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# Spectral tilt as a correlate of Papuan Malay word stress

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## Abstract

Papuan Malay, like related languages, is claimed to have regular word stress. However, acoustic evidence to support this claim is lacking. In addition, the existence of word stress in Malayo-Polynesian languages has been topic of discussion in recent work. In particular, studies have struggled to keep apart prosodic phenomena on the word level from those at the phrase level. Therefore, it remains to be investigated to what extent impressionistic claims on word stress find empirical support. This issue is investigated in the current study by means of an acoustic analysis of spectral tilt. Spectral tilt has been shown to be a consistent correlate of word stress crosslinguistically. The spectral tilt measures are taken from spontaneous Papuan Malay speech and provide preliminary evidence for word stress.

**Index Terms**: word stress, spectral tilt, prominence, Papuan Malay, prosody.

## 1. Introduction

Papuan Malay is one of the Trade Malay varieties, spoken in the Eastern-Indonesian provinces Papua and Papua Barat. Other Trade Malay varieties include Ambonese, Banda, Kupang, Larantuka and Manado and North Moluccan [1]. For most of these varieties as well as for Indonesian word stress has been claimed to occur regularly. However, the little empirical work on Trade Malay varieties has indicated that word stress [2] and phrase level prominences [3] are either absent or serve a different function compared to well-studied languages. The current study provides a brief overview of the existing stress claims for Trade Malay (section 1.1) and Indonesian (section 1.2), and the role of empirical work in this debate. Furthermore, acoustic correlates of stress are discussed in a crosslinguistic context (section 1.3). The aim of the current paper is to provide an empirical study on the existence of word stress in Papuan Malay. To this extent an acoustic analysis of spectral tilt is carried out (section 2.4).

### 1.1. Trade Malay varieties

The overall majority of the available literature on Trade Malay varieties analyses word stress as occurring regularly on the penultimate syllable and alternatively on the ultimate syllable when the penult consists of schwa ([4], [5], [6], [7], [8], [9]). As for Ambonese Malay, word stress has been initially analysed as irregular [10]. The varieties furthermore differ as to whether word stress is phonemic; i.e. whether word stress can be the sole difference between two segmentally identical words which differ in meaning (minimal pairs). Phonemic word stress has been shown for most Trade Malay varieties, except Papuan, Larantuka and Tidore (North Moluccan). For the latter languages no minimal stress pairs are reported. Schwa may occur in unstressed positions in these languages, which has been seen as the reason why phonemic stress did not develop [1]. That is, where full vowels occur in stressed positions, the insertion of schwa in unstressed counterparts would block the possibility of having minimal stress pairs.

While perceptual impressions of word stress might give interesting insights into the prosody of a language, it cannot be ruled out that the native language of the authors biased the claims. Acoustic measurements of the main correlates of stress could shed light on its realization. For most of the stress claims on Trade Malay little to no acoustic evidence exists, except for Ambonese Malay [2]. In this study, a re-evaluation of word stress claims in [10] was done by taking acoustic measurements of read speech samples (similar to the ones in [10]). No reliable acoustic evidence for word stress in the duration, F0 peak alignment and spectral tilt was found. The acoustic evidence furthermore led to a reanalysis of the Ambonese Malay vowel inventory. That is, the vowel /a/ that occurred in syllables described as unstressed in [10] was shown to be a different phoneme (a-*caduc*) on the basis of its distinct spectral characteristics in [2]. Thus, adding this vowel to the inventory made it possible to reanalyze words with alleged minimal stress differences in as being segmentally different. In this way, no evidence for the existence of word stress was left. Furthermore, the lack of segmental anchors for tonal movements in Ambonese Malay syllables was taken as evidence that pitch accents do not exist in this language. The pitch movement commonly observed at the right phrase edge was interpreted as boundary tone with a weak temporal integration [2].

As for Papuan Malay, extensive fieldwork on 44 speakers, dominantly coming from the Sarmi region in the Papua province, was carried out [4]. Observations based on 1116 words consisting of Papuan Malay roots revealed that word stress was located on the penultimate syllable in 90% of the cases [4]. In the remaining 10% stress occurred on the ultimate syllable. Many of the cases in which stress was located on the ultimate syllable, the penultimate syllable consisted of the vowel /ɛ/. However, it was not the case that /ɛ/ rejected word stress, as 7% of the words with penultimate stress contained /ɛ/ ([4], p.96). Although older and smaller descriptions of Papuan Malay exist, word stress has been undisputedly assumed to occur on the penultimate syllable regularly (i.e. [11]). Other than the authors' judgments, no acoustic evidence is provided to support these observations.

