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Acoustic Correlates of Phonation Type in Chichimec

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Abstract

Chichimec is an Oto-Manguean language of Mexico with a phonological contrast between modal, breathy and creaky vowels. This study is the first acoustic investigation of this contrast in Chichimec, based on spectral tilt and Cepstral Peak Prominence (CPP) measures. We consider the change of these measures over the course of the vowel and include a high vowel, which was omitted in most phonation studies of other languages. The present study not only contributes to the description of Chichimec with respect to the different portions of the vowel, but also explores the adequacy of the acoustic measures of phonation type for low and high vowels.

Our results show that phonation changes in the course of the vowel, and that this change is a relevant factor for phonation types in Chichimec. We find that CPP is the best measure to characterize Chichimec phonation contrasts in all vowels. For the vowel /a/, spectral tilt measures are better indicators of phonation type for women than for men. The results for /i/ indicate that spectral tilt distinguishes breathy from modal vowels for men, but that these measures might generally not be appropriate to describe phonation contrasts in women's high vowels.

Index Terms: Chichimec, phonation type, voice quality, spectral tilt, Cepstral Peak Prominence

1. Introduction

Chichimec (also 'Chichimeco Jonaz', [pei]) is an Oto-Manguean language spoken by a few hundred speakers in the state of Guanajuato (Mexico). It has a phonological three-way phonation contrast in vowels: modal voice /V/, breathy voice /V̤/, and creaky voice /V̰/. The purpose of this study is to determine which acoustic measures of spectral tilt (H1-H2, H1-A1) and harmonics-to-noise-ratio (Cepstral Peak Prominence, CPP) best illustrate these three phonation types and to provide a first (quantitative) acoustic analysis of phonation types in Chichimec.

Herrera [1] showed that there is distinctive breathy voice /V̤/ in Chichimec and that phonological non-modal phonation only occurs in the stem (i.e., the second, prominent syllable of content words). These findings were confirmed in an earlier analysis by the first author [2] and extended upon: She found that phonological creaky voice /V̰/ is a third phonation category. In addition, she showed that all three phonation types occur with both high-tone (marked with acute accent) and low-tone (marked with grave accent), for instance, *kìn**ú*** 'his/her field' – *kín**ù*** 'my field' (modal /V/); *nìm**á̤*** 'his/her plate' – *ním**à̤*** 'your plate' (breathy /V̤/); *ùn**ḭ́*** 'your wife' – *ún**ḭ̀*** 'his wife' (creaky /V̰/). Similar to other languages with phonological tone *as well as* phonological phonation contrasts [1, 3-5], non-modal and modal phonation are *sequenced* in Chichimec, and non-modal phonation is most often expressed towards the end of the vowel rather than for its whole duration, e.g. /nìmá̤/ → [nìmːáá̤]; /ùnḭ́/ → [ʊ̀nːíḭ́] ~ [ʊ̀nːíḭ́í]. So far, no thorough *acoustic* study has been made of non-modal phonation in Chichimec.

Spectral tilt measures distinguish phonological phonation types in several languages [4, 6-11]. It reflects the continuum of laryngeal constriction [12, 13], and is *steeper* in less constricted (i.e., breathy) voice than in modal voice and *flatter* in more constricted (i.e., creaky) voice than in modal voice. Another frequently used acoustic measure of phonation type is Cepstral Peak Prominence (CPP), which measures the harmonics-to-noise-ratio. Irregular vibration of creaky voice and noise in breathy voice due to turbulent airflow result in lower values for this measure than 'clear' modal voice [13, 23]. Hence, the expectations for the measures used in this study are:

Spectral tilt: *breathy > modal > creaky*
CPP: *modal > breathy, creaky*

Considerable variability was found for acoustic measures as correlates of phonation: *Which* spectral tilt measures represent phonation contrasts, and *how well* they represent these contrasts varies for sex [4, 7, 8], and between languages [9, 10, 14, 15]. This suggests that "language/speaker differences in voice quality [might be] larger than phonation category differences" [9]. Furthermore, it was found that *vowel height* can affect spectral tilt measures, especially in women and other high-pitched speakers (e.g., [16]). Due to a potential interaction of F0 and a low F1, acoustic studies of phonological phonation contrasts in other languages have limited their investigations to non-high vowels [4, 6, 7, 9, 14, 17]. However, such an interaction has not been explored in languages with phonological phonation contrasts. To the best of our knowledge, there exist only two explorative studies of phonation contrasts for high vowels: Blankenship [14] reported lower values of H1-H2 and H1-A2 for laryngealized /i/ than modal /i/ in Mpi, and Esposito [18] reported a similar tendency of H1-A3 for /i/ as for /a/ in Zapotec. Both studies investigated relatively few tokens of one male speaker only. Finally, acoustic studies of the temporal realization of non-modal phonation in languages with phonological phonation contrasts are rare and have not followed a consistent methodology so far [4, 8, 14, 17, 18].

