Prosody of Tone Sandhi in Vietnamese Reduplications

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Abstract

In this paper we take advantage of the segmental control afforded by full and partial Vietnamese reduplications on a constant carrier phrase to obtain acoustic evidence of assymetrical prominence relations (van der Hulst 2005), in support of a hypothesis that Vietnamese reduplications are phonetically right headed and that tone sandhi is a reduction phenomenon occurring on prosodically weak positions (Shih, 2005). Acoustic parameters of syllable duration (onset, nucleus and coda), F0 range, F0 contour, vowel intensity, spectral tilt and vowel formant structure are analyzed to determine: (1) which syllable of the two (base or reduplicant) is more prominent and (2) how the tone sandhi forms differ from their full reduplicated counterparts. Comparisons of full and partial reduplicant syllables in tone sandhi forms provide additional support for this analysis.

Key words: tone sandhi, prosody, stress, reduplication, Vietnamese, acoustic analysis

We would like to thank our subjects for offering their voices for the analysis, Dr. Nguyen Hong Nguyen for statistical advice and the anonymous reviewers for their valuable comments and suggestions. The Postdoctoral research fellowship granted to the first author by the University of Queensland is acknowledged.

1. Introduction

Vietnamese is a contour tone language, which is strongly syllabic in its phonological organization and morphology. However, reduplication is also a highly productive word formation process, with disyllabic word forms predominating, raising the question of whether there exists a distinctive level of phonological structure identifiable with the phonological word. In traditional accounts of Vietnamese phonology, the existence of stress at the word level has been a matter of unresolved controversy. It is generally claimed that Vietnamese has no system of culminative word stress (Thompson 1987; Nguyen Dang Liem 1970, among others); and the examination of "stress" has been largely in the sense of accentual prominence at the phrasal level (Hoang Tue & Hoang Minh, 1975; Gsell 1980; Jones & Huynh1960; Thompson 1987; Nguyen Dang Liem 1970).

In this paper, acoustic parameters including syllable duration (onset, nucleus and coda), F0 range, F0 contour, vowel intensity, spectral tilt and vowel formant structure are analyzed to determine: (1) which syllable of the two (base or reduplicant) is more prominent and (2) how the tone sandhi forms differ from their full reduplicated counterparts, in forms such as:

1a. *Pha trà cho* ***đậm đậm*** fully reduplicated

1b. *Pha trà cho* ***đầm đậm*** partially reduplicated (tone sandhi)

| |
reduplicant base

1.1. Tone and tone sandhi in Vietnamese

Vietnamese has 6 tones divided into two groups on the basis of register; high tones: level (*ngang*: high level), rising (*sắc*: high rising), broken fall-rise (*ngã*: fall glottalised and abrupt rise) and low tones: falling (*huyền*: low gradual falling), dropping (*nặng*: low dropping), and curve (*hỏi*: gradual fall and rise) (Doan 1977; Vuong and Hoang 1994; among others). The number of tones, as well as their realisation, varies according to dialect: Northern dialect has 6 tones while Central and Southern dialects have 1 tone less due to the historical merging of the curve (hỏi) and broken (ngã) tones. Tone height, tone direction and voice quality (phonation type: breathiness, creakiness) are important distinctive features of tones in Vietnamese, while other phonetic features such as duration and intensity have been mentioned but not considered as distinctive (Do, Tran & Boulakia 1998; Pham 2003, among others).

It is generally claimed that there is no tonal neutralisation due to "sandhi" in Vietnamese, a phenomenon that occurs in other tone languages like Chinese and Thai. Tonal variation due to the influence of neighbouring tones can, however, be observed and is described as a type of tonal assimilation or coarticulation. Tonal coarticulation in Vietnamese introduces considerable variation in both slope and height of fundamental frequency and its perseverative or progressive effects are greater than its anticipatory or regressive effects, (Han & Kim 1974; Seitz 1986). Do The Dung (1986) underlines the importance of progressive assimilation according to the height reached by the tone which precedes it. After a rising tone such as Rising or Curve, any immediately following tone will start one or two quarter tones higher than its normal target value, and after Dropping and Falling tones it will start one or two quarter tones lower. Apart from this, a relative difference in register and contour is generally preserved. However, in spite of the claimed absence of tone sandhi in Vietnamese by most linguists, it cannot be denied that tone sandhi occurs in a subset of Vietnamese reduplication words (Thompson 1987; Tran Huong Mai 1969).

Vietnamese has no system of culminative word stress; nevertheless, it is widely accepted that there is stress in the sense of accentual prominence at the phrasal level (Nguyen Dang Liem 1970; Thompson 1987). It is shown by Do The Dung (1986) that duration and intensity are important parameters for describing stress in Vietnamese. Chaudhary (1983) remarks that intensity is one stable acoustic correlate of Vietnamese stress. Some other authors, such as Hoang Tue and Hoang Minh (1975), or Gsell (1980) consider that full tonal realization of accented syllables is one of the positive marks of accent. Jones and Huynh (1960) remark that normally stresses in a Vietnamese utterance are conditioned by junctures. Generally, these studies examined stress in the sense of phrasal- level accentual prominence but do not address the question of stress at the word level, which is the aim of this study.

1.2. Reduplication

Reduplication is a productive process in Vietnamese. Almost every adjective and adverb has its reduplication forms. There are 5000 entries in the recently published dictionary of Vietnamese reduplicants (Vien Ngon Ngu, 1995), which, compared to a regular dictionary of 50,000 entries, is a significant amount (approximately about 10%) (Aves 1999).

Phonologically, there are four main types of reduplication: full reduplications: copying of full segmental composition and tone, and partial reduplications with three main sub categories: (1) same rhyme and tone but with alternate onset consonant, (2) same segmental composition but with alternate tones, and (3) same onset consonant but alternate tones and rhymes. There is a constraint on tone harmony in reduplication forms that the tone of the copying (reduplicant) syllable must be in the same register as that of the base form: a phonological patterning of high tones: level (*ngang*: high level), rising (*sắc*: high rising), curve (*hỏi*: gradual fall-rise) and that of three low tones: falling(*huyền*: gradual falling), dropping(*nặng:* low dropping), and broken(*ngã*: fall glottalised and abrupt rise). In addition, many full reduplications undergo tone sandhi, which is also constrained by the within-register tone harmony. For example, the full reduplication *đỏ đỏ* (red red = rather red) with the same curve (fall-rise) tone has an alternative form with a tone sandhi: *đo đỏ* with a combination of two high-register tones: a level and a curve tones. In reduplications with syllables ending in stop consonants, when the first syllable of the word undergoes tone sandhi, its final stop consonant is replaced by its correspondent homorganic nasals (e.g., p-m: *đẹp đẹp* vs. *đèm đẹp*, t-n: *tốt tốt* vs.*tôn tốt*). A summary of patterns of reduplication on a phonological basis and tone sandhi rules is presented in table 1 below.

Table 1 A summary of patterns of reduplication on a phonological basis

Full reduplication	Partial reduplications		
	Tone sandhi	Onset change, same rime	Same onset, rime change
sáng sáng (rather bright)	sang sáng (rather bright)	sáng láng (bright and clear)	sáng suốt (clear-minded) sáng sủa (bright and clear)
sột sột (rustle: paper or cloth)	sồn sột (rustle: paper or cloth)	lột sột (rustle: paper or cloth)	sột sạt, sột soạt (rustle: paper or cloth)

It is widely agreed among Vietnamese linguists that in full reduplication and tone sandhi bisyllabic words, the right-edged component is the base or the stem, thus carries the semantic weight and is therefore more prominent (Ho Le 2002, among others). There are reduplications with a reverse direction of tone sandhi (e.g., *héo héo* (SacSac:RisingRising tones: tree leaves becoming dry) –> *héo* ***hẹo*** (SacNang: RisingDropping tones: becoming very dry) as opposed to ***heo*** *héo* (NgangSac: LevelRising tones: rather dry)). This study investigates only the right-to-left sandhi forms of the full reduplications. Apart from a few reduplications that have only one form (e.g., *nòng nọc, lông lốc* which have no full form counterparts *nọc nọc* or *lốc lốc*), most full reduplications and their right-to-left sandhi forms are in free variation and both indicate the same meaning (Thompson 1987; Nguyen Tai Can 1981).

1.3.Hypotheses

In order to test the hypothesis that both full and sandhi disyllabic reduplications are prosodically right-headed, a list of disyllabic reduplications of adjectives and adverbs was constructed, consisting of disyllabic words with the same segmental composition and tones (e.g., *sáng sáng*: bright bright) and their tone sandhi counterparts (i.e those with the same segmental composition but with alternate tones: e.g., *sang sáng*: fairly/rather bright). In addition, in order to provide a counterargument for the word-boundary effect(if the 2nd syllable is found to have longer duration than the 1st), the base syllable of the reduplication (underlined above) is embedded in the initial position of two other control/baseline words of different segmental makeup: (1) in a word with the same tone on both syllables (e.g., *sáng chói*: dazzlingly bright with the same rising tone) and (2) in a word with two different tones (e.g., *sáng choang*: very bright). The design of the linguistic material, as shown in the following table, aims to test two hypotheses:

Table 2 Design of linguistic material. R for reduplicated syllable, B for base syllable, number 1-2 for syllable position 1st and 2nd, aa for same tone, ab for different tone.

Full reduplication		Tone sandhi reduplication		Control condition 1 Base + same tone		Control condition 2 Base + different tone	
sáng Rn1	sáng Bn2	sang Rs1	sáng Bs2	*sáng* Baa1	chói	*sáng* Bab1	choang

1) H1: If the reduplicated syllable (Rn1 and Rs1) is less acoustically prominent (indicated by shorter duration, less tone range, smaller intensity and a reduced or centralised vowel) than its corresponding base syllable in the reduplication forms (Bn2, Bs2) but not less prominent than the control syllables (Baa1 and Bab1), the difference in acoustic cues in the constituent syllables of the reduplication form (Rn1 vs. Bn2 and Rs1 vs. Bs2) may be due to the word-boundary effect.
2) H2: If the reduplicated syllable (Rn1 and Rs1) is less acoustically prominent (indicated by shorter duration, less tone range, smaller intensity and a reduced or centralised vowel) than both its corresponding base syllable in the reduplication forms (Bn2, Bs2) and the control syllables (Baa1 and Bab1), the stronger acoustic cues on the base syllable (Bn2 and Bs2 compared to Rn1 and Rs1 respectively) is due to the accentual effect.

2. Methodology

2.1 Linguistic materials

There were 6 reduplications for each of the five Southern tones (6 ngang-ngang, 6 sac-sac, 6 huyen-huyen, 6 hoi-hoi, 6 nang-nang) and six for each of the 3 tone sandhi counterparts of the sac-sac (6 ngang-sac), hoi-hoi (6 ngang-hoi), and nang-nang (6 huyen-nang). The total number of items:

((5 reduplicated tones x 6) x 2 control words) + (3 tone sandhi x 6)) x 10 speakers = 780 items

These reduplications were then embedded in an imperative carrier sentence in such a way that they all appeared utterance medial and between the same adjacent syllables (the same preceding preposition and following imperative particle) so as to avoid final lengthening effect and tone coarticulation effect. All carrier sentences of reduplications have the same grammatical structure (See appendix 1 for the complete list of words)

V + O + *prep* + **adjective/adverb reduplication** + *imperative particle*
Pha trà cho **đậm đậm/đầm đậm** đi nhé
(Drop-Drop tones)/ (Falling-Drop tones)
Make tea so as to strong strong particle
(Make tea rather strong)
Sơn tường cho **xanh xanh** (Level-Level tones) đi nhé
Paint wall so as to blue blue particle
(Paint the wall rather blue)

2.2 Subjects

Ten speakers (5 males and 5 females) of Southern Vietnamese (Saigon dialect) participated in the study. They were all students aged 20-30 years at the University of Queensland who came from HoChiMinh city and had been in Australia from 4 months to 1.5 years.

2.3 Procedures

The utterance list of sentences was arranged in a pseudo-random order. Subjects were asked to speak the sentences as if they were instructing an imagined silent listener to do something. This was designed to elicit natural and rather spontaneous speech from subjects. Before the recording, subjects were provided sufficient time for familiarization and practice. They then spoke the sentence aloud in their normal speaking manner. The recording was made in a quiet room using a sound recording and editing computer software (Praat) at 20 kHz sampling rate and 16 bit precision.

2.4. Measurements

The reduplication words were then segmented via the Emu Speech Tools, (Cassidy 1999). First, the Emu Labeller was used to mark the edges of the target syllables and vowels, relying primarily on the spectrographic display in the Labeller. As shown in figure 1, the token was labelled at three tiers: a phonetic tier for vowel and consonant segmentation, a tone tier for tonal F0 and an F0min-F0max tier which marks the minimum and maximum points in the F0 contour. Then the Emu-R was used to extract vowel duration, vowel formant and fundamental frequency. The following acoustic parameters were measured:

1) Duration of vowels, onset and coda
2) Vowel formant at vowel mid point

3) Fundamental frequency (F0) at 10 equidistant points on the tone contour of each syllable rime.
4) Tonal F0 range (=F0 max-F0min)
5) Vowel intensity (db) at vowel mid point
6) Spectral tilt: A syllable produced with higher vocal intensity would be expected to possess a lower spectral tilt than one of lower intensity. Spectral amplitude is measured at the first two harmonics (H1, H2) and the first three formants (A1, A2, A3). Four spectral parameters were calculated: H1-H2, H1-A1, H1-A2, H1-A3 (Stevens and Hanson's model, 1995).
7) Euclidean distance: the distance between vowel pairs in a perceptually scaled F1- F2 formant space.

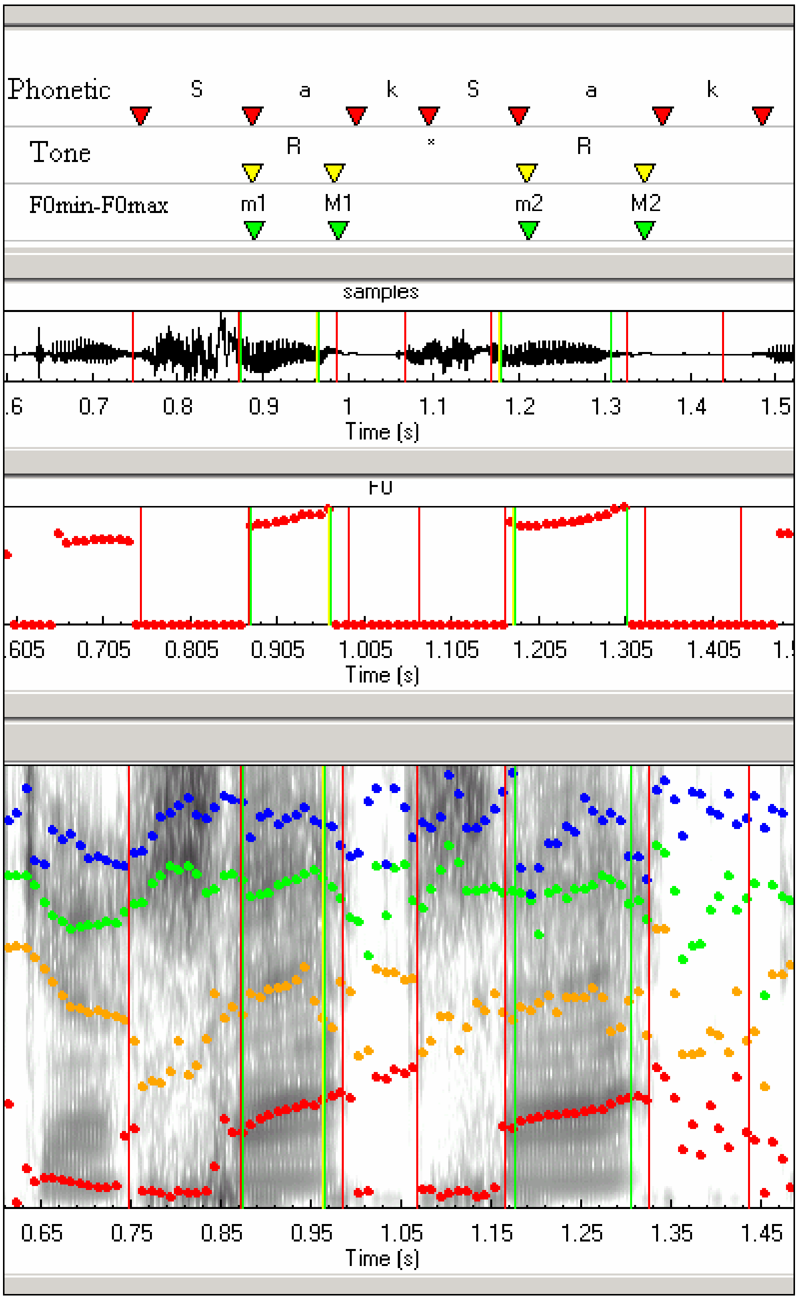

Figure 1 Illustration of an EMU-labelled token

2.5. Analysis

The use of reduplicated forms removed potentially confounding effects of inherent segment duration, fundamental frequency, or intensity upon the measurement of prosodic influences on these variables; that is, acoustic measures of the two constituent syllables of the same word can be compared without confounding effects due to different segmental makeup. The statistical analysis involves the acoustic parameters (listed above) as the dependent variables and two factors: (1) syllable positions (Rn1, Bn2, Rs1, Bs2, Baa1, Bab2) and tone types (level[ngang], falling[huyen], rising[sac], dropping[nang], and curve[hoi]), words (30 test items) and speakers (10 speakers). In order to account for the effect of speakers' differences and intrinsic segmental as well as tonal differences among the 30 test items, a restricted maximum likelihood (REML) applied to mixed model methodology was performed on each of the acoustic parameters. The fixed effects included syllable positions (Rn1, Bn2, Rs1, Bs2, Baa1, Bab1) and tone types (five tone types) and their two-way interactions. The random effects were speakers and words. A Tukey post-hoc test was then conducted to determine the significant differences among levels of the main fixed factors and their interaction effects, particularly the pair-wise comparison among the six syllable positions. The results of the post-hoc pair-wise comparison among syllable types were presented in appendix 2.

3. Results

3.1 Duration

The ANOVA results on duration showed significant main effect for syllable positions across all syllable constituents (onset: $F(5,1516)=9.01$, $p<.0001$, vowel: $F(5,1516)=91$, $p<.0001$, coda: $F(5,1100)=35$, $p<.0001$ and whole syllable: $F(5,1516)= 66.5$, $p<.0001$) while no significance was found for tone types or the interaction effect syllable positions x tone types. The results of the post-hoc pair-wise comparison among syllable types were presented in appendix 2.

As shown in figure 2 and appendix 2, there was a marginal significance for onset; the control syllables had longer onset than both syllable constituents of the reduplication form (Baa1~Bab1>Rn1~Rs1~Bn2~Bs2). The vowel of the reduplicant syllables was significantly shorter than the control syllables, which was shorter than the corresponding base syllables (Rn1~Rs1 <Baa1~Bab1<Bn2~Bs2). The coda of the reduplicant syllables was significantly shorter than the corresponding base syllables and the control syllables (Rn1~Rs1 <Baa1~Bab1~Bn2 ~Bs2). Taken together, in terms of whole syllable duration, the reduplicant syllables were significantly shorter than the corresponding base syllables and the control syllables (Rn1~Rs1<Baa1~Bab1<Bn2~Bs2). This result suggests that the shortening of the reduplicated syllables in comparison to their base syllables was not due simply to an absence of a phrase final lengthening effect, but to an accent-related shortening at the level of the (compound) word.

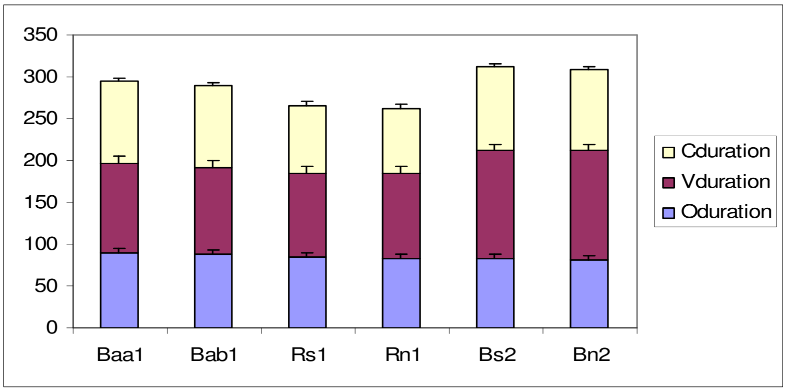

Figure 2 Mean duration (ms) of Onset, Vowel and Coda across six syllable positions; the error bars show standard error of the mean.

3.2. Intensity

The ANOVA results on intensity (db) showed significant main effect for syllable positions ($F(5,1516)=20$, $p<.001$) while no significance was found for tone types or the interaction effect between syllable positions x tone types. Post-hoc pair-wise comparisons showed that the reduplicant syllable with the sandhi tone had significantly greater intensity than the other five syllables (Rs1> Rs2~Baa1~Bab1~Rn1~Bn2, see appendix 2). This result suggests an effect due to tonal variation rather than a prominence effect since this tone sandhi syllable had a different tone from five other syllables of the same tone. A detailed analysis by tone types (for each sandhi pair: level-curve, falling-dropping, level-rising, see fig. 3) showed that the significant effect held for only two tone pairs: level-curve and falling-dropping (Rs1>Bs2) but not for the level-rising sandhi form (Rs1~Bs2: insignificant). Therefore, this intensity effect can be explained as an artefact due to tonal variation because the curve and dropping tones tend to be creaky/glottalised and intensity(db) tends to correlate with tonal F0 (Vu Thanh Phuong 1981)

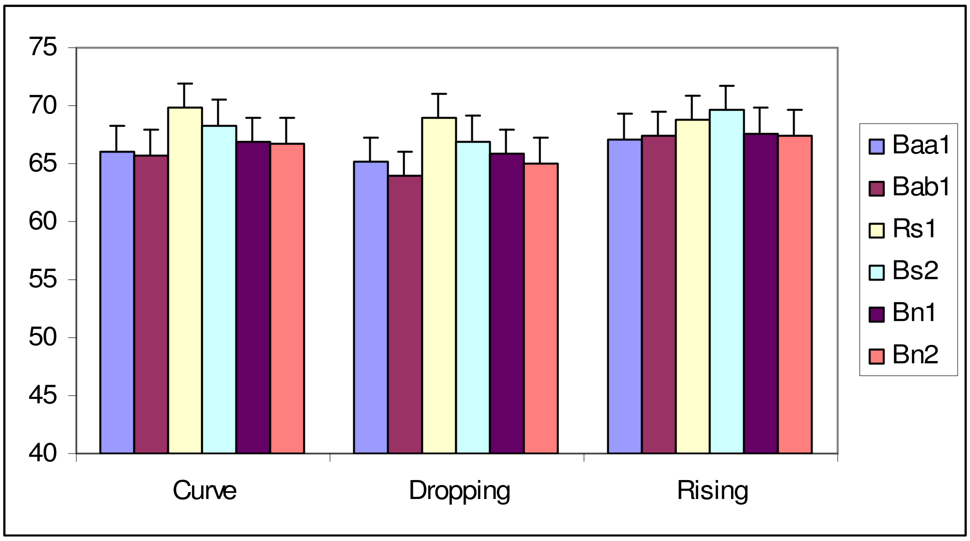

Figure 3 Mean values of intensity (db) across six syllable positions of the three dynamic tones that undergo tone sandhi; the error bars show standard error of the mean.

3.3 Spectral tilt

A syllable produced with higher vocal intensity would be expected to possess a lower spectral tilt than one of lower intensity. The ANOVA results of four spectral parameters (H1-H2, H1-A1, H1-A2, H1-A3) showed significant main effect for syllable positions across all syllable positions (H1H2: $F(5,1516)= 4.8$, $p<.001$; H1A1:$F(5,1516)=14$, $p<.0001$; H1A2: $F(5,1516)= 13$, $p<.0001$; H1A3: $F(5,1516)= 9$, $p<.0001$) while no significance was found for tone types or the interaction effect syllable positions x tone types. Post-hoc pair-wise comparisons (see figure 4 and appendix 2) shows that the reduplicant syllable with the sandhi tone had significantly higher spectral tilt than all other syllables (H1H2, H1A1, H1A2, H1A3: Rs1> Rs2~Baa1~Bab1~Rn1~Bn2). This tone sandhi syllable had a different tone from five other syllables of the same tone. A detailed analysis by tone types (for each sandhi pair: level-curve, falling-dropping, level-rising) showed that the significant effect held for all three tone pairs: the sandhi syllables had higher spectral tilt value than their corresponding base syllables, suggesting that the sandhi syllables were less prominent or less loud than their base syllable. This result, on the one hand, suggests that the significant difference may be due to tonal variation (tone sandhi) but, on the other hand, seems to imply an underlying prominence reduction by means of tone sandhi (i.e., tone sandhi enhances prominence difference in sandhi reduplication forms).

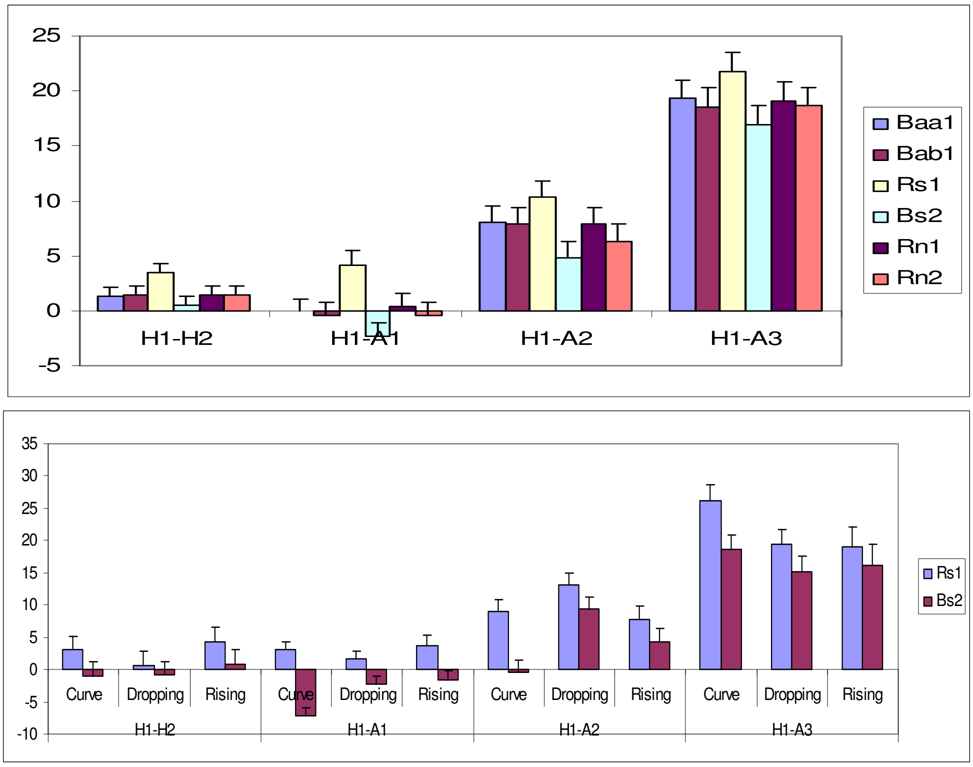

Figure 4 a) top fig.: Mean values of spectral tilt values across six syllable positions; b) bottom fig.: Mean values of spectral tilt values of the components of the sandhi forms.

3.4. Vowel formants

Prosodically prominent syllables may be expected to be accompanied by syllable nuclei that contain more clearly articulated vowels that attain more peripheral targets in a perceptually scaled F1- F2 formant space. It would be predicted that the average Euclidean distance between target vowels in a position of lower prosodic prominence would be significantly less than those in a higher position of prosodic prominence. We hypothesised that: a) vowel formant targets in second syllable (base) position would be more peripheral than corresponding vowel formant targets in first syllable (reduplicant) position, and that, b) vowel formant targets in first syllables of partial reduplications (tone sandhi syllables) may be less peripheral than their fully reduplicant (non-tone sandhi) counterparts.

An ANOVA analysis was performed on the Euclidean distance of vowel pairs (Rs1-Bs2): components of the tone sandhi form, Rn1-Bn2: components of the full reduplication, (Rs1-Bab1) and (Rn1-Bab1): Euclidean distance between the sandhi and non-sandhi reduplicant vowel and the control vowel in word-initial position respectively. A preliminary analysis found no significant difference between the vowels of the two word-initial control syllables (Baa1 and Bab1) and thus only one of them (Bab1) was included in the analysis and the vowel plot for spatial clarity of graphical presentation.

The ANOVA results and the formant plot (figure 5) showed three main things. First, the vowel of the reduplicant syllables (Rs1 and Rn1) tended to be more centralised than their base syllables (Bs2 and Bn2 respectively). Second, the vowel of the word-initial control syllables (Bab1) seemed to cluster with those of the base syllables. Third, the Euclidean distance between components of the tone sandhi form was significantly larger than that between components of the full reduplication (Rs1-Bs2> Rn1-Bn2, p<.03). This is further supported by the fact that the Euclidean distance between the sandhi vowel and the control vowel was significantly larger than that between the non-sandhi reduplicant vowel and the control vowel (Rs1-Bab1> Rn1-Bab1, p<.03). This result indicated that: (1) the reduplicant syllables were centralised/reduced in comparison with the base syllables and (2) the sandhi vowels were more reduced/more centralised than the non-sandhi reduplicant vowels.

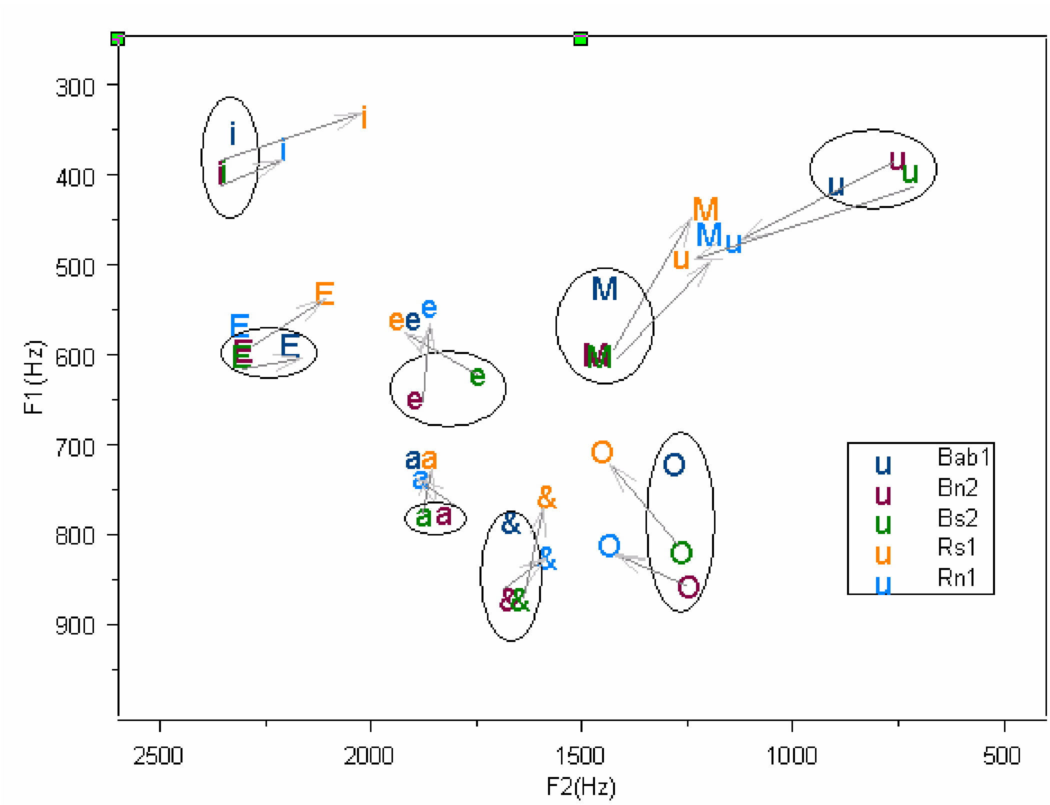

Figure 5 Formant plot of vowels in six positions: dark blue: Bab1: formant targets in the vowel in control initial position; purple: Bn2: formant targets in the base vowels of the full reduplication word; green: Bs2: formant targets in the base vowels of the partial reduplication words with tone sandhi; yellow: Rs1: formant targets in vowels undergoing tone shift in tone sandhi ; light blue: Rn1: formant targets in full reduplicant vowels. *Vowel symbols: a:/ɐ:/, &:/ɐ/, o:/ɔ/, E: /e/, e:/ɛ/, i:/ι/, M: /ɯ/*

