused on Arabic, but we also considered previous non-Arabic research findings [5], [22] to compare the rhythm patterns of L1/L2 Arabic and English.

A. *Experimental Setup*

The Linguistic Data Consortium (LDC) West Point Arabic corpus was used throughout the experiments [13]. The labeling of this corpus was carried out according to the parallel processing methods described in Section5. The West Point corpus consists of collections of the four main Arabic scripts. The first script contains 155 sentences spoken by 75 native Arabic speakers. The second script is composed of 40 sentences uttered by 23 non-native speakers. The third script contains 41 sentences spoken by four non-native speakers. Finally, the fourth script contains 22 sentences spoken by eight non-native speakers. The total number of distinct words is 1131 Arabic words. All scripts are diacritized. In total, the utterances of 110 speakers were analyzed; the speakers had the following distribution: 66 male (41 native and 25 non-native) and 44 female (34 native and 10 non-native). Each sentence of the LDC West Point corpus was labeled according to its vocalic intervals and consonantal intervals based on the criteria described in [22] and [23]. The duration of these intervals was derived from the labeled speech files provided by our parallel framework described in Section 5. Short pauses in mid-utterances were excluded as well as the glottalized sections between vowels.

B. *Method*

We investigated the ability of 11 rhythm metrics to analyze the variable duration patterns observed in the pronunciation of the modern standard Arabic spoken by native and non-native speakers. We considered the LDC West Point corpus for the Arabic language data because it was the only publicly available MSA corpus suitable for our processing tasks; specifically, it was suitable because it includes data from both native (Arabic L1) and non-native Arabic speakers (Arabic L2). All non-native speaker data in the corpus is from speakers whose mother language is English. The evaluation of the automatic parallel labeling framework showed that it was very efficient in providing quantitative rhythm measurements.

C. *Analysis of Variance Results*

In the first stage of the experiments, we performed a one way ANOVA to study the effect of L1/L2 and gender differences on rhythm metrics. Results are illustrated in Table III and Table IV. The significance level of α for the F-test and p-value was set to α=0.05. Values under α in Table III and Table IV are bold-faced.

TABLE III. RESULT OF F-TEST AND P-VALUES WITH L1/L2 AS GROUPING VARIABLE

Metrics	F-test	p-value
ΔV	0.974	**0.031**
ΔC	0.005	0.169
%V	0,018	**<0.001**
VarcoV	0.0001	**0.002**
VarcoC	0.051	**0.010**
VarcoVC	0.011	**<0.001**
nPVI-V	0.998	0.206
nPVI-C	0.066	**0.033**
rPVI-C	0.150	**0.040**
nPVI-VC	0.041	**<0.001**
rPVI-VC	0.001	**0.006**

TABLE IV. RESULTS OF F-TEST AND P-VALUES OF ONE-WAY ANOVA ANALYSIS WITH GENDER PARAMETER AS FACTOR

Metrics	F-test	p-value
ΔV	0. 378	0.362
ΔC	0.317	0.257
%V	0.027	0.513
VarcoV	0.168	0.473
VarcoC	0.417	0.767
VarcoVC	0.786	0.238
nPVI-V	0.417	0.398
nPVI-C	0.349	0.437
rPVI-C	0.028	0.071
rPVI-VC	0.621	0.978
nPVI-VC	0.719	0.398

Both PV (pair-wise variability) and IM (interval measure) acoustic rhythm metrics are sensitive to the effect of the origin factor (L1/L2). As shown in Table III, the rhythm metrics influenced by the investigated factor (origin)were related to the vocalic duration measurements (%V, ΔV, VarcoV, VarcoVC, rPVI_C, and nPVI-VC) as well as the three consonant-based duration measurements (VarcoC, nPVI-C, and rPVI-C). The metrics mostly affected by the origin factor were %V, nPVI-VC, and VarcoVC, where their p-value was close to zero, at just below 0.001. According to the one-way ANOVA results presented in Table III, we confirmed a significant effect of the L1/L2 factor on the rhythm metrics for Arabic speech.

TABLE V. RESULTS OF F-TEST AND P-VALUES OF TWO-WAY ANOVA WITH GENDER X L1/L2 FACTORS

Metrics	F-test	p-value
ΔV	1.068	0.303
ΔC	1.108	0.294
%V	0.851	0.358
VarcoV	1.593	0.209
VarcoC	4.976	**0.027**
VarcoVC	2.276	0.133
nPVI-V	1.626	0.204
nPVI-C	2.291	0.132
rPVI-C	1.095	0.297
nPVI-VC	0.775	0.380
rPVI-VC	0.045	0.833

As shown in Table IV, the rhythm metrics were not sensitive to the gender parameter factor. Next, as shown in Table V, the interaction of the two abovementioned factors (gender and origin) was investigated by performing a two-way ANOVA. All the rhythm metrics except for VarcoC were not affected by the interaction of the two factors; VarcoC was sensitive to this interaction at a p-value= 0.027.

In the next section, we attempt to confirm these findings by comparing the performance of two classification frameworks based on theL1/L2 and gender factors.