The aim of this study is to provide a first systematic acoustic investigation of the phonological three-way phonation contrast (modal vs. breathy vs. creaky) of Chichimec. We take the changes over the time course of the vowel into account, which is indispensable to characterize the sequencing of phonation types in this and other Oto-Manguean languages. The more general innovative value of this study beyond language description is two-fold. First, it compares the production of men

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and women to extend upon the scarce research on sex differences in languages with a phonological phonation contrast. Second, this is the first elaborate acoustic study of *phonological phonation contrasts* that includes a high vowel and compares and validates spectral tilt measures as correlates of phonation type for both low and high vowels.

2. Materials and methods

2.1. Data and acoustic measures

For this study, the first author recorded the speech of four speakers of Chichimec (2 female, 2 male) in Mexico in 2017 with a handheld recorder at 44kHz/16bit. Three speakers were in their 30s and one male speaker in his 70s. This age group was chosen because of two ongoing sound changes concerning phonation type that affect the speech of the younger generation [19, 20].

We investigated 30 nouns recorded in the carrier phrase *kíní ___ émʔa̰* ('This is called ___'), surrounded by two high tones. The phrases were elicited by translation from Spanish. As Chichimec does not have a standard orthography, and speakers were mostly illiterate, read speech was not an option. At least three repetitions of the nouns in their carrier phrase were recorded for each speaker. All nouns were bisyllabic and the target vowels /a/ and /i/ were phonologically modal, breathy and creaky in the second, prominent syllable. All prominent syllables carry H- or L-tone and have a simple CV structure. We excluded words with glottal, glottalized or aspirated consonants to avoid effects of these consonants on spectral tilt.

Speakers realized the contact of the target vowel and the following /é/ in various ways: slightly breathy, as a diphthong, with an epenthetic glottal stop, or with a short pause between the words. Since these different realizations may affect spectral tilt measurements, we labelled them accordingly and included them in the analysis.

The target vowels (n = 441) were manually segmented by the first author in *Praat* [21] and then automatically divided into four equal intervals. We extracted H1*-H2*, H1*-A1* and CPP in *VoiceSauce* [22] and calculated the average for each of the four vowel portions. Asterisks indicate that *VoiceSauce* automatically corrected the measurements for vowel quality. We manually excluded tokens of individual vowel portions (n= 145) with obvious errors in the calculation of spectral tilt, which occurred in case of erroneous F0 or F1 retrieval. For CPP, which does not rely on F0 calculations [23], no tokens had to be excluded. In an earlier analysis [24], we found that fundamental frequency and tone (high or low) correlate in all three phonation types (i.e., that high- and low-tone are distinguished in modal /V/, breathy /V̤/ and creaky voice /V̰/). For that reason, here we included the variable tone only.

2.2. Statistical analysis

In order to investigate the effect of phonation on the acoustic measurements, we built linear mixed effects regression models with the acoustic measures as dependent variables: **H1*-H2***, **H1*-A1*** and **CPP**. In all models, we included the independent variables *Phonation* (modal, breathy, creaky), *Tone* (high, low), and *Vowel_Portion* (t1, t2, t3, t4), which described whether the measurements were extracted from the first, second, third or fourth quarter of the vowel. Furthermore, we included *Cons_Context (i.e.,* the syllable-initial consonant) with the values flap, nasal, nasal flap, voiced fric., voiceless fric., voiced plosive, voiceless plosive, and *Final_Context* (i.e., the realization of the vowel contact between the target vowel and the following vowel of the verb), with the values breathy, creak, tense glottalization, diphthong, pause, pause with tense onset, (cf. Section 2.1.) and the continuous variable *Duration*, as well as the random variables *Word* (30 types) and *Speaker*. In our initial models, we additionally included the independent variables *Sex* (male, female) and *Vowel* (/a/, /i/). As the resulting models contained multiple significant high level interactions (up to 5-way) and thus were not interpretable anymore linguistically, we decided to split the data and build four separate models for each dependent variable: **MaF**: a-vowels for women (n=117); **MiF**: i-vowels for women (n=105); **MaM**: a-vowels for men (n=112); and **MiM**: i-vowels for men (n=107).