3.5. F0 range and contours

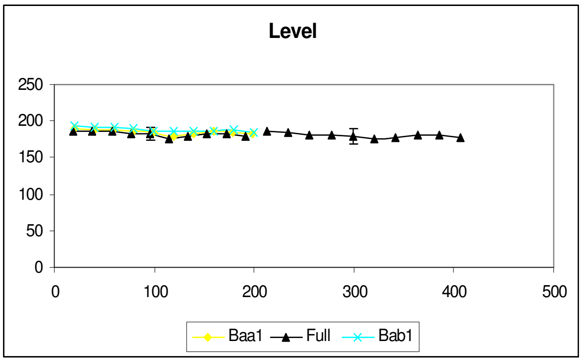

Figure 6a

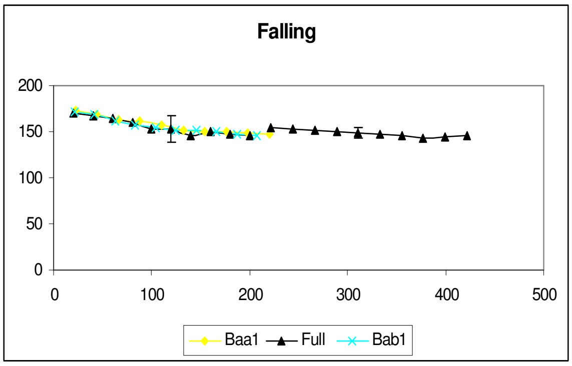

Figure 6b

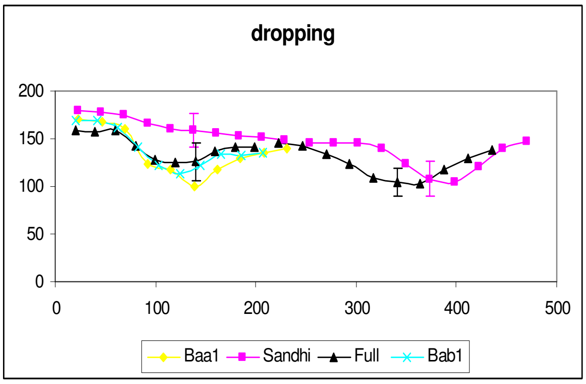

Figure 6c

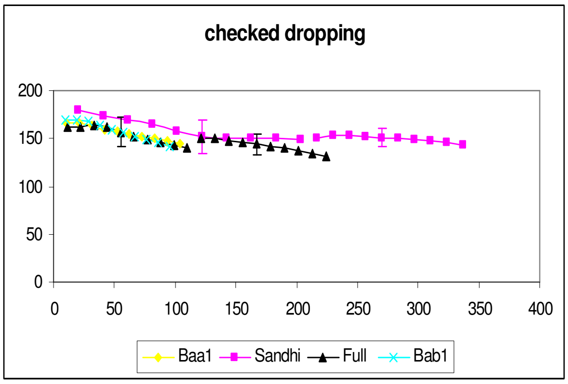

Figure 6d

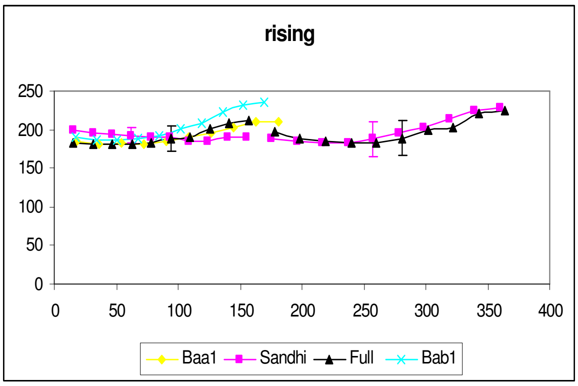

Figure 6e

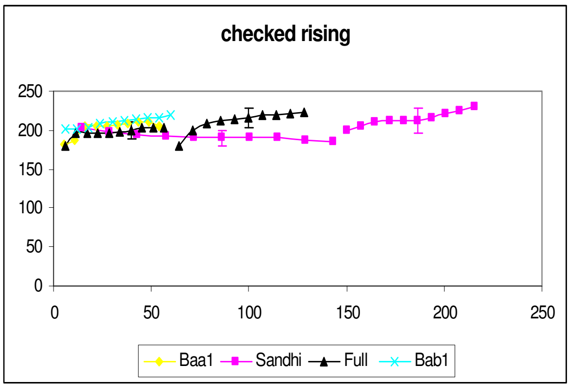

Figure 6f

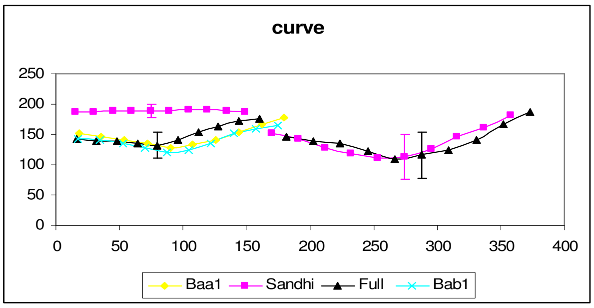

Figure 6g

Figure 6 The average F0 contours and F0 range of the six syllable positions under investigated. Vertical bar: mean F0 range (Hz). Horizontal lines: mean F0 contours (Hz). X- axis: tone duration (ms). Y- axis: mean F0 in Hz. Baa1 and Bab1: tones of the two word-initial control syllables, sandhi: tones of the partial reduplication words with a sandhi tone, full: tones of the full reduplication words: points 1-10: the 1st syllable, points 11-20: the second syllable.

The basic prediction for F0 contours is that the dynamic range of F0 change would be expected to be greater on tones in positions of prosodic prominence. The effects of tonal sequencing or down-step and boundary marking need to be taken into account in interpreting F0 contours, as well as inherent attributes of particular tones. Since only reduplications with the three dynamic tones (curve, dropping, rising) have a sandhi counterpart while those with the two even tones(level and falling) do not, the data was split into two separate data sets(a curve-dropping-rising set and the level-falling set) and submitted to two separate ANOVAs. Post-hoc pairwise comparison among syllable positions were also conducted (appendix 2). Figure 6 showed the pair-wise comparison of mean F0 range among syllable positions for each tone type (vertical bar) and the mean F0 contour plotted on normalised duration (horizontal line).

The statistical results on F0 range and the examination of F0 contour (Fig.6) showed four main things. First, the base syllables (Bs2, Bn2) tended to have longer tone / F0 contour than both the reduplicant syllables (Rs1, Rn1) and the word-initial control syllables (Baa1, Bab1), consistent with the result on syllable duration presented in section above. Second, the base syllable of the rising and curve tone tended to have a larger F0 range than their reduplicant counterparts (Rising: Bs1<Bn1< Bs2~Bn2~ Baa1~Bab1, p<.01; Curve: Bs1<Bn1< Baa1~Bab1<Bs2~Bn2, p<.001). By contrast, the F0 contour of the base syllable with falling and dropping tone, though falling lower, had smaller F0 range than their initial reduplicant counterparts as a result of a flatter contour with lower F0 onset (Falling: Baa1~Bab1~Rn1>Bn2, p<.0001; Dropping: Baa1~Bab1~Rs1~Rn1~Bs2~Bn2, ns.). Third, there was no significant difference in terms of F0 range and F0 contour between the two control syllables even though they were followed by two different tones: one followed by the same tone and the other followed by a different tone (Baa1 and Bab1). Even though the two control syllables were similar to reduplicant syllables in terms of a shortened tone length, they were generally more similar to the base syllables in terms of F0 range and fuller tonal shape. This result suggests that the reduplicant syllables had a more "reduced" tone in comparison to that of the base syllables. Fourth, the examination of tone contour in tone sandhi minimal pairs: dropping-dropping vs. falling-dropping (figure 6c-d), and rising-rising vs. level-rising (figure 6e-f), and curve-curve vs. level-curve (figure 6g) shows that in tone-sandhi words, the tone contour of the second syllable tends to start from the ending point of the tone contour in the previous syllable. In other words, there is a smoother transition between tones in tone-sandhi words. For example, in level-dropping word (fig 6c-d), a sandhi counterpart of dropping-dropping, the second dropping tone falls further from the previous falling tone. In level-rising, a sandhi of rising-rising, the second rising tone begins rising from where the previous level tone ends. Similarly, in level-curve word, a sandhi form of curve-curve, the second curve tone falls from where the level tone ends. In contrast, in non-sandhi full reduplication forms such as dropping-dropping, rising-rising and curve-curve, the second tone contour repeats the whole process of the first one except in the case of the two uni directional tones: level-level and falling-falling(fig. 6a-b), the second tone simply continues staying level (in level-level) or declines a little from the first. This shows that there is tonal coarticulation in sandhi forms compared to their non-sandhi counterparts, which may stem from the ease of articulation and a tendency to avoid tone clashes. This result, together with the investigators' auditory observation that many speakers in this study tend to produce the sandhi forms in sentences in which the non-sandhi counterparts are embedded, implies three things. First, the sandhi forms stem from ease of articulation and probably also for the sake of perceptual salience which needs to be investigated in a perceptual experiment. Second, the fact that many speakers produce the sandhi form as an alternative for the non-sandhi form indicates that the sandhi forms are produced as phonetic variants of the non-sandhi counterparts, suggesting that the sandhi forms are phonologised from tonal assimilation as a result of ease of articulatory constraint. Thirdly, the fact that the reduplicant syllable is the target of the tone sandhi process supports the main finding that disyllabic forms in Vietnamese are right headed.

4. Discussion

First, in terms of whole syllable duration, the reduplicant syllables were significantly shorter than the control syllables which were shorter than corresponding base syllables (Rn1~Rs1<Baa1~Bab1<Bn2~Bs2). The point of discussion here is whether the lengthening of the base (second) syllables in comparison to the reduplicant syllables is due to a "word boundary lengthening" effect (boundary tone) or to a temporal effect of accentual prominence. The above result together with the insignificant difference between the coda of the word-initial control syllables in comparison with the word-final base syllables suggests that the shortening of the reduplicated syllables in comparison to their base syllables was not due to lack of final lengthening or being in a non-final position but due to a reduction, and thus rejects hypothesis 1 and supports hypothesis 2.

Second, the results on spectral tilt showed that the reduplicant syllable with a tone sandhi had greater spectral tilt than the base syllables, suggesting that the sandhi syllables were less prominent or less loud than their base syllables. This result, on the one hand, suggests that the significant difference may be due to tonal variation (tone sandhi) but, on the other hand, seems to imply an underlying prominence reduction by means of tone sandhi.

Third, the results on vowel formant change showed that the vowels of the reduplicant syllables were centralised in comparison with that of the base syllables and the sandhi vowels were more centralised than the full (non-sandhi) reduplicant vowels while the vowels of the word-initial control syllables clustered in the same space as the base vowels, suggesting that the reduplicant vowels were reduced to promote right-headed prominence effect which was further enhanced by tone sandhi.

Fourth, the results on F0 showed that the base syllables tended to have longer tone/ F0 contour, larger F0 range and more fully realised tone contour than the reduplicant syllables particularly in the two dynamic tone pairs (higher and more sharp rise of the second rising tone in the rising-rising reduplication, a deeper fall and higher rise in the second curve tone in curve-curve words). The lowering of F0 contour on the second syllable compared to that of the first for the three uni-directional tone pairs: level-level, falling-falling, and dropping-dropping can be interpreted in different ways. First, it might be interpreted as a down-step or pitch declination effect at word boundary. Second, it may show a prominence effect on the second syllable as a result of downward pitch expansion as found in Mandarin Chinese, in which tonal range is expanded both upward and downward under prominence effect: high tones become higher and low tones become lower (Shen 1990; Shih 1988). Third, the further lowering of the F0 on the second syllable can also be attributed to anticipatory or carry-over coarticulation effect due to the low offset of the preceding tone as found in Bejing Mandarin by Xu (1997) "a tone with a low offset lowered the f0 of the following tone, and a tone with a high offset raised the f0 of the following tones" (p.74). In addition, even though the two control syllables were similar to reduplicant syllables in terms of a shortened tone length, they were generally more similar to the base syllables in terms of F0 range and fuller tonal shape. This F0 result suggests that the reduplicant syllables had a more "reduced" tone in comparison to that of the base syllables. Furthermore, comparative

examination of the pitch contours between fully reduplicated syllables and their sandhi counterpart showed a smoother transition in tonal contour of the latter, suggesting tone-sandhi may result from one or more of the following: a) phonologized tone assimilation to avoid tone clash, b) tonal coarticulation, in the interests of ease of articulation, and possibly also, c) 'de-accenting' to promote right syllable perceptual salience (headedness).
In brief, the results of the acoustic analysis provide evidence supporting hypothesis 2 that the difference in duration, spectral tilt, vowel formant and F0 values between the reduplicant syllables and the base syllables is due to an accentual effect rather than a word boundary effect. In other words, the reduplicant syllables were shown to be acoustically reduced in comparison to the base syllables. Furthermore, the difference between the sandhi forms in comparison with their full (non-sandhi) reduplications in terms of spectral tilt, vowel quality in addition to the tone change suggests that tone sandhi in reduplication words is a form of 'de-accenting' to promote right syllable perceptual salience (headedness). However, this needs to be confirmed in a perceptual study.

5. Conclusion

In conclusion, the acoustic parameters examined in this study suggest that the second syllable of Vietnamese reduplication forms is more acoustically prominent. In other words, if there is a word stress pattern in these Vietnamese disyllabic reduplications, it will be right-headed. This prominence pattern is further supported by the tone sandhi which is confined to first syllables, and which can be explained on both phonetic and phonological grounds. First, phonetically, tone sandhi is motivated by tonal assimilation and preferential preservation of tonal contrast on the second syllable. Second, phonologically, tone sandhi has been postulated to occur on weak syllables (Chen 2000; Ngo 1984; Rose 1990); particularly as found in this study, tone sandhi is accompanied by enhanced vowel reduction and less articulatory effort (spectral tilt), suggesting that "tone sandhi is a reduction phenomenon occurring on prosodically weak positions"(Shih 2005). Perceptually, in Bejing Mandarin, in the majority of cases, the second syllables were perceptually judged to be more prominent than those in the first (Lin *et al* 1984, cf. Luke, Chen, Lee, and Shen 2001). From auditory observation as a native speaker, it is predicted that the same results can be obtained for Vietnamese, however, this needs to be further investigated in an empirical perceptual study. The acoustic results of this study show phonetic evidence of prosodic constituency at the level of the bisyllabic word in Vietnamese and has implication for theory of prosodic structure. However, the status of the prosodic unit - whether it constitutes a stress foot or a phonological word – is yet to be determined and awaits further study.