### 1.2. Indonesian

Indonesian is historically closely related to and currently still highly influential for the Trade Malay varieties. Initially, descriptions of Indonesian assumed the existence of word stress [12], which was countered or nuanced later empirical work [13]. In particular, research that took into account the


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diversity of languages in Indonesia, revealed clear differences among their prosodies. Based on a crosslinguistic survey of stress patterns, it was argued that Malay varieties spoken in Indonesia could have lost stress due to contact with other languages [14]. Therefore, it was predicted that future investigations are more likely to reveal the absence of stress, in particular in Malayo-Polynesian languages. The observed prosodic characteristics in these languages are more likely to be interpreted as prosodic phenomena at the phrase level [14].

### 1.3. Acoustic correlates

Word stress' most common acoustic correlates include duration, pitch (F0), formants (F1 and F2), intensity and spectral tilt (see [15] for an overview of 110 studies on 75 languages). Although duration appears to be the most consistent correlate of word stress across languages, not all acoustic correlates are equally reliable. For example, some of the studies on Indonesian word stress found pitch to be the most important correlate ([12], [16], [17]). While these outcomes hold for the Indonesian varieties that were studied, work on Germanic languages generally treats pitch as a correlate of phrase level prosody (i.e. [18], [19]). Moreover, many studies on word stress failed to keep word and phrase level phenomena apart [20]. In particular, words read in isolation as well as the lack of control for phrase-level accents in the experimental design have confounded the two levels. It could therefore be problematic to rely on pitch as a correlate of word stress, in particular if little is known about a language's prosody at other levels.

None of the common acoustic correlates is exclusively related to word stress. Spectral tilt appears to be the least associated with other phenomena than word stress, although a related measure (spectral emphasis) correlates with focus in Swedish [21]. Spectral tilt measures express the intensity difference between low and high frequencies in the spectrum. Stressed syllables are produced with more acoustic energy, which is mainly reflected in the higher frequencies. Therefore, the intensity roll off (tilt) is shallower (lower values) in stressed syllables than in unstressed syllables [19]. The complexity of the measure and the different ways in which it can be calculated lead to a minimal amount of studies actually investigating this correlate [15]. Spectral tilt has several advantages over other measures. Foremost, the measure is relative and therefore less sensitive to differences between syllables at a phrase level (i.e. overall intensity, speaking rate, segmental makeup etc.). Furthermore, this measure combines spectral and amplitudinal information and therefore covers more aspects of the speech signal compared to, for example, pitch or overall intensity.

### 1.4. Research question

Taken together the discussion of the literature above, it remains to be investigated to what extent there is acoustic evidence for word stress Papuan Malay. Although many stress claims have been made for Trade Malay varieties, little empirical work has been carried out. As has been shown for Ambonese Malay [2] and Indonesian [13], acoustic evidence does not need to match earlier claims. Word stress in Papuan Malay is claimed to occur regularly on the penultimate syllable [4]. In the current study, this claim is evaluated by means of an acoustic analysis of spectral tilt taken from spontaneous Papuan Malay narratives.

## 2. Methodology

### 2.1. Data collection procedure

Speech was collected in a story retelling task. In this task speakers were instructed to watch a short video clip and retell what they had seen to an interlocutor who did not see the video. The video clip has been used previously in cross-linguistic studies on narrative production (Pear Film; [22]) as it elicits spontaneous speech. Spontaneous speech is more representative of a language compared to for example, scripted laboratory speech. The clip showed a small story about a man picking pears. The actors in the video clip did not use any speech. Recordings were made at the Center for Endangered Languages Documentation (CELD) in Manokwari, West Papua [23]. Participants received instructions about the experimental procedure before the start of the task. They were verbally instructed to watch the video clip in order to retell the story displayed in the clip to an interlocutor who did not see it. The video clip was shown to the participants on a laptop computer and lasted six minutes. Thereafter, participants were introduced to their interlocutor and were instructed to retell the story from the video clip. The participants and interlocutor were seated next to each other during the retelling. The interlocutor could ask clarification questions during the participant's retelling (approx. three times per participant).