For building the models, we used the *lmer* function of the *lme4 package* in *R* [25]. We included all mentioned independent variables and two-way and three-way interactions of *Phonation*, *Tone* and *Vowel_Portion* into the models. We subsequently reduced the predictors and interactions using the step-function [26]. We further excluded non-significant factors and interactions as long as the model would still improve, given its AIC values, its degrees of freedom [27] and a model-comparison using ANOVA. The following section presents and discusses the results for the independent variable *Phonation,* and the interaction of *Phonation* with *Vowel_Portion*.

3. Results and discussion

3.1. H1*-H2*

In the model **MaF** for **H1*-H2***, *Phonation* was not significant, but its interaction with *Vowel_Portion* was: B*reathy* voice was significantly higher than modal voice in t2 ($\beta = 4.18$, $t = 2.14$, $p = .033$) and in t4 ($\beta = 6.77$, $t = 2.73$, $p < .007$). *Creaky* voice was significantly lower than modal voice in t2 ($\beta = -7.07$, $t = -2.88$, $p = .004$), t3 ($\beta = -8.34$, $t = -3.21$, $p = .001$) and in t4 ($\beta = -9.12$, $t = -3.51$, $p = .001$). Figure 1 (left panel) illustrates that the mean values of breathy /a/ are higher than of modal /a/ in the middle and the end of the vowel (cf. black triangles), and that the mean values of creaky /a/ are lower than of modal /a/ towards the end of the vowel (cf. black squares).

In **MiF** for **H1*-H2***, *Phonation* was a significant predictor: *Breathy* /i/ was marginally significantly *higher* than modal /i/ ($\beta = 5.65$, $t = 2.09$, $p = .054$). In the interaction with *Vowel_Portion*, breathy voice was significantly lower than modal voice in t2 ($\beta = -5.23$, $t = -2.98$, $p = .003$), t3 ($\beta = -9.21$, $t = -5.23$, $p < .001$) and t4 ($\beta = -13.84$, $t = -7.75$, $p < .001$) (cf. grey triangles in Figure 1, left panel).

In **MaM**, **H1*-H2*** was not significantly affected, neither by *Phonation* nor by its interaction with *Vowel_Portion*. Also in **MiM** for **H1*-H2*,** *Phonation* was not a significant predictor. Its interaction with *Vowel_Portion*, however, was: breathy /i/ was significantly higher than modal /i/ in t3 ($\beta = 2.98$, $t = 1.83$, $p = .07$) and t4 ($\beta = 3.39$, $t = 2.06$, $p = .04$) (cf. grey triangles in Figure 1, mid-left panel). In both MiF and MiM for H1*-H2*, creaky voice was neither significantly different from modal voice on its own nor in interaction with *Vowel_Portion*.

The results for H1*-H2* show that it is necessary to consider the change of spectral tilt over the course of the vowel, since only in women's vowel /i/, breathy voice was distinct from modal voice over the whole vowel duration. In the time course, however, this measure distinguished breathy and creaky from modal voice for women's production of /a/. For men, it

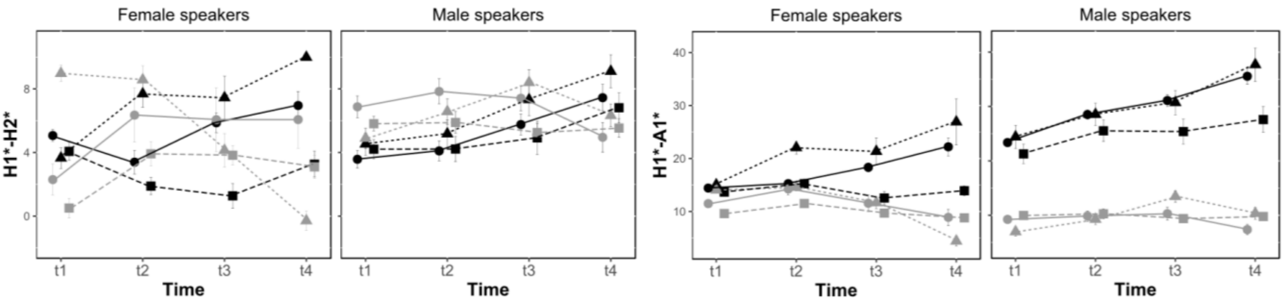

Figure 1: *Mean values and error bars of spectral tilt values (left: H1*-H2*; right: H1*-A1*) for modal (circle, solid line), breathy (triangle, dotted line) and creaky (square, dashed line) vowels /a/ (black) and /i/ (grey) for women and men.*