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Appendix 1: List of test words

Tones	Full reduplications	Sandhi reduplication	Control condition1 Base + same tone	Control condition 2 Base + different tones
Curve (hỏi)	đỏ đỏ	đo đỏ	*đỏ* thắm	*đỏ* chói
	nhỏ nhỏ	nho nhỏ	*nhỏ* nhuyễn	*nhỏ* mứt
	cũ cũ	cu cũ	*cũ* kỹ	*cũ* rích
	thẳng thẳng	thăng thẳng	*thẳng* hẳn	*thẳng* thớm
	vững vững	vưng vững	*vững* chải	*vững* chắc
	xỉn xỉn	xin xỉn	*xỉn* hẳn	*xỉn* say
Dropping (nặng)	lạnh lạnh	lành lạnh	*lạnh* bụng	*lạnh* buốt
	nhẹ nhẹ	nhè nhẹ	*nhẹ* nợ	*nhẹ* túi
	rộng rộng	rồng rộng	*rộng* rình	*sệt* cứng
	nhạt nhạt	nhàn nhạt	*nhạt* phèo	*rộng* tuếch
	đẹp dẹp	đèm đẹp	*đẹp* tuyệt	*đẹp* mắt
	sệt sệt	sền sệt	*sệt* đặc	*nhạt* thếch
Rising (sắc)	sáng sáng	sang sáng	*sáng* chói	*sáng* choang
	nóng nóng	nong nóng	*nóng* ấm	*nóng* sôi
	khó khó	kho khó	*khó* lắm	*khó* khăn
	chắc chắc	chăn chắc	*chắc* cứng	*chắc* trân
	sát sát	san sát	*sát* khít	*sát* sao
	khít khít	khin khít	*khít* nút	*khít* khao
Level (ngang)	xanh xanh		*xanh* đen	*xanh* thắm
	ngon ngon		*ngon* tươi	*ngon* mắt
	đen đen		*đen* thui	*đen* đúa
	thơm thơm		*thơm* tho	*thơm* ngát
	dơ dơ		*dơ* tay	*dơ* dáy
	dai dai		*dai* hơn	*dai* dẻo
Falling (huyền)	giòn giòn		*giòn* đều	*giòn* tan
	hồng hồng		*hồng* hào	*hồng* tươi
	bằng bằng		*bằng* hàng	*bằng* chan
	tròn tròn		*tròn* đều	*tròn* vo
	dày dày		*dày* cồm	*dày* cui
	vàng vàng		*vàng* hườm	*vàng* tươi

Appendix 2: Mean difference (MD) and significant level (p-value) of the post-hoc pair-wise comparison among syllable positions. Highlighted are variables of importance to the study. Bolded italics: between the control syllables (Baa1 and Bab1) and the reduplicant syllables (Rs1 and Rn1); Bolded: between the reduplicant syllables (Rs1 and Rn1) and their base (Bs2 and Bn2)

Syll. position		Onset duration		Vowel duration		Coda duration		Syll. duration		Tone duration		F0 range		Intensity		H1-H2		H1-A1		H1-A2		H1-A3	
		MD	p.value	MD	p.value	MD	p.value	MD	p.value	MD	p.value	MD	p.value	MD	p.value	MD	p.value	MD	p.value	MD	p.value	MD	p.value
Baa1	Bab1	2.3	0.1	2.2	0.22	0.9	0.65	5	0.06	7	0.03	-3	0.17	0.2	0.54	-0.2	0.75	0.4	0.53	0.0	0.97	0.7	0.22
Baa1	***Rs1***	***5.3***	***<.01***	***6.7***	***<.01***	***16.2***	***<.0001***	***24***	***<.0001***	***-15***	***<.0001***	***18***	***<.0001***	***-2.8***	***<.0001***	***-2.1***	***<.001***	***-4.2***	***<.0001***	***-2.3***	***<.001***	***-2.5***	***<.001***
Baa1	Bs2	6.5	<.001	-21.7	<.0001	-1.7	0.50	-17	<.0001	-22	<.0001	-6	<.01	-1.9	<.0001	0.9	0.15	2.3	<.01	3.2	<.0001	2.4	<.001
Baa1	***Rn1***	***6.5***	***<.0001***	***5.4***	***<.01***	***20.2***	***<.0001***	***27***	***<.0001***	***14***	***<.0001***	***5***	***<.03***	***0.0***	***0.98***	***-0.1***	***0.82***	***-0.5***	***0.44***	***0.1***	***0.84***	***0.2***	***0.78***
Baa1	Bn2	8.5	<.0001	-23.2	<.0001	1.5	0.47	-13	<.0001	-16	<.0001	2	0.40	0.4	0.22	-0.1	0.85	0.4	0.55	1.6	<.01	0.7	0.25
Bab1	***Rs1***	***3.0***	***0.08***	***4.5***	***<.05***	***15.3***	***<.0001***	***18***	***<.0001***	***-22***	***<.0001***	***20***	***<.0001***	***-3.0***	***<.0001***	***-2.0***	***<.001***	***-4.6***	***<.0001***	***-2.3***	***0.001***	***-3.2***	***<.0001***
Bab1	Bs2	4.2	0.02	-24.0	<.0001	-2.6	0.29	-22	<.0001	-29	<.0001	-3	0.15	-2.1	<.0001	1.0	0.09	1.9	0.01	3.2	<.0001	1.7	0.02
Bab1	***Rn1***	***4.2***	***<.01***	***3.2***	***<.05***	***19.3***	***<.0001***	***22***	***<.0001***	***7***	***<.03***	***7***	***<.001***	***-0.2***	***0.56***	***0.0***	***0.93***	***-0.9***	***0.16***	***0.1***	***0.87***	***-0.6***	***0.34***
Bab1	Bn2	6.2	<.0001	-25.5	<.0001	0.6	0.78	-18	<.0001	-23	<.0001	4	0.03	0.2	0.54	0.1	0.90	-0.1	0.97	1.6	0.007	0.0	0.94
Rs1	**Bs2**	**1.2**	**0.53**	**-28.5**	**<.0001**	**-17.9**	**<.0001**	**-40**	**<.0001**	**-7**	**0.10**	**-24**	**<.0001**	**0.8**	**0.05**	**3.0**	**<.0001**	**6.5**	**<.0001**	**5.5**	**<.0001**	**4.9**	**<.0001**
Rs1	Rn1	1.2	0.50	-1.3	0.56	4.0	0.11	4	0.28	30	<.0001	-13	<.0001	2.8	<.0001	2.0	<.001	3.8	<.0001	2.4	<.001	2.7	<.001
Rs1	Bn2	3.2	0.07	-29.9	<.0001	-14.7	<.0001	-37	<.0001	-1	0.88	-16	<.0001	3.2	<.0001	2.0	<.001	4.6	<.0001	3.9	<.0001	3.2	<.0001
Bs2	Rn1	-0.1	0.99	27.2	<.0001	21.9	<.0001	44	<.0001	37	<.0001	11	<.0001	1.9	<.0001	-1.0	0.10	-2.7	<.001	-3.1	<.0001	-2.2	<.01
Bs2	Bn2	2.0	0.25	-1.5	0.50	3.2	0.20	4	0.29	6	0.10	8	0.01	2.3	<.0001	-1.0	0.11	-1.9	0.01	-1.6	0.03	-1.7	0.02
Rn1	**Bn2**	**2.0**	**0.17**	**-28.7**	**<.0001**	**-18.7**	**<.0001**	**-40**	**<.0001**	**-30**	**<.0001**	**-3**	**0.16**	**0.4**	**0.23**	**0.0**	**0.97**	**0.9**	**0.18**	**1.5**	**0.01**	**0.5**	**0.38**