No soundproof or silent rooms were available at the recording location. Therefore, recordings were made outside, behind a building where background noise was kept to a minimum. The recordings were made using a Sony ECM-MS957 unidirectional microphone connected to a Sony HDR-SR11 portable video camera. The microphone was directed to the participant and interlocutor. The experimenter supervised the entire recording procedure. The duration of the collected recordings ranged between two and five minutes.

### 2.2. Participants

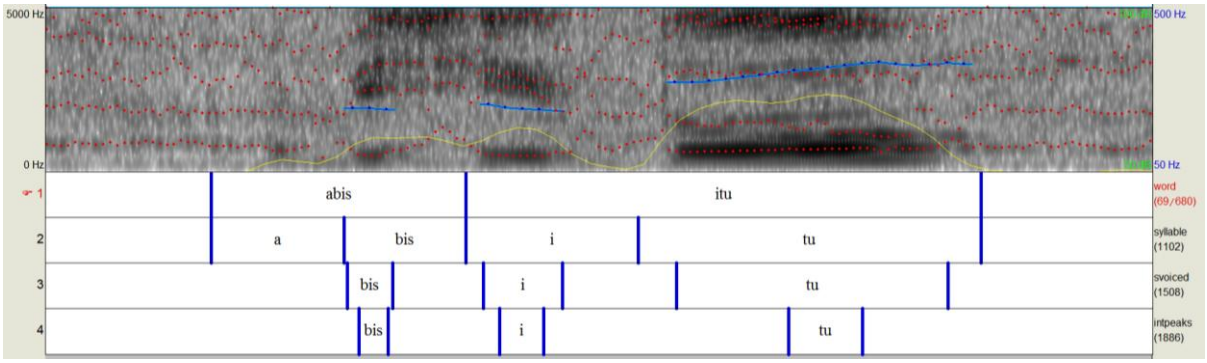
All participants were students at the University of Papua. There were 10 male and 9 female participants ($M_{age}$ = 22, age range = 20-28). All were native speakers of Papuan Malay.

### 2.3. Data processing and selection

Audio-tracks were extracted from the recordings on the portable video camera and converted to 48kHz, 16 bit, stereo wave-files. Trained native speakers of Papuan Malay transcribed the participant's speech and segmented it into intonation units [24]. Then, a group of seven trained labelers annotated all words and syllables produced by the participants for each wave file using Praat [25] on the basis of auditory and visual inspection of the waveform. Syllable boundaries were set on the basis of word lists provided in [4].

A subset of the labelled syllables was selected on the basis of the following criteria. Syllables in words that were part of an interrupted or cut off utterance were omitted. Reduplicated words (e.g. *tiba-tiba*) were omitted, whereas the syllables of single occurrences (e.g. *tiba*) were taken into account. The syllables of words produced with hesitation or that were unidentifiable due to laughter, heavy speech reduction or background noise were also omitted. Words containing double vowel sequences were also omitted, as these sequences allow for two ways of syllabification (either as diphthong VV or as V.V, see [4]) and resulted in ambiguous annotations. Syllables occurring in final or prefinal phrase position were omitted. This was done to avoid possible interference

Figure 1. Praat [25] screen capture showing an annotated example "abis itu" (*after that*) with a tier representing words (1), syllables (2), voiced subintervals (3) and intensity peak portions (4); see section 2.4 for interval criteria.




with phrase level intonation. That is, these syllables are commonly assumed to be locations for possible phrase accents in Trade Malay and Indonesian varieties (i.e. [14]). In addition, this selection avoided effects of phrase-final lengthening, which mainly concerns the final syllable and possibly the penultimate syllable ([26], [27]). As the Papuan Malay lexicon has a considerable number of loanwords, only syllables in words classified as native roots [4] were selected. Single syllable words were omitted as their acoustic characteristics cannot be compared to other syllables in the word. This comparison is required to investigate stressed and unstressed syllables in the same word.

After applying the selection criteria just described, a total of 3629 syllables were left for acoustic analysis (20% of the data). They were labelled 'stressed' (1796) or 'unstressed' (1833) following word lists in [4]. The number of unique words was 192 (187 two syllable words and 5 three syllables words). The most common stress position was the penultimate syllable, confirming distributions reported in [4].