did not distinguish phonation types for the vowel /a/ at all. For /i/, H1*-H2* only distinguished breathy from modal phonation, but not creaky from modal phonation. It is surprising that women's breathy /i/ in the time course is *lower* than modal /i/. Instead, it would be expected that values for breathy voice are *higher*, and values for creaky voice are *lower* than modal voice [13] (cf. Section 1).

3.2. H1*-A1*

In the models **MaF** and **MiF** for **H1*-A1***, *Phonation* was not a significant predictor, but its interaction with *Vowel_Portion* was. In MaF, breathy voice was significantly higher than modal voice in t2 ($\beta = 6.19$, $t = 2.77$, $p = .006$) and in t4 ($\beta = 4.74$, $t = 1.73$, $p = .085$), and creaky voice was significantly lower than modal voice in t3 ($\beta = -4.52$, $t = -1.91$, $p = .057$) and in t4 ($\beta = -7.30$, $t = -3.48$, $p = .001$) (cf. black symbols in Figure 1, mid-right panel). In **MiF,** breathy /i/ was *lower* than modal /i/ in t2 ($\beta = -5.00$, $t = -1.89$, $p = .059$), t3 ($\beta = -11.16$, $t = -4.22$, $p < .001$) and t4 ($\beta = -10.38$, $t = -3.83$, $p < .001$), and creaky /i/ was significantly *higher* than modal /i/ in t3 ($\beta = 5.65$, $t = 2.92$, $p = .004$) and t4 ($\beta = 5.62$, $t = 2.81$, $p = .005$).

In comparison to all other models of **H1*-A1***, **MaM** was the only case in which *Phonation* was significantly lower for creaky voice ($\beta = -9.01$, $t = -3.61$, $p < .001$) than for modal voice (cf. black squares in Figure 1, right panel). The interaction of *Phonation* and *Vowel_Portion* was not significant. In **MiM**, *Phonation* was not a significant predictor for **H1*-A1***. In the interaction with *Vowel_Portion*, breathy /i/ was higher than modal /i/ in t3 ($\beta = 5.49$, $t = 2.68$, $p = .008$) and t4 ($\beta = 5.38$, $t = 2.61$, $p = .010$) (cf. grey triangles in Figure 1, right panel).

An *a posteriori* inspection of our data set suggests that the less conclusive results for men's /a/ could be a consequence of individual differences. The older speaker's values for /a/ were lower compared to the younger male speaker's /a/ (*breathy*: $\beta = -8.26$, $t = -3.30$, $p = .001$; *creaky*: $\beta = -8.61$, $t = -3.60$, $p < .001$), which might have skewed the values for men's /a/ vowels, but not for /i/ vowels.

Over the whole vowel duration, H1*-A1* only distinguished men's creaky from modal /a/. For men's /i/ and for /i/ and /a/ produced by female speakers, the time course has to be considered: H1*-A1* distinguished women's breathy and creaky from modal vowels, as well as men's breathy from modal voice in the vowel /i/ in later vowel portions. Again, women's spectral tilt values for the vowel /i/ were unexpected, as breathy /i/ tended to be *lower* rather than higher, and creaky /i/ tended to be *higher* rather than lower, compared to modal /i/. Overall, the results for H1*-A1* and H1*-H2* show similar tendencies and limitations with respect to representing phonation types.

