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Stress in Spoken and Whistled Greek

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Abstract

This paper presents experimental results testing vowels of a register of whistled Greek called **Sfyria**. We used a frame sentence and minimal pairs. Each participant performed the experiment in whistled Greek, then again in spoken Greek. The results suggest that all five vowel qualities of Greek remain distinct in the whistled register (/i/ /e/ /o/ through F0 alone; /a/ /u/ through intensity). While acoustic differences were found between stressed and unstressed versions of all spoken vowel qualities (namely intensity), whistled correlates of a stress distinction were not found for /i/. This might be a ceiling effect from general high intensity of front vowels in the whistled register, and we tentatively suggest that stressed /i/ in Sfyria is not produced differently from its unstressed counterpart.

Index Terms: phonology, language surrogate, whistling, vowels, experimental phonetics

1. Introduction

Many communities around the world can converse through whistling [1][2]. This method of communication is a type of surrogate language [3], where spoken utterances are predictably converted into sequences of distinct and interpretable whistles. This paper examines a whistled variety of Greek named **Sfyria** (1.1) found in one rural village [4][5] to systematically examine how a whistled surrogate language encodes stress.

1.1. Sfyria

Sfyria is a whistled surrogate language based on Greek. It was traditionally found in the small village of Antias, on the southern end of Euboea in Greece [5]. Sfyria seems to have always been restricted to this single village which has a current population under 30 residents. The population of Greek whistlers has likely never been large, but Sfyria seems to have been robustly used by the community into the 1980s [4]. The number of proficient Greek whistlers seems to number well below ten today – cautiously estimated at 5.

1.1.1. Prior Research

The existence of whistled Greek seems to be a relatively recent discovery in 1980 [1], and Sfyria was noticeably absent from major work on whistled languages for a long time [2][6]. The first linguistic description of Sfyria seems to have been a short 1989 description [7], followed by a 1994 phonetics study by the same authors [4]. Some subsequent work has built on this to create a general picture of the sociolinguistic situation of Sfyria [5] and a phonological sketch of the register [1].

1.2. Phonology of whistled languages

A longstanding literature establishes a two-way typology between *tone-based* and *articulation-based* whistled languages [2][1].

1.2.1. Vowels

In short, languages with lexical tone like Mazatec [8], Akan-Twi [9], and Hmong [10] encode tone transparently into the pitch of a whistled utterance. Whistled surrogates that are derived from languages without lexical tone pattern differently, and typically encode aspects of vowel quality into whistled pitch [2][1]. Generally, this category of whistled surrogate encodes high-front vowels /i/ as high-pitched, and low-back vowels /a o/ as low-pitched. This has been analyzed as an effect derived from converting the second formant F2 of a spoken utterance into the fundamental frequency of the whistled pitch [10][11]. Examples of this type of whistled language are whistled Spanish in the Canary Islands (Silbo Gomero), whistled Turkish, and whistled Occitan [2], as well as whistled Greek [1].

An initial analysis of whistled Greek vowels [4] attempted to plot *formants* (presumably harmonics) of whistled vowels as is typically done for spoken vowels, and found a three-way contrast between /i/, /e u/ and /a o/. Later authors replicated these categories [1] using pitch of the whistled signal instead of measuring formants, as whistled formants are not controllable in the way spoken formants can be independently modulated ([1], p. 108). That is to say, papers employing two separate methodologies have pointed to the same three-way contrast in whistled Greek vowels.

1.2.2. Consonant Manner

Consonant manner is crosslinguistically encoded in whistled languages through modulation of intervocalic pauses [10][1]. Prototypically, a liquid /j w l r/ will have very short whistled intervocalic pause (if any) while obstruents /p t k/ will be encoded as long pauses. This pattern seems robust across whistled languages, and generally holds for whistled Greek [1].

1.2.3. Consonant Place

Encoding consonant place features in whistled languages is a point of typological variation [2][10][1]. Tone-based whistled languages typically do not represent consonant place [9][8][10]. Whistled languages derived from languages lacking lexical tone systematically encode place through pitch movements at the edges of vowels [2][10][1]. Whistled Greek patterns with languages lacking lexical tone, with dental consonants like /n t/ pushing adjacent vowel edges upwards, and labials like /m v/ pushing adjacent vowel edges downwards [1].

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1.2.4. Stress

Spanish and Turkish, which are stress-based languages, seem to encode stress in their whistled registers through pitch and intensity [1]. On the other hand, Siberian Yupik, a stress language, is suggested to encode stress through pitch and vowel duration in its whistled register [1]. For whistled Greek, an early study found that stressed vowels were systematically whistled 50-250 Hz higher than unstressed counterparts at their midpoints, but took no measures of duration or intensity [4]. Later work corroborates this account of a small increase in pitch on stressed vowels, and mentions that amplitude also generally increases in stressed vowels of whistled Greek [1]. However, detailed analyses of stress in spoken Greek highlight three core correlates of stress in vowels: duration, amplitude, and, to a smaller degree, pitch [12].

1.3. Research Question

This asymmetry in the literature on whistled Greek and the phonology of stress in spoken Greek brings us to our research question:

What are the acoustic correlates of stress in whistled Greek?

Prior work on whistled Greek has tested only one of the three attested correlates for stress in spoken Greek, and mentioned another in passing [1]. This paper tests all three correlates of Greek stress (duration, intensity, pitch) in the whistled surrogate through controlled phonetic experiments, and compares the results with those of spoken Greek by the same participants. Built into this design is an examination of vowel quality in whistled Greek. Prior work [4][1] claims mergers in whistled Greek for /e u/ and /a o/, and this experiment will test those categorizations in addition to testing the correlates of stress in whistled vowels.

1.4. Methodology

This paper employs a 90-sentence experiment to test these questions through minimal pairs for stress. Previous work [1][9] has stressed an experimental parameter around fatigue, that participants cannot typically manage more than 100 whistled sentences in one session. The experiment used a frame sentence, adapted from previous work in Greek phonetics [12]:

Ipe [word] kathara.
She said [word] clearly.

Three repetitions per token reduce the number of tokens to 30. The tokens fit a CVCV template with stress alternating between the first or second syllable, and with the medial obstruent consonant specified for coronal place. Non-word tokens were not used (c.f. [10]).

The sentences with the target tokens were put on 90 Google Slides and then the order was randomized with the extension *Slide Randomizer*. Participants were shown one slide at a time and instructed to whistle the sentence written on the screen. After completing the set of whistled sentences, the experiment was rerun in the spoken modality, yielding 180 sentences per participant. Three adult male L1-Greek whistlers from Antias participated in this study, representing a significant portion of Greek whistlers alive today. Recordings were taken outdoors for two reasons: the whistles are deafening indoors for all involved parties, and echos in concrete rooms seriously degrade recording quality. However, this means that the recordings are imperfect due to noise from wind and cicadas. Two participants were recorded with a Zoom H4N Pro in Karystos and one on the island of Syros. All three whistlers employed a method of whistling without the use of fingers, and that was not bilabial; instead they created a loud, high-pitched whistle made between the tongue and the teeth.

1.4.1. Data Processing

Annotated textgrids were segmented in Praat [13] for all four CVCV phones of target words. Participants often paused for significant portions of time between the first word and the token word, leading to the exclusion of target words' initial consonants from the analysis. A Praat script [14] was run to take ten equidistant measurements of duration (ms), amplitude (dB), pitch (Hz), and formants (Hz) for each segment. Measurements were speaker- and modality-normalized. Due to consonant place effects on vowel edges (section 1.2.3), only the middle section (third quintile) of the vowels was used in the analysis.

2. Findings

Our findings are as follows:

- All five whistled vowels have distinct pitch/intensity from each other in unstressed position, including /a/ versus /o/ and /e/ versus /u/ (contra [4][1]).
- The whistled front vowel /i/ does not seem to differ acoustically in stressed and unstressed contexts.
- Whistled vowels /a/ and /o/ show significantly higher pitch, duration, and intensity when stressed. The whistled vowel /u/ shows significantly higher duration and intensity when stressed. The whistled vowel /e/ is significantly longer when stressed.

2.1. Five vowel qualities in spoken and whistled Greek

Unlike prior analyses which posited that Sfyria does not distinguish /e/ versus /u/ or /a/ versus /o/ [1][4], this experimental data shows that Sfyria distinguishes all five vowels present in spoken Greek. Previous literature on whistled languages [2][10][1] have used F0 as the primary correlate in establishing differences in vowel quality. A series of linear mixed effects models were run in rStudio [15] with the lmer package [16] testing normalized F0, normalized duration, and normalized intensity with vowel quality and stress as fixed variables, and participant, word, and iteration as random effects. After 3 whistled tokens as duration outlier (z-score greater than 3), the total number of tokens was 1075. Regressions were run separately for the spoken and the whistled data (figs. 8, 9, 10; spoken regressions omitted for space).

Only utilizing F0 measurements would result in positing fewer distinguishable whistled vowel classes in Sfyria than in spoken Greek: /i/ /e/ /a o u/ in stressed positions (fig.1), and /i/ /e/ /a o/ /u/ in unstressed positions. However, once duration and intensity are accounted for, most vowels become distinct. For example, /a/ is systematically louder than /u/ in both stressed and unstressed positions (fig.6). This fact, in combination with pitch distinctions, makes a recoverable five-way distinction in unstressed vowels of whistled Greek. An interaction matrix simultaneously accounting for significant differences in pitch, duration, and intensity reveals that only two pairs of vowels are not distinct in this data:

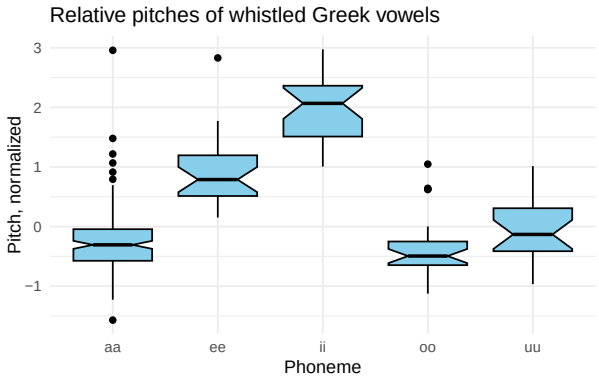

Figure 1: *Three vowels (/a/ /o/ and /u/) significantly overlap in pitch for stressed whistled vowels.*

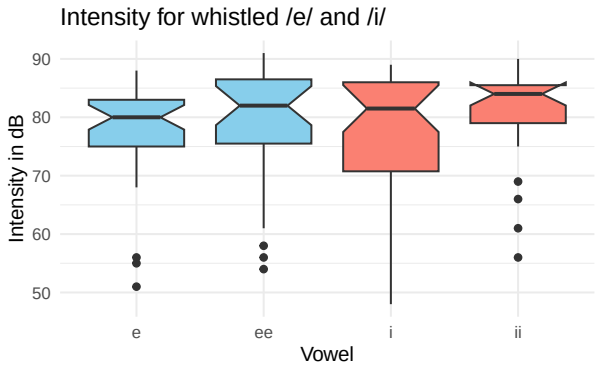

Figure 2: *Stressed and unstressed front vowels are not distinct in **loudness** for whistled Greek. Doubled vowels indicate stress.*

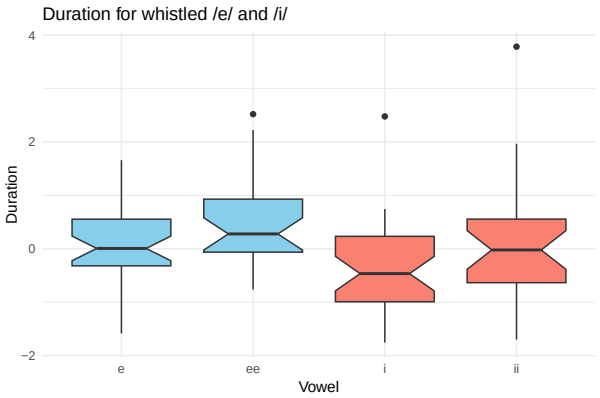

Figure 3: *Stressed and unstressed front vowels would not seem distinct in **duration** for whistled Greek, though the linear mixed-effects model suggests an effect on /e/ but not on /i/. Doubled vowels indicate stress.*

- stressed /a/ is not distinct from stressed /o/ (however, unstressed /a/ is significantly higher-pitched in whistling than unstressed /o/)
- the stressed and unstressed whistled variants of /i/ are not distinguished by any acoustic measurement (however, our data shows spoken Greek /i/ is louder when stressed)

This means that 43/45 vowel pairs in whistled Greek are significantly distinguishable on some acoustic axis. Of these, whistled pitch can play a distinctive role in 38 vowel pairs, whistled duration in 27 pairs, and whistled intensity in 26 pairs. For the spoken data, out of 40/45 distinct pairs, pitch alone is significantly different for 30 vowel pairs, duration 28 pairs, and intensity 33 pairs. By this metric, pitch generally seems to play a greater role in distinguishing vowel quality and stress in whistled Greek, while intensity plays a larger role in spoken Greek.

2.2. Stress correlates in spoken Greek

The results for spoken Greek in this experiment match prior descriptions of Greek stress [12]. The linear mixed-model regressions establish that all spoken vowel qualities are significantly louder when in stressed position. Duration additionally appears significant as an effect on stressed variants of /a/ while pitch distinguishes stress on /u/; stress in /e/ and /o/ is distinguished by all three measures (pitch, duration, intensity). This means that intensity (amplitude) is the most reliable correlate of stress in spoken Greek and is a reliable indicator for all vowel qualities, followed by duration and pitch which are distinct in a subset of vowel qualities each. These findings corroborate prior descriptions of spoken Greek, where intensity has been argued to be the most robust stress correlate, followed by duration and pitch [12].

2.3. Stress and vowels in Sfyria

Conversely, we find that none of the three established correlates of Greek stress [12] reliably distinguish stress in /i/ of whistled Sfyria. The statistical analysis confirms that the stressed and unstressed counterparts of /e/ and /i/ do not significantly differ in loudness (fig.2) or pitch (fig.4), but /e/ does seem to be statistically associated with longer duration in stressed position (fig.3). All three acoustic correlates of stress are significantly different for stressed and unstressed versions of /a/ and /o/, with stressed versions of these vowels being significantly louder (fig.6), longer (fig.7), and higher-pitched (fig.5) than unstressed counterparts. Stressed /u/ is significantly longer (fig.7) and higher-pitched (fig.5) than its unstressed counterpart, but not significantly louder (fig.6).

3. Discussion

The results for the spoken portion of this experiment corroborate prior accounts of Greek stress [12], which posit that intensity is the most reliable correlate for stress, followed by duration (all except /i/), and then with pitch as the least reliable correlate (only /a/ and /o/). Unlike prior analyses [4][1], we find reliable pitch (F0) distinctions between four classes of unstressed Greek vowels /i/ /e/ /o/ and /a u/. In addition, unstressed /a/ is systematically louder than unstressed /u/ in Sfyria, yielding an acoustic correlate that maintains a distinction between them. This means that all five unstressed vowel qualities are, in principle, distinguishable by a listener of whistled Greek. This data demonstrates that /e/ is distinct from /u/ in all positions (contra prior literature), but that stressed /a/ is not acoustically different from stressed /o/ along the measures taken in this analysis, even though the unstressed counterparts are mutually distinct. Thus, prior analyses were correct in positing overlap between /a/ and /o/, though it seems to only be partial overlap. Stressed /a/ and /o/ in Sfyria are reliably distinct from their unstressed counterparts in all three stress metrics; stressed /u/ is signif-

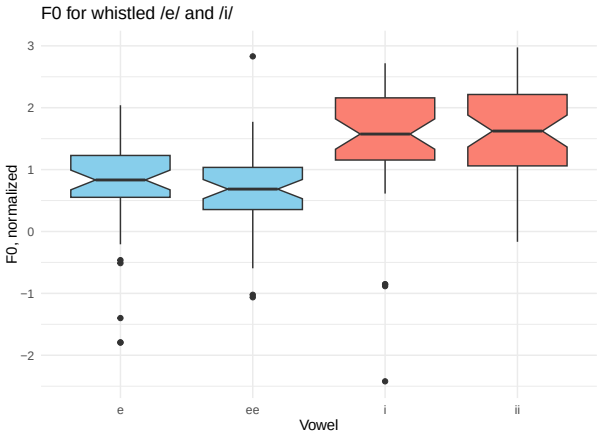

Figure 4: *Stressed and unstressed front vowels are not distinct in **pitch** for whistled Greek. Doubled vowels indicate stress.*

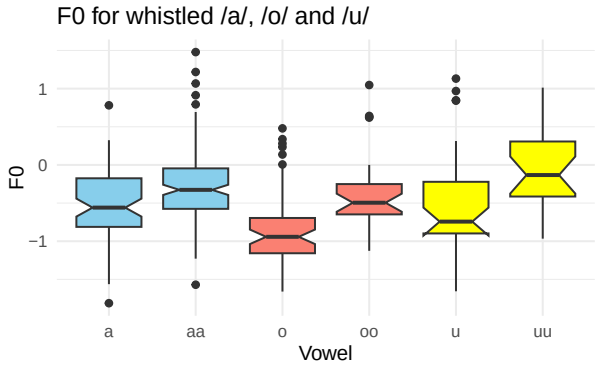

Figure 5: *Stressed back vowels significantly higher in **pitch** compared with their unstressed counterparts in whistled Greek. Doubled vowels indicate stress.*

icantly longer and higher-pitched, but not louder. While this asymmetry could be a dampening effect on stressed /u/ as a result of a load-bearing intensity contrast with /a/, another possibility is that articulatory replication of spoken /u/ would create a narrower constriction of the lips which might acoustically impede the whistled signal. Future perceptual and articulatory work (perhaps using video) would be necessary to unpack this question. Finally, the results surprisingly lack evidence of any contrast between stressed and unstressed /i/. Ceiling effects can be ruled out for duration (fig.3), as they are significantly shorter than stressed /u/ (fig.7), for example; pitch ceilings can be ruled out as the whistlers routinely employ a range of 1000Hz above these front vowel midpoints to mark coronal consonants. Intensity might be attributable to a ceiling effect, as these front vowels are systematically the loudest sounds in Sfyria: front vowels in fig.2 all average over 80dB, while back vowels in fig.6 all average under 80dB, even when stressed. If intensity is the only measurable correlate of stress for /i/ in spoken Greek, then a ceiling effect in whistled Greek intensity could result in a loss of contrast between these two phones for Sfyria. However, an obvious adjustment would be to whistle unstressed /i/ less loudly in order to maintain the contrast, so a full explanation for the lack of distinction for stressed and unstressed /i/ is not yet clear.

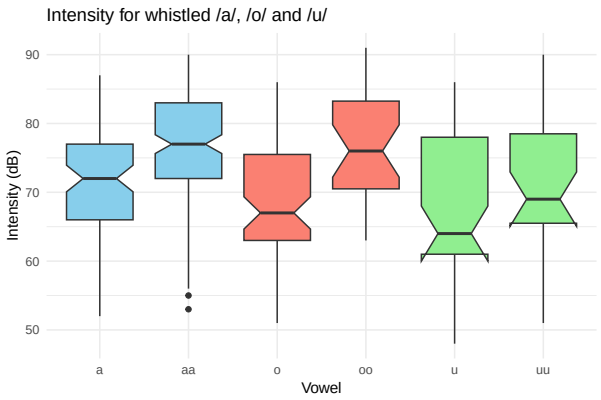

Figure 6: *Vowels /a/ and /o/ are distinct in **intensity** compared with their unstressed counterparts in whistled Greek, but /u/ is not significantly different. Doubled vowels indicate stress.*

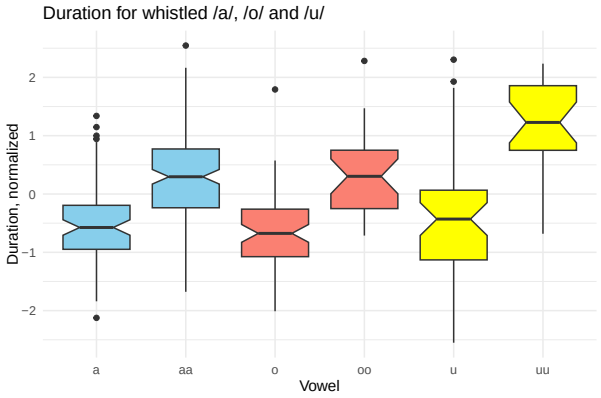

Figure 7: *Back vowels are distinct in **duration** compared with their unstressed counterparts in whistled Greek. Doubled vowels indicate stress.*

4. Conclusion

This paper presents results from an experimental study on spoken and whistled Greek (Sfyria) which tests vowel quality and stress correlates through the use of frame sentences and minimal pairs. Contra prior literature which posit a three-way distinction in whistled Greek vowels [4][1], these results show acoustic correlates maintaining a five-way contrast in unstressed vowels of whistled Greek. While three whistled vowel qualities are discernible through F0 alone (/i e o/), the phonemic distinction between /a/ and /u/ seems to be preserved through producing /a/ systematically louder than /u/. This difference in intensity between /a/ and /u/ is also present in speaking, so whistled Greek seems to be leveraging a preexisting phonological phenomenon. The results of this experiment suggest that whistled /i/ does not maintain any of the canonical stress correlates of spoken Greek. We cannot rule out that whistled versions of stressed /i/ might be discernibly distinct from their unstressed counterparts through a different acoustic correlate unaccounted for in this analysis. However, these results preliminarily suggest a lack of acoustic distinction, and offer a testable hypothesis for future perceptual work on Sfyria.

```
Random effects:
 Groups             Name        Variance Std.Dev.
 word               (Intercept) 0.03421  0.185
 participant_factor (Intercept) 0.00000  0.000
 Residual                       0.58519  0.765
Number of obs: 487, groups:  word, 30; participant_factor, 3

Fixed effects:
                              Estimate Std. Error        df t value Pr(>|t|)
(Intercept)                   -0.28976    0.11701 130.13379  -2.476  0.01456 *
stressstressed                 0.70665    0.11997 220.05350   5.890 1.43e-08 ***
vowel_qualitye                 0.46744    0.18558 155.44359   2.519  0.01279 *
vowel_qualityi                -0.15593    0.19368 159.53592  -0.805  0.42198
vowel_qualityo                -0.15932    0.15476 140.58604  -1.030  0.30501
vowel_qualityu                 0.27133    0.18282 149.28146   1.484  0.13987
iterationsecond               -0.24196    0.08491 455.47622  -2.850  0.00457 **
iterationthird                -0.24566    0.08617 450.68777  -2.851  0.00456 **
stressstressed:vowel_qualitye -0.23197    0.26019 186.10233  -0.892  0.37378
stressstressed:vowel_qualityi -0.18871    0.28516  82.12138  -0.662  0.50997
stressstressed:vowel_qualityo  0.32285    0.23468 173.07097   1.376  0.17070
stressstressed:vowel_qualityu  0.65450    0.27280 134.91221   2.399  0.01780 *
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Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
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Figure 8: *Normalized duration in a linear mixed models regression for whistled Greek vowels*

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Random effects:
 Groups             Name        Variance Std.Dev.
 word               (Intercept) 0.01570  0.1253
 participant_factor (Intercept) 0.01407  0.1186
 Residual                       0.56852  0.7540
Number of obs: 487, groups:  word, 30; participant_factor, 3

Fixed effects:
                              Estimate Std. Error        df t value Pr(>|t|)
(Intercept)                   -0.13120    0.12846  14.56803  -1.021  0.32374
stressstressed                 0.58455    0.11319 183.62700   5.164 6.24e-07 ***
vowel_qualitye                 0.98013    0.17250 105.27754   5.682 1.20e-07 ***
vowel_qualityi                 1.07647    0.18030 109.65914   5.970 2.97e-08 ***
vowel_qualityo                -0.33180    0.14360 104.86410  -2.311  0.02281 *
vowel_qualityu                -0.19755    0.17001 110.68078  -1.162  0.24772
iterationsecond               -0.10820    0.08356 453.83849  -1.295  0.19600
iterationthird                -0.26526    0.08488 447.01346  -3.125  0.00189 **
stressstressed:vowel_qualitye -0.59013    0.24332 125.33677  -2.425  0.01672 *
stressstressed:vowel_qualityi -0.58959    0.25867  56.79116  -2.279  0.02643 *
stressstressed:vowel_qualityo  0.33995    0.21928 128.00953   1.550  0.12352
stressstressed:vowel_qualityu -0.17954    0.25280 101.30558  -0.710  0.47921
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 9: *Normalized intensity in a linear mixed models regression for whistled Greek vowels*

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Random effects:
 Groups             Name        Variance Std.Dev.
 word               (Intercept) 0.01697  0.1303
 participant_factor (Intercept) 0.00000  0.0000
 Residual                       0.28406  0.5330
Number of obs: 487, groups:  word, 30; participant_factor, 3

Fixed effects:
                              Estimate Std. Error        df t value Pr(>|t|)
(Intercept)                   -0.55632    0.08170 106.94639  -6.809 5.93e-10 ***
stressstressed                 0.28471    0.08371 190.51165   3.401 0.000818 ***
vowel_qualitye                 1.46300    0.12954 130.85572  11.293  < 2e-16 ***
vowel_qualityi                 2.45009    0.13520 134.50859  18.122  < 2e-16 ***
vowel_qualityo                -0.31233    0.10804 117.01773  -2.891 0.004582 **
vowel_qualityu                 0.06602    0.12762 124.85006   0.517 0.605863
iterationsecond                0.01620    0.05916 449.85577   0.274 0.784343
iterationthird                -0.04221    0.06004 443.85933  -0.703 0.482454
stressstressed:vowel_qualitye -0.19135    0.18159 159.27315  -1.054 0.293596
stressstressed:vowel_qualityi -0.34822    0.19923  66.50087  -1.748 0.085118 .
stressstressed:vowel_qualityo  0.37159    0.16380 146.64166   2.269 0.024755 *
stressstressed:vowel_qualityu  0.18987    0.19047 111.98057   0.997 0.320980
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Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
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Figure 10: *Normalized pitch in a linear mixed models regression for whistled Greek vowels*

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