

The Acoustics of Lexical Stress in Italian as a Function of Stress Level and Speaking Style

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Abstract

The study is part of a series of studies, describing the acoustics of lexical stress in a way that should be applicable to any language. The present database of recordings includes Brazilian Portuguese, English, Estonian, German, French, Italian and Swedish. The acoustic parameters examined are *F₀-level*, *F₀-variation*, *Duration*, and *Spectral Emphasis*. Values for these parameters, computed for all vowels (a little over 24000 vowels for Italian), are the data upon which the analyses are based. All parameters are examined with respect to their correlation with *Stress* (primary, secondary, unstressed) and speaking *Style* (wordlist reading, phrase reading, spontaneous speech) and *Sex* of the speaker (female, male). For Italian *Duration* was found to be the dominant factor by a wide margin, in agreement with previous studies. *Spectral Emphasis* was the second most important factor. *Spectral Emphasis* has not been studied previously for Italian but intensity, a related parameter, has been shown to correlate with stress. *F₀-level* was also significantly correlated but not to the same degree. Speaker *Sex* turned out as significant in many comparisons. The differences were, however, mainly a function of the degree to which a given parameter was used, not how it was used to signal lexical stress contrasts.

Index Terms: speech prosody, lexical stress, Italian

1. Introduction

The present study is part of a series describing the acoustics of word stress in a number of typologically different languages. The goal is to develop an analysis model that may be applied to any language. We have recorded data from Brazilian Portuguese, English, Estonian, French, German, Italian and Swedish. Analyses have been published for Brazilian Portuguese, [1, 2] Estonian [3], English [4] German [5] and Swedish [6, 7].

All languages that have contrastive word stress have primary stress. In some languages, the stress contrast is binary; stressed or unstressed. Many languages, also have secondary stress, in which case three levels of stress must be considered.

In our studies we have found that the acoustic correlates of stress are influenced by speaking style. Word list reading tends to produce the most prototypical stress realization, typically described in lexica, whereas in spontaneous speech acoustic correlates are often reduced. Phrase reading falls somewhere in between. We therefore also study the influence of speaking style on the acoustics of word stress. The speaking styles

investigated in the studies are, wordlist reading, phrase reading, and spontaneous speech.

The study of the acoustics of word stress has a long tradition. Classical studies are those by Fry in the 1950s [8]. In his study of English word stress, he found that *F₀-level* and variation, vowel duration and vowel amplitude correlated with word stress but not to the same degree. The findings have been confirmed in a broad sense in studies of other languages like Polish [9], French [10], Swedish [11], and Spanish [12, 13]. Amplitude has not turned out to correlate very well with stress level or perception but Spectral Emphasis, a measure related to vocal effort, has been shown to correlate with stress in studies of Dutch [14, 15]. It has also been shown to play a role in American English [16, 17] and Swedish [6, 7, 18].

The study of the acoustics of word stress in Italian goes back a long time. Panconcelli-Calzia [19] suggested that duration, intensity and frequency jointly increase under stress, while Gemelli [20] proposed a strict hierarchy: duration > frequency > intensity. The first reliable studies, performed after the introduction of the *Sonograph* and intensity and frequency meters proposed the hierarchy duration > intensity > frequency [21], or a duration/frequency trade-off, with these cues operating in combination or compensating each other [22]. The precedence of duration over intensity was confirmed in [23]. Duration has been proposed as the only reliable cue in production in [24], while Bertinetto [25] found the hierarchy duration > intensity > frequency in perception. All subsequent studies have, with minor differences, confirmed, the relevance of duration as the most reliable acoustic stress cue in Italian. In a study of regional variation [26], duration and intensity were found to be the most salient factors. Studies of formant structure have found stressed vowels to be more peripheral [27-29]. A series of works have analysed the articulatory counterpart of stress production [27, 30-32] and found that stressed vowels show larger jaw and labial aperture.

As in our previous studies we will approach the acoustics of word stress in Italian by analysing the following parameters: *F₀-level*, *F₀-variation*, *Duration*, and *Spectral Emphasis*.

2. Method

To minimise the influence of variation at the segmental level, we adopted a method that produced identical speech material in all speaking styles. Each speaker was first recorded in a semi-spontaneous interview situation. They were free to choose the topic of the conversation. The interviews lasted 15–25 minutes. The recordings were transcribed using Praat TextGrids [33] and from these transcriptions we picked out 30 phrases where speech was fluent (i.e. no pauses, no false starts etc.) and which

contained suitable target words of two or more syllables. The target words selected from the spontaneous recordings were not phrase initial, phrase final or focally accented. Two manuscripts were prepared, one containing the target words in isolation, and one containing the corresponding phrases. Each word and phrase occurred three times in the lists, and the order between items was randomised. Two to four weeks after the interview session the speakers were recorded again, now reading the word and phrase lists based on their own spontaneous speech.

2.1. Speakers

The speakers (17 female; 15 male) were recruited among students at Scuola Normale Superiore di Pisa all, except 4, speaking a variety of Tuscan Italian. They were all in the same age range (female speakers, 21–30 yrs., mean 25 yrs.; male speakers, 20–29 yrs., mean 24 yrs.).

2.2. Recordings

The recordings were made in a sound treated studio using Sennheiser HSP 4 cardioid headset microphones connected to a computer using the M-AUDIO ProFire 2626 audio interface. Recordings were originally sampled at 48 kHz/16 bit but they were downsampled to 16 kHz/16 bit for the acoustic analyses.

2.3. Parameters used in the acoustic analyses

Fundamental frequency level is here defined as the F_0 median in the vowel in order to minimize the influence of outliers. The median is measured in semitones relative to 1 Hz.

Fundamental frequency variation is defined as the Standard Deviation of F_0 in semitones.

Duration is measured in ms.

In these analyses we used a simplified version of the *Spectral Emphasis*.

$$\text{Spectral Emphasis (dB)} = \text{SPL}_{\text{full}} - \text{SPL}_0$$

SPL_{full} is the SPL of the full spectrum in a given segment and SPL_0 is the SPL of the low-pass filtered segment using a cutoff frequency of $1.5 * F_{\text{mean}}$ at 18 dB/octave (see [34]).

The use of the semitone scale for frequency means that we may expect the variation to be approximately the same for male and female speakers. The semitone scale also reduces skew. Using a log scale tends to make the distribution more normal. For this reason, we express duration as $\text{Log}_2(\text{ms})$. Log-scales are thus used for all parameters.

2.4. Fixed factors used in the statistical analyses

Sex: Male, Female

Stress: Unstressed, Secondary, Primary

Style: Spontaneous, Phrase, Word

2.5. Extracting the parameter values

The parameter values were extracted using a Praat script specifically designed for the purpose. The script extracted a large number of parameters used in preliminary tests. Here we will only consider the parameters described in 2.3.

In preparation for applying the script, all recordings were transcribed in Praat TextGrids using four tiers; Phrase, Word, Segment and Stress level. The TextGrid files together with the sound files were used to extract the above-mentioned values segment by segment. The output from the script was a table

were each line in the table contained the acoustic data segment by segment together with its phonological symbol, type (vowel/consonant), and stress level (primary, secondary, unstressed). Stress level annotation was based on a recognised pronunciation dictionary [35]. In the analyses presented here only the vowels in the target words have been considered.

2.6. Database used in the analyses

The procedure described in 2.5 gave us a database of parameter values for about 24000 vowels in total. The number of vowels per speaker group (male/female) is about 11000 and 13000 respectively. The exact numbers vary slightly depending on the analysed parameter.

3. Results

3.1. Fundamental frequency level

As we may see in Figure 1, the basic patterns of F_0 -level in the vowel as a function of stress level are very similar for male and female speakers. For this parameter we know, however, that male and female speakers will differ in overall F_0 -levels. The overall means for the female and male speakers are 91.45 semitones and 83.98 semitones (197 Hz and 128 Hz) respectively, corresponding to a mean difference of 7.47 semitones between the groups. In order to make the analyses of between-subjects effects including *Sex* more meaningful, we equalized the mean F_0 -level by subtracting 7.47 semitones from each data point in the female data. A Univariate ANOVA using the equalized F_0 values as the dependent variable and *Stress*, *Sex* and *Style* as fixed factors showed significant main effects of *Stress* [$F(2,24253)=30.2$; $p < .001$], *Sex* [$F(2,24253)=15.0$; $p < .001$], and *Style* [$F(2,24253)=325.6$; $p < .001$], as well as significant interactions between *Sex* and *Stress* [$F(2,24253)=10.4$; $p < .001$], *Sex* and *Style* [$F(2,24253)=10.2$ and between *Stress* and *Style* [$F(4,24253)=171.9$; $p < .001$]. The interactions between *Sex*, *Style* and *Stress* is not significant. The explained variance of this model is 8.3%.

