Khoekhoegowab tone sandhi: New experimental evidence

Abstract

Khoekhoegowab has a tone sandhi process that replaces each underlying tonal melody with an arbitrary secondary melody. This process at first appears to be an unusual example of a "left-dominant" sandhi process in the sense of Yue-Hashimoto (1987); Zhang (2007). Within a given domain, the leftmost word retains its base from, but the other words undergo paradigmatic substitution; left-dominant systems typically involve spreading of a tonal melody rather than substitution. However, this description of Khoekhoegowab sandhi seems to break down when we consider verbs. Prior descriptions disagree as to whether verb sandhi depends on the placement of a tense-marking clitic (Haacke 1999) or the embedding status of the clause (Brugman 2009). This paper presents the results of a new prosodic production experiment aimed at resolving this conflict. The result is a hybrid generalization: verbs in matrix clauses undergo sandhi when preceded by a tense marker, but verbs in embedded clauses resist sandhi across the board. Thus, Khoekhoegowab continues to look like an exceptional left-dominant system: The verb and tense marking form a sandhi domain in matrix clauses (triggering sandhi on the verb whenever it is not leftmost within that domain), but in embedded clauses verbs form their own independent domain instead.

Keywords: prosody, sandhi, tone, Khoisan, understudied languages

1 Introduction

Tone sandhi processes, broadly speaking, can be classified based on whether they preserve the underlying tone of the leftmost or rightmost item in a sandhi domain (Yue-Hashimoto 1987; Zhang 2007). These two classes have been correlated with a strong typological trend: "left-dominant" systems typically involve spread of the tone from the leftmost item across the domain, while "right-dominant" systems typically involve paradigmatic substitution of tones on all but the rightmost item. Shanghai Wu is a typical example of a left-dominant system (1a): The tone on the first syllable spreads

across the disyllabic word, neutralizing the tone on the second syllable (Zee & Maddieson 1980; Zhu 1999; 2006). By contrast, Mandarin Tone 3 sandhi is an example of a right-dominant system (1b): The dipping tone 213 is substituted with a rising tone 35 exactly when followed by another 213; the rightmost 213 is preserved.

(1) a. **Left-dominant**: Shanghai Wu
51-X → 55-31
b. **Right-dominant**: Mandarin
213 → 35 / __ 213

The focus of the present study is Khoekhoegowab, an understudied Khoisan language from Namibia with about 200,000 speakers (Lewis, Simons & Fennig 2016). Khoekhoegowab (also called Khoekhoe) has a sandhi process of opaque melodic substitution (Haacke 1999; Brugman 2009). As typically described, this process is typologically unusual in that it is left-dominant but involves paradigmatic substitution: The leftmost word in each domain keeps its underlying tonal melody, while all other words have their melody replaced. For example, (2) shows that only the leftmost word in a DP retains its underlying tone, while all other words undergo sandhi. In this example, all of the words are underlying high-rising [45]; sandhi causes this melody to be replaced with a level low tone [2] whenever the word is not leftmost in the DP.[1].

(2) Sandhi in DPs (citation forms highlighted): Brugman (2009)
a. **súűku**
pots
b. **|ápấ** sùùku
red pots
c. **!nánǐ** |àpa sùùku
six red pots
d. **‖náấ** !nàni |àpa sùùku
those six red pots

[1] I will follow the tonal notation convention used for Khoekhoegowab by Brugman (2009), in which the diacritics /ấ á à ầ/ correspond to superhigh ([5]), high ([4]), low ([2]), and superlow ([1]), respectively. A vowel with no tone marked indicates that no tone target is associated with it; this results in F0 interpolation between the last tone target and the next. Other than the addition of tone marking where relevant, all examples are presented in Khoekhoegowab standard orthography.

There is a wrinkle in the description of Khoekhoe sandhi as left-dominant, however: In the default SOV word order, verbs show anomalous behavior. Prior descriptions of Khoekhoe disagree on the distribution of verbal sandhi. Brugman (2009) finds that verbal sandhi is determined purely by the syntax: Verbs in matrix clauses undergo sