2. Methods

We compare the contrastive phonations of four unrelated languages on several acoustic measures, and for three languages on measures from electroglottographic (EGG) recordings. Summary information about the languages, their phonation contrasts, and the corpus of recordings is given in Table 1. For each language, a wordlist of words contrasting in phonation, in minimal pairs/sets whenever possible, was compiled. Although these wordlists included vowels of different heights, in the present study we selected only words with low (Gujarati, Mazatec, Hmong) or low and lower-mid (Yi) vowels. Onsets included a variety of consonants, though for most of the analyses reported here, aspirated onsets were excluded. In the three tone languages, tones were also systematically varied in the wordlists; in Mazatec, only level tones were included, and in Yi, only non-high tones were included.
łYi

2.1. Acoustic Measures

Two-channel recordings with audio plus EGG signals were first split, with the audio converted to .wav format and the EGG signal converted to .wav format using a utility in EggWorks, a free volume) found that it contributes to listeners' identification of speaker sex, while Kuang (in preparation) found that it distinguishes low and mid tones in southern Yi.

2.2. EGG Measures

We discovered that recordings made via a laptop soundcard, as was the case with our Yi recordings, are inverted. Therefore the first step in processing the EGG signals was inversion of the Yi EGG recordings, a function provided by EggWorks. Then all EGG signals were analysed automatically using EggWorks. This program takes EGG signals in either their original PCQuirer .pmf format, or in .wav format, and calculates five measures phonation as random slopes). The results of these within-language comparisons are shown in Table 2. More details can be found in the papers reporting on individual-language analyses (Esposito, submitted; Garellek and Keating, this volume; Khan, in preparation; Kuang, in preparation).

Table 2. *Results of within-language tests of significance of phonation contrasts on each acoustic or physiological measurement. For Gujarati, the categories are modal and breathy. For Hmong and Mazatec, the categories are modal, breathy, and creaky. For Yi, the categories are tense and lax. A checkmark in a cell indicates that that measure significantly distinguished some or all of the phonations in that language in the expected direction. N/A indicates that no EGG measures are available for Mazatec.*

3.1.1. Phonation contrasts

From Table 2, it can be seen that the only acoustic measure that distinguishes phonation categories in all four languages is H1*-H2*. Mean values are shown in Figure 1. As expected, breathy and lax phonations have the highest values, while creaky and tense phonations have the lowest values, though the average differences are often fairly small. However, not every pair-wise comparison is significant. This is partly due to the fact that means over entire vowels are compared here (with the exception of Mazatec); some comparisons are significant only over specific portions of vowels. The Hmong results presented here are different from Esposito (submitted) because the current study averages the measures across the entire vowel, while Esposito looks at three timepoints within a vowel. Another factor is that some comparisons are skewed by imbalances of male and female speakers. Also, it can be seen that the values are

Figure 1. *Mean H1*-H2* for the contrasting phonations in the four languages, separately by tone in the three languages with lexical tone, but combining data from men and women. The*

changes within glottal cycles in the EGG signal are greatest for breathy phonation, and these changes are also faster. Sample signals (EGG and its derivative) are shown in Figure 4. (Note that EggWorks does not display any signals; this display is from PCQuirerX.)

Figure 2. *EGG Contact Quotient (Hybrid method, 25% threshold) for phonations in three languages, separately by tone in the two languages with lexical tone, but combining data from men and women. In Hmong, tones are grouped together into three basic levels. In Yi, tense phonation does not occur with high tone. Values come from means over entire vowels.*

Figure 3. *EGG 3.*

Figure 4. *Sample EGG signals from Hmong, breathy (top) vs. modal (middle) vs. creaky*

However, these are the languages in which the acoustic measure CPP also distinguished the phonations. The connection between PIC and CPP should be explored further.

3.1.2. Timecourse effects

Table 2 shows results for measures over entire vowels (with the exception of Mazatec), but the languages in fact differ in what portion of a vowel most clearly shows phonation contrasts. Only in Yi is the contrast clear over entire vowels. In Gujarati, contrasts are clearest in the middle of vowels, though the patterns of results are no different when only these portions of vowels are compared. In Mazatec, contrasts are clearest at the beginnings of vowels, and only those data have been presented here. In Hmong, breathiness is concentrated early in vowels, but creakiness is strongest at the ends of vowels. When the phonation types of Hmong are compared at beginnings, middles, and ends of vowels, we find that modal is distinct from creaky only at vowel ends. Modal is distinct from breathy at all three timepoints, but the distinction is found in the most measures at mid-vowel; most notably, CPP is different only there. Creaky and breathy are distinct at all timepoints.

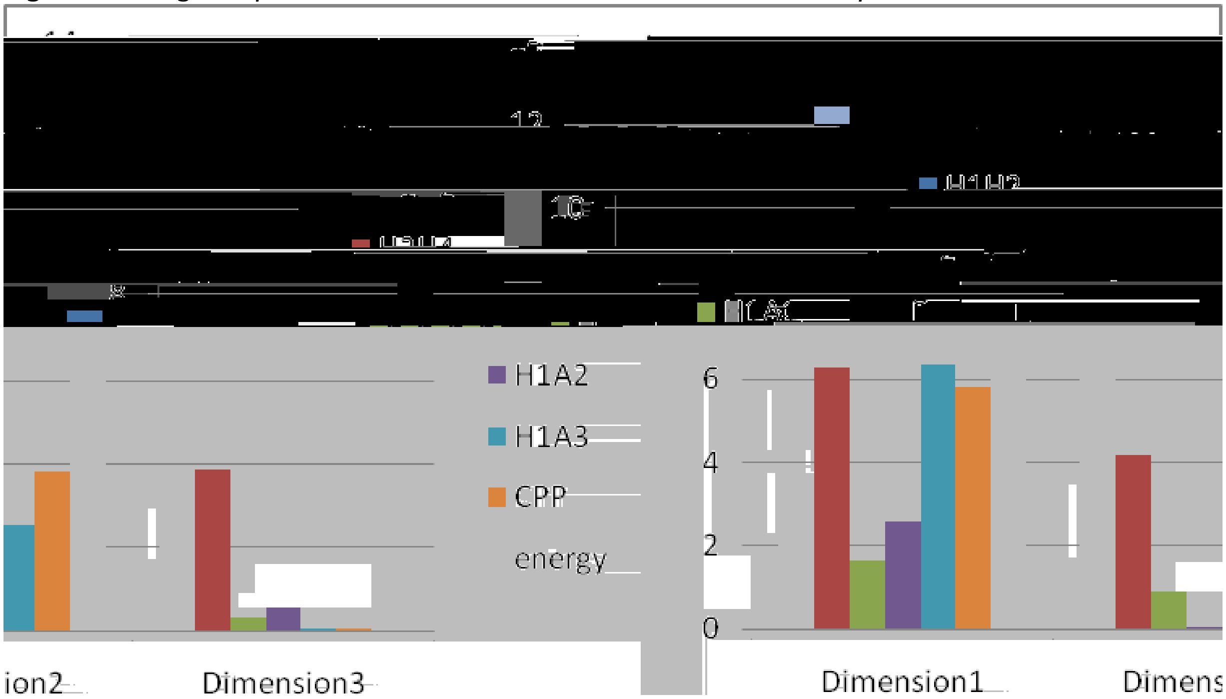
3.1.3. Gender effects

While many measures show main effects of speaker gender (that is, women have overall higher or lower values on a measure), there are no significant interactions of phonation with gender in any of the [illegible]

Mixed Effects models, one for each of the acoustic measures, with speaker and item as random effects. The result was that every category differed from every other, i.e. the most conservative extreme. The modal, breathy, and lax phonations all differed on a large set of measures. The creaky and tense phonations differed on only three measures (H1*-A1*, CPP, and energy), but they were significantly different across all the languages. That is, in this corpus, the result was the perhaps unexpected extreme, that phonation categories with the same descriptive names (e.g. Gujarati breathy, Hmong breathy, and Mazatec breathy) nonetheless significantly differ in several acoustic dimensions. This suggests that speaker and language differences (including differences between our corpora for the different languages) are larger than phonation differences. This possibility is examined in another way in the next analysis.

on(hi)-112(onP[)E(c)al1y5nifi6eo1am T*hey1e c,methri p Tc2 ag10 heyre-12(on0w n-4(at))-11()-11(e,m)-6(

Figure 6. *Weights of seven acoustic measures on each dimension of the 3-D MDS solution.*



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