Effects of stress level: Unstressed and secondary stressed vowels have almost identical F_0 -levels while primary stressed ones are significantly lower (5.5 Hz if converted to Hz). If we look at female and male speakers separately we find the same pattern but the difference is greater in the female data (6.4 Hz vs. 4.5 Hz), hence the significant interaction between sex and stress.

Effects of speaking style: F_0 -level varies significantly with style with spontaneous speech producing the lowest levels and phrase reading the highest. If we look at the female and male speakers separately we find that the range is somewhat higher for the male speakers (18 Hz vs. 13 Hz) which accounts for the interaction between style and sex.

3.2. Fundamental frequency variation

A Univariate ANOVA with F_0 standard deviation (in semitones) as dependent variable, and the same independent variables as in the model for F_0 -level shows significant main effects of *Stress* [$F(2,23954)=29.5$; $p < .001$], *Sex* [$F(1,23954)=28.3$; $p < .001$] and *Style* [$F(2,23954)=137.1$; $p < .001$], as well as an interaction between *Stress* and *Sex* that only just reached significance [$F(2,11004)=3.1$; $p = .042$]. The other interactions are not significant. The explained variance for this model is 3.3 %.

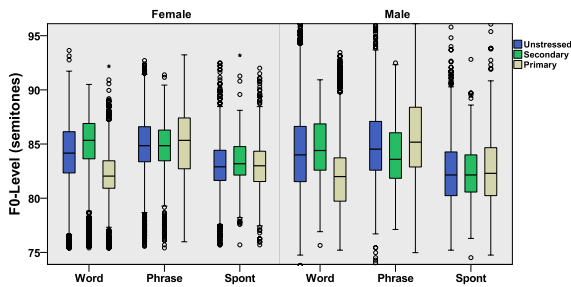


Figure 1: Fundamental frequency level as a function of speaking style and stress level.

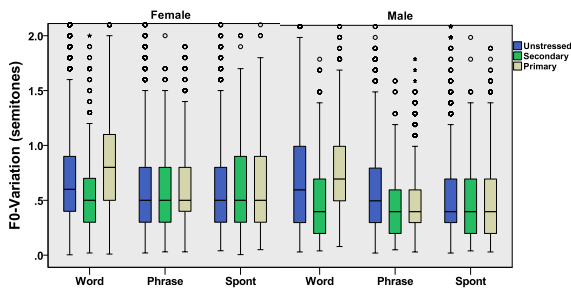


Figure 2: Fundamental frequency variation as a function of speaking style and stress level.

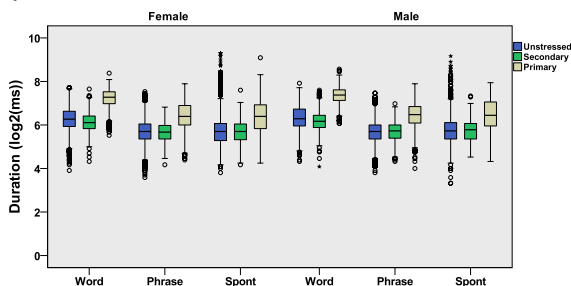


Figure 3: Vowel duration as a function of speaking style and stress level.

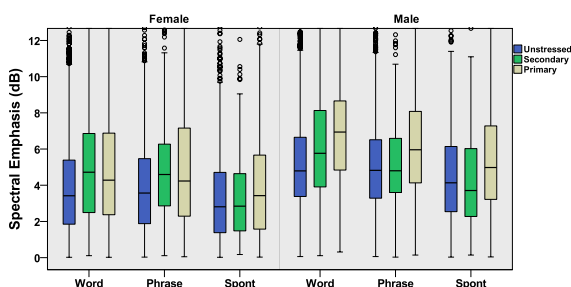


Figure 4: Spectral Emphasis as a function of speaking style and stress level.

Effects of stress level: The significant effect of *Stress* is primarily due to the fact that F_0 -variation is markedly smaller in secondary stressed vowels. Looking at female and male speakers separately, we find that the secondary stressed vowels are the least varied in both speaker groups but that the primary stressed vowels are the most varied in the female groups and the unstressed ones in the male group. Female speakers also show generally higher variation than male speakers (0.684 vs. 0.668 semitones; $p = 0.039$). This is the explanation for the significant interaction between *Stress* and *Sex*.

Effects of speaking style: Examining the effects of speaking style, we find that the F_0 -variation is significantly greater in word list reading than in spontaneous speech and phrase reading (0.77, 0.60, 0.59 semitones respectively). The latter difference is not significant. If we look at male and female speakers separately we find exactly the same pattern. The significant interaction between *Sex* and *Style* is therefore caused only by the generally somewhat greater variation in the female group. The interaction between *Style* and *Stress* is caused by a combination of the above mentioned factors.

3.3. Duration

A Univariate ANOVA with duration of the vowel (expressed as the binary logarithm of duration in ms) as dependent variable, and the same independent variables as in the other models shows significant main effects for *Stress* [$F(2,24654)=4225$; $p < .001$], *Style* [$F(2,24654)=2595$; $p < .001$] and *Sex* [$F(1,24654)=23.4$; $p = .015$]. In addition, there are significant interactions between *Stress* and *Style* [$F(2,24654) = 95.8$; $p < .001$], *Stress* and *Sex* [$F(2,24654) = 5.0$; $p = .007$] and *Sex* and *Style* [$F(2,24654) = 3.6$; $p < .028$]. The explained variance for this model is 45.8 %.

Effects of stress level: Stress level has a significant effect on vowel duration but primarily between the primary stressed vowels and the unstressed and secondary stressed ones. If we express the mean durations in milliseconds, they are 64, 61, and 116 ms for unstressed, secondary stressed and primary stressed vowels, respectively. The significant effect of *Sex* is due to longer mean durations for the male speakers (76 ms vs. 73 ms). If we look at the details, we may see that the difference is caused by the markedly longer primary stressed vowels in the male group (120 ms vs. 113 ms) which explains the significant interaction between *Stress* and *Sex*.

Effects of speaking style: *Style* also makes a significant difference. The main difference is between word list reading (92 ms) and the other two styles, phrase reading (59 ms) and spontaneous speech (61 ms), but all comparisons are statistically significant. The moderate interaction between *Sex* and *Style* is caused by the fact that whereas mean durations in spontaneous speech and phrase reading are almost identical for male and female speakers, the duration in wordlist reading is longer for male speakers (95 ms vs. 90 ms).

3.4. Spectral Emphasis

A Univariate ANOVA with spectral emphasis in the vowel (in dB) as dependent variable, and otherwise the same independent variables as in the other models shows significant main effects of *Stress* [$F(2, 24654)=311$; $p < .001$], *Style* [$F(2,24654)=164$; $p < .001$] and *Sex* [$F(1, 24654)=580$; $p < .001$]. In addition, there are significant interactions between *Sex* and *Style* [$F(2, 24654) = 17.2$; $p < .001$], *Sex* and *Stress* [$F(2, 24654) = 18.5$; $p < .001$], *Stress* and *Style* [$F(2, 24654) = 15.8$; $p < .001$] and *Sex*, *Style*

and *Stress* [$F(2, 24654) = 3.7; p < .01$]. Explained variance is 10.2 %.

Effects of stress level: Stress level has a significant effect on *Spectral Emphasis*. The mean levels for unstressed, secondary stressed and primary stressed vowels are 4.3 dB, 5.1 dB and 5.5 dB and all differences are statistically significant ($p < 0.001$). If male and female speakers are tested separately, the secondary vs. primary difference is not significant for the female speakers. Male speakers have on average 1.3 dB higher *Spectral Emphasis*. The increment in spectral emphasis from unstressed to primary stressed is also somewhat larger for male speakers (1.5 dB vs. 1.0 dB). This explains the interaction between *Stress* and *Sex*.

Effects of speaking style: Style has a corresponding effect on *Spectral Emphasis* increasing from 4.1 dB to 4.9 dB in three significantly different steps. If male and female speakers are analysed separately, the same pattern is found except that there is no difference between phrase and word list reading for female speakers. The increase from spontaneous to word list is also somewhat less for the female speakers (0.7 dB vs. 1.0 dB). This explains the interaction between *Style* and *Sex*. For male speakers the three steps are significantly different for stress as well as style. This explains the three-way interaction *Sex*, *Style* and *Stress*.

4. Discussion

4.1. Fundamental frequency level

Fundamental frequency level has been identified as an acoustic correlate of stress in Italian as pointed out in the introduction. The results in our study agree with these earlier findings although the effect of stress level on F_0 -level is moderate with an explained variance of 8.3 %. We also found, somewhat surprisingly, that the primary stressed vowels had generally lower F_0 -level. This may be due to the fact that words that carry the last sentence accent (i.e., the last accent in a sentence) are produced at a significantly lower F_0 -level in declarative sentences. The dependency of F_0 on intonation considerably weakens the contribution of this parameter. We found spontaneous speech to produce the lowest levels and phrase reading the highest.

4.2. Fundamental frequency variation

Our results show a minimal effect of stress level on F_0 -variation and the effect is primarily caused by less variation in the secondary stressed vowels. This is the case in both speaker groups. The results confirm the dubious status of secondary stress in Italian, as proposed by Bertinetto [25] where a difference is made between “rhythmical” stress and “secondary” stress proper. The latter only occurs in compounds and has a true phonological status; the former only occurs on polysyllables in hyperarticulated speech and may shift from one syllable to another depending on the context. Female speakers show generally higher variation than male speakers. F_0 -variation is also, as one might expect, significantly greater in word list reading than in the other two speaking styles.

4.3. Duration

Duration is the factor that is by far the most affected by *Stress*. Explained variance is 45.8 %. The effect is primarily between primary stressed vowels and the unstressed and secondary stressed ones although the differences between the three levels

are all significant both for all speakers pooled and for male and female speakers analysed separately. Male speakers have significantly longer mean durations, but again the difference is mainly due to longer primary stressed vowels. *Style* also affects duration. Word list reading produces the longest vowels.

4.4. Spectral Emphasis

Spectral Emphasis also turned out to be a reliable correlate of word stress. With an explained variance of 10.2 % it comes second only to *Duration*. For all data pooled, *Spectral Emphasis* increases gradually from unstressed to primary stressed and all differences are significant. Male speakers produce 1.3 dB higher *Spectral Emphasis* on average. The increment from unstressed to primary stressed is also greater for male speakers. *Spectral Emphasis* in Italian has not been studied in any previous study. There is a small but significant correlation between *Spectral Emphasis* and *Duration*. *Spectral Emphasis* is a vocal effort related measure and it makes sense to assume that applying more effort requires more time. Our present data do not, however, make it possible to test this hypothesis.

5. Conclusions

Studies of Italian have often ranked the acoustic parameters: *Duration*, *Intensity*, *Frequency*. If we go by the degree of explained variance our ranking is basically the same – *Duration* (45.8%), *Spectral Emphasis* (10.2%), and F_0 -level (8.3%). The dominant role of *Duration* found in previous studies also receives strong confirmation in our results.

For F_0 -variation, *Duration* and *Spectral Emphasis*, the effect of *Style* is most marked in word list reading. This may at least partly be due to the fact that in this speaking style phrase prosody inevitably interacts with word prosody to a greater extent than in the other speaking styles. We have not found a suitable way of handling this possible asymmetry in the present data.

The present study shows Italian to be yet another language where *Spectral Emphasis* plays a significant role. This has not, as far as we are aware, been observed before. Intensity, which is related to Spectral Emphasis, has been studied, however, and found to correlate with stress. In our previous studies of other languages, we have also found male speakers to produce greater *Spectral Emphasis* e.g. [2, 4, 6]. The difference varies between languages but is on the same order of magnitude 1–3 dB.

An observation we made in our analysis of English, was that the male and female speakers produced the stress contrast basically the same way. The same observation may be made in the Italian data analysed here. This may sound contradictory given that in all the analyses above *Sex* was found to be a significant factor. We may resolve this apparent contradiction by looking at the results concerning *Spectral Emphasis*. Both speaker groups signal stress variation the same way – by varying *Spectral Emphasis* as a function of stress level – but the range of variation is somewhat smaller in the female group. Similar observations may be made for the other parameters

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7. References

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