3.3. Cepstral Peak Prominence (CPP)

Only in **MaF** for **CPP**, *Phonation* was significantly higher for breathy voice ($\beta = 1.77$, $t = 2.28$, $p = .030$) than for modal voice, but not significant for creaky voice. In all other models for CPP, *Phonation* on its own was not significant. In all four models for CPP, however, the interaction of *Phonation* and *Vowel_Portion* had significant effects: *Breathy* voice was lower than modal voice in the course of time in **MaF** (*t2*: $\beta = -5.34$, $t = -6.72$, $p < .001$; *t3*: $\beta = -10.78$, $t = -13.55$, $p < .001$; *t4*: $\beta = -8.55$, $t = -10.75$, $p < .001$), in **MiF** (*t2*: $\beta = -1.91$, $t = -1.78$, $p = .076$; *t3*: $\beta = -7.58$, $t = -7.06$, $p < .001$; *t4*: $\beta = -8.91$, $t = -8.29$, $p < .001$), in **MaM** (*t2*: $\beta = -3.06$, $t = -3.48$, $p < .001$; *t3*: $\beta = -3.85$, $t = -4.37$, $p < .001$; *t4*: $\beta = -3.25$, $t = -3.69$, $p < .001$), and in **MiM** (*t2*: $\beta = -2.97$, $t = -3.29$, $p < .001$; *t3*: $\beta = -2.59$, $t = -2.87$, $p = .004$; *t4*: $\beta = -3.01$, $t = -3.35$, $p < .001$). *Creaky* voice was also lower than modal voice in the course of time in **MaF** (*t2*: $\beta = -5.77$, $t = -7.63$, $p < .001$; *t3*: $\beta = -8.55$, $t = -11.30$, $p < .001$; *t4*: $\beta = -5.43$, $t = -7.19$, $p < .001$), in **MiF** (*t2*: $\beta = -5.00$, $t = -5.36$, $p < .001$; *t3*: $\beta = -7.18$, $t = -7.69$, $p < .001$; *t4*: $\beta = -6.94$, $t = -7.44$, $p < .001$), in **MaM** (*t2*: $\beta = -3.56$, $t = -4.23$, $p < .001$; *t3*: $\beta = -6.34$, $t = .7.54$, $p < .001$; *t4*: $\beta = -4.08$, $t = 4.85$, $p < .001$), and in **MiM** (*t2*: $\beta = -2.54$, $t = -3.19$, $p = .002$; *t3*: $\beta = -2.84$, $t = -3.57$, $p < .001$; *t4*: $\beta = -1.87$, $t = -2.34$, $p = .020$).

Results for CPP were more consistent for both sexes and both vowels than the spectral tilt measurements, with a wider range of values (estimates as well as mean values) for women than for men (cf. Figure 2). Not accounting for time course, this measure only distinguished women's breathy /a/ from modal /a/. Nevertheless, CPP distinguished both modal vowels /a/ and /i/ from non-modal vowels in the time course, for men and for women. Modal vowels started at lower values, probably due to effects of the initial consonant, rose in the middle and fell again slightly towards the end, probably due to a slightly breathy offset when the vowel contact was produced with a pause. Breathy and creaky vowels started at similar values but fell to

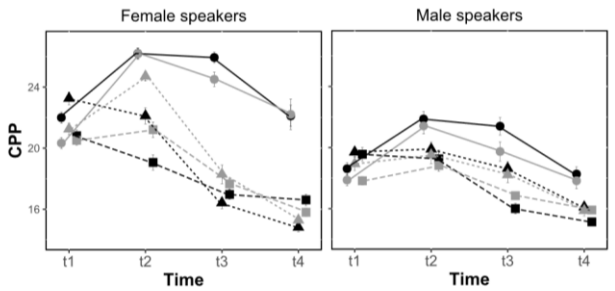

Figure 2: *Mean values and error bars of CPP values for modal (circle, solid line), breathy (triangle, dotted line) and creaky (square, dashed line) vowels /a/ (black) and /i/ (grey) for women (left) and men (right).*

much lower values in the middle and towards the end of the vowel (cf. Figure 2). These results correspond to expectations of CPP for non-modal vowels (e.g., [6, 23]) and show that non-modal phonation is located in the second half of vowels.

4. General discussion and conclusions

The purpose of this study was to find out which acoustic measures (H1*-H2*, H1*-A1*, Cepstral Peak Prominence) are correlates of the phonological phonation contrast in Chichimec, considering low and high vowels. Table 1 presents a comparison of these measures for men and women, separately for the vowels /a/ and /i/.

One of the main findings of this study is that CPP is the best measure to distinguish breathy and creaky voice from modal voice for both sexes and both high and low vowels. However, CPP is a measure that can only distinguish modal from non-modal voice, but not the two non-modal phonation types from each other. For this purpose, we investigated two measures of spectral tilt, H1*-H2* and H1*-A1*. The results for spectral tilt are more complex and show that these measures were not equally good correlates for phonation types for high and low vowels, and for the speech produced by men and women. Both spectral tilt measures distinguished *breathy* and *creaky* from *modal* vowels for women, and *breathy* from *modal* /i/ for men. Our results showed that, for the vowel /i/, spectral tilt measures are better correlates for the contrast *breathy* vs. *modal* than *creaky* vs. *modal* in Chichimec. For men's /a/, however, only H1*-A1* significantly distinguished *creaky* from *modal* phonation. Different tendencies of individual speakers (cf. Section 3.1.) indicate that a study that differentiates between speakers, and not just sex, might yield better results for men, and reveal whether these differences are due to idiosyncrasies or age (cf., [28]).

Another important finding of our study is that all acoustic measures had the best results when considering different portions of the vowel. Except for H1*-A1* values of men's /a/, both spectral tilt measures and CPP distinguished phonation types towards the end of the vowel (cf. Table 1). We thus provide acoustic evidence for the observation that non-modal phonation is predominantly produced towards the end of phonologically breathy /V̤/ and creaky /V̰/ vowels [2].

Women's spectral tilt values of /i/ were incongruent with expectations for spectral tilt as a representation of a constriction continuum (cf. Section 1), whereas men's results did correspond to these expectations and confirmed previous studies of phonation contrasts in /i/ [14][18]. Women's results for /i/, on the other hand, confirm claims made in the literature that more interaction of certain spectral tilt measures with vowel height is expected for speakers with a high F0 (cf., [16, 29]). However, the influence of vowel height on spectral tilt of *different* phonation types was not straight forward. The high vowel did not simply *lower* the values for spectral tilt in comparison with the low vowel (cf., [16]), though this tendency is visible in the mean values of H1*-A1* (cf. Figure 1, mid-right and right panel). Instead, spectral tilt values for women's /i/ vowels were *reversed* for breathy vs. modal, and creaky vs. modal, rather than just lowered (cf., Table 1). Accordingly, our results indicate that spectral tilt measures are not generally inappropriate to characterize phonation types in high vowels, as some authors have cautioned (e.g., [6], cf., Section 1), but that these acoustic measures might not be suitable to describe phonation types of high vowels in women's speech.

Further research, ideally including more spectral tilt measures, is required to fully understand the issue of a stronger interaction of voice source and vocal tract in phonation contrasts for women, and to understand why results for spectral tilt of men's and women's production of /a/ differ. On the basis of the present data, we are able to conclude that CPP is a good measure to characterize phonation contrasts in Chichimec. Additionally, H1*-H2* and H1*-A1* characterize women's production of /a/, and men's contrast of breathy vs. modal voice in /i/. Thus, our results suggest that spectral tilt is not generally inadequate to describe phonation types in high vowels, but that this limitation might only apply to female speakers. Finally, for all measures, it is essential to account for the time course of the vowel in order to accurately describe the acoustics of phonological non-modal vowels in this, and potentially also other languages.

5. Acknowledgements

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Table 1: *Results for H1*-H2*, H1*-A1*, and CPP for* Phonation *(B = breathy, M = modal, C = creaky) in the whole vowel (grey), and its relationship with the portion of the vowel (p < .001 = ***, p < .01 = **, p < .05 = *, p < 0.1 = °, √ = significant, but in unexpected direction).*

	Women				Men			
	Vowel /a/		Vowel /i/		Vowel /a/		Vowel /i/	
H1*-H2*	—	—	B > M *	—	—	—	—	—
	B > M ** in middle and end of V	C < M*** towards end of V	B < M***√ towards end of V	—	—	—	B > M* towards end of V	—
H1*-A1*	—	—	—	—	—	C < M***	—	—
	B > M** in middle and end of V	C < M*** towards end of V	B < M***√ towards end of V	C > M**√ towards end of V	—	—	B > M** towards end of V	—
CPP	B > M *	—	—	—	—	—	—	—
	B < M*** towards end of V	C < M*** towards end of V	B < M*** towards end of V	C < M*** towards end of V	B < M*** towards end of V	C < M*** towards end of V	B < M*** towards end of V	C < M*** towards end of V

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