D. *Bagging Decision Tree Classification*

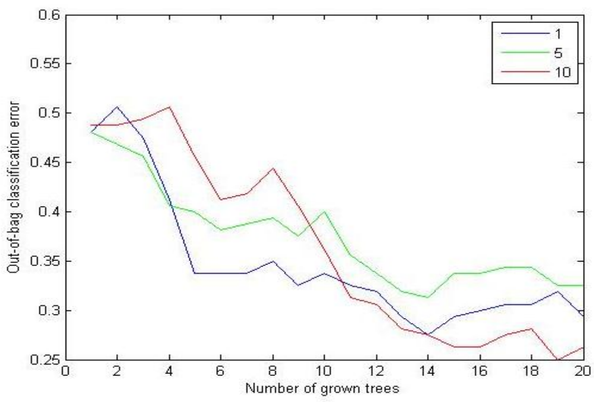

Figure 1. Classification error of different leaf sizes of framework1.

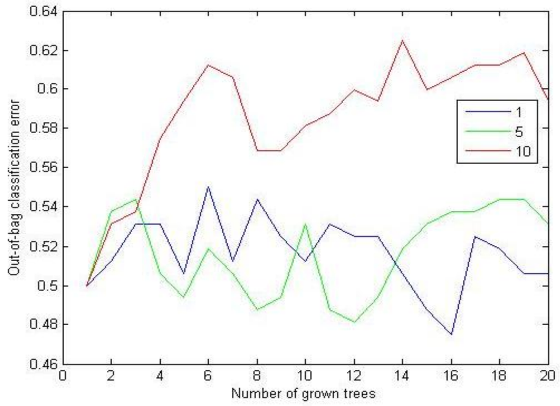

Figure 2. Classification error of different leaf sizes of framework2.

We randomly chose 160 sentences belonging to two equal subsets according to gender (male/female) (Framework1) or first language (native/non-native) (Framework2). The goal was to evaluate the classification performance for Framework1 and Framework2 and compare the outcome of the experiment with the ANOVA results. The classification framework was based on Bagging Decision Trees [24]; *n* decision trees are bagged for classification. Every i^{th} tree is grown on an independently drawn bootstrap replica of input data. Then, the average of the predictions from individual trees is taken. To estimate the prediction error for the bagged ensemble, predictions for each tree on its out-of-bag observations are computed, and then the error is averaged over the entire ensemble for each observation and compared with its true values. Note that we did not have to split data into training and test subsets. This was done implicitly; at each iteration, the bootstrap replica is the training set, and any remaining data “out of bag” are used as test corpora to estimate the out-of-bag classification error. The first step in this framework is to find the best leaf size for the individual trees; here we started with only 20 trees because the goal is to compare the percentage of classification error between different leaf sizes. Fig. 1 and Fig. 2 show that the best results are obtained when the number of leaves is set to 10 for Framework1 and to 1 for Framework2.

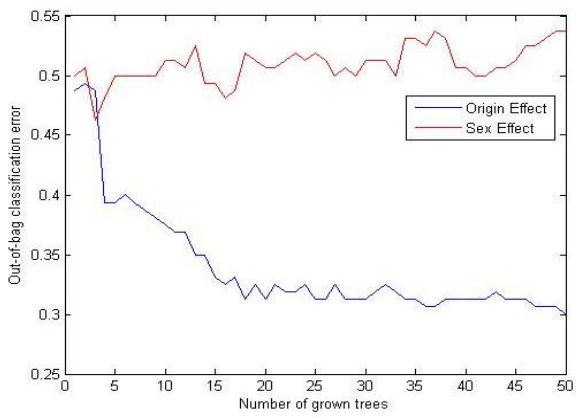

Figure 3. Classification error for framework1 and framework2.

In the next step, the number of leaves in each framework is set according to results shown in Fig. 1 and Fig. 2. The out-of-bag classification error is computed each iteration. A comparison between the two frameworks is illustrated in Fig. 3; specifically, Framework1, in which data is divided in two subsets according to the L1/L2 parameter, outperforms Framework2 based on gender.

Results shown in Fig. 3 are in concordance with the results obtained from the ANOVA analysis. The out-of-bag classification error for Framework1 was typically smaller than that for Framework2. It tended to be lower when the number of grown trees increases. The opposite was true, however, for Framework2.Rhythm metrics were again proved to be sensitive to the L1/L2 effect, but not to the gender effect.

VII. Conclusion

In this paper, we investigated the rhythm metrics of L1/L2 Arabic speech. Our original finding from this study is that acoustic rhythm metrics capture the perceptual differences between native and non-native Arabic speech. The effectiveness of rhythm metrics is then demonstrated by analyzing variable duration patterns observed in the pronunciation of L1/L2 Arabic. We also implemented a new parallel processing framework designed to rapidly obtain accurate time-aligned labels for rhythm-based speech processing. Although the scaling factor was not near linear, it still provided significant performance improvements. Currently, we are investigating new rhythm measures that may be able to better characterize various dialects.

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