## 2.4. Acoustic analysis

All acoustic measures were taken in Praat [25] in an automated way using scripts [28]. Spectral tilt was measured based on the method by [19], [29] and [30], where the intensity of first harmonic (H1) was compared to intensities in higher frequencies. Spectral tilt measures vary as to where the boundary between low and high frequency bands is drawn [21]. In this study, the intensity of the second (A2) and the third formant (A3) are subtracted from the intensity of H1 respectively. H1 was not corrected for spectral magnitude (unlike [19], [29] and [30]), following the method by [31]. The resulting measures are henceforth called H1-A2 and H1-A3.

All measures were taken from voiced portions of syllables where the intensity reached its peak (Figure 1). These portions were automatically extracted in two subsequent phases. First, subintervals of syllables for which Praat [25] was able to detect periodicity were taken (Fig. 1, tier 3). Syllables for which pitch could not (accurately) be detected were omitted (3.7%). Second, within the voiced subintervals, portions were taken where formant values were detected accurately. Stable formant values guarantee accurate frequency measurements and were mostly found close to where intensity levels reached their peak. Therefore, boundaries of these stable portions were calculated relative to the intensity peak. This was done by taking the time stamps at which the intensity had dropped 4% relative to the peak intensity on either side. The 4% margin was chosen after careful visual inspection of the spectrogram in order to find an optimum between stability of formant detection and interval length. That is, smaller margins resulted in intervals that were too short for representative formant measures, whereas larger margins resulted in intervals including parts of speech where formants showed much variability or where formants could not be identified accurately. Within the resulting intervals (Fig. 1, tier 4), all frequency and intensity measures were taken, using different formant maxima for male (5000 Hz) and female (5500 Hz) speakers. In addition to the "raw" measures of spectral tilt, relative measures of spectral tilt were calculated in order to further exclude possible effects from outside the word domain. That is, the relative measure ensured that the spectral tilt value was compared to the other syllable(s) in the same word. Relative spectral tilt was calculated for both H1-A2 and H1-A3 by subtracting the spectral tilt value of the syllable labelled as unstressed from the spectral tilt value of the syllable labelled as stressed. For three syllable words, the average value of the two syllables labelled as unstressed was subtracted from the value of the syllable labelled as stressed. In this way, negative relative spectral tilt values indicate that the intensity was reduced more towards higher frequencies in 'unstressed' syllables compared to 'stressed' syllables.

## 2.5. Statistical analysis

Statistical analyses were carried out using R [32] and the lme4 package [33]. Separate statistical tests were carried out for H1-A2 and H1-A3, as well as the raw and relative measures. As for raw spectral tilt as dependent variable, linear mixed model (lmm) analysis fit by maximum likelihood (using Satterthwaite approximations to degrees of freedom to calculate *p*-values) was carried out with stress (two levels: stressed, unstressed) and stress position (two levels: penultimate, ultimate) as independent variables and with subjects (speakers) and items (words) as random variables. As for relative spectral tilt, a likelihood ratio test ($\chi^2$) was carried out to compare an intercept-only model with a model in which the intercept was set to zero. This was done in order to test whether the mean relative spectral tilt values were significantly different from zero. A mean of zero would have been expected when there was no difference between the syllables labelled as stressed and unstressed respectively (section 2.4). Subjects (speakers) and items (words) were included as random variables for the statistical analysis of relative spectral tilt.

Means were calculated for the overall dataset ($N$ = 3629) and for two subsets, created according to stress position (penult: $N$ = 3431, ultimate: $N$ = 198).

Table 1. Means, *SD*s and statistics of stress effects on the two raw (*b*) and relative ($\chi^2$) spectral tilt measures in dB.

| | | H1-A2 | | | H1-A3 | | |
|---|---|---|---|---|---|---|---|
| | | raw | | relative | raw | | relative |
| | | stressed | unstressed | | stressed | unstressed | |
| (sub)set | penult | 7.30 (*11.54*) | 9.95 (*10.35*) | -2.21 (*13.91*) | 12.89 (*10.33*) | 13.92 (*9.68*) | -.85 (*11.45*) |
| | ultimate | 9.27 (*12.21*) | 11.72 (*9.29*) | -2.74 (*13.96*) | 12.58 (*10.52*) | 13.09 (*8.93*) | -1.40 (*11.90*) |
| | overall | 7.40 (*11.58*) | 10.05 (*10.3*) | -2.24 (*13.91*) | 12.87 (*10.34*) | 13.87 (*9.64*) | -.88 (*11.47*) |
| statistic | $b$ / $\chi^2$ | -2.31 | | 4.95 | -.89 | | 1.45 |
| | *SE* | .33 | | - | .30 | | - |
| | *df* | 3469 | | 1 | 3481 | | 1 |
| | *t* | -7.08 | | - | -3.02 | | - |
| | *p* | < .001 | | < .05 | < .01 | | n.s. |

## 3. Results

Mean spectral tilt values and statistics are given in Table 1. Overall, the raw spectral tilt values were lower for syllables labelled as stressed compared to syllables labelled as unstressed. This difference appeared to be significant in the lmm analyses for both H1-A2 and H1-A3. No effects of stress position nor interaction effects were found. As for the relative spectral tilt measures, the overall mean showed a negative value. This value appeared to be significantly different from zero for the H1-A2 measure and not for the H1-A3 measure.

## 4. Conclusion and discussion

The outcomes of the current study provide insights into one of the possible acoustic correlates of word stress, which was claimed to exist in Papuan Malay. All values reported show evidence for shallower spectral tilt in syllables that were claimed to be stressed compared to syllables claimed to be unstressed. These findings essentially confirm earlier reports of word stress in Papuan Malay ([4], [11]), unlike the case of Ambonese Malay ([2], [10]).

It has been shown that the intensity distribution throughout the spectrum (spectral tilt or spectral emphasis) correlates with focus in Swedish [21]. As little is known about phrase level prosody in Papuan Malay, it is possible that spectral tilt is correlate of phrase prosody in this language. While this theoretical possibility cannot be ruled out, careful analysis in the current study minimized potential influences outside the word domain. That is, phrase final syllables reported to show pitch movements in previous work [14] were excluded. In addition, the relative spectral tilt measures were approximately 1.4 dB smaller in the H1-A3 measure, compared to the H1-A2 measure (Table 1). This is likely an indication of overall lower intensity levels towards higher frequencies, resulting in smaller tilt differences that failed to reach significance.

The lack of significant spectral tilt differences due to the location of the stressed syllable (penultimate, ultimate) could falsely indicate that there was no difference in stress realization between the penultimate and ultimate syllable (type II error). The size of the datasets with either penultimate (95%) or ultimate stress (5%) differed to such an extent, that possible realization differences might not have shown in the reported statistical tests. Although this asymmetry in the data reflects stress placement distributions in [4], no conclusions can be drawn from the acoustic data on the mobility of word stress. That is, ultimate word stress in Papuan Malay cannot be confirmed nor rejected. It has to be noted, however, that relative spectral tilt differences were larger in ultimate syllables than in penultimate syllables (Table 1). This could be the result of a stress realization in a non-default location. It has been shown that acoustic differences between accented and unaccented syllables were larger when a pitch accent was shifted away from its default location (i.e. contrastive intonation in Dutch; [34],[35]). This comparison then questions the extent to which the current results are reflective of word prosody only, or also of phrase prosody. Although phrase prosody influences were kept to a minimum, pitch accents (due to intermediate phrasing or focus) could still have influenced the current results. More research on Papuan Malay phrase prosody is needed to support this explanation.

The current study is part of a more elaborate acoustic investigation of word stress in Papuan Malay. It is important to consider more acoustic correlates in order to conclude to what extent word stress is indeed present in Papuan Malay. In addition, future perception studies could shed further light on the role of stress for word identification. If Papuan Malay has a form of word stress, it is unlikely to be phonemic [4], which could reduce its perceptual relevance compared to languages that do have phonemic word stress (i.e. [19]).

This study has shown the importance of evaluating impressionistic claims empirically; not to prove those as correct or incorrect, but to account for the possibility of subjectivity as well as language diversity. The outcome, as shown here, suggests that generalizations on the prosody of Malayo-Polynesian languages deserve to be interpreted with caution. In particular, within the branch of Trade Malay varieties languages could differ substantially (cf. [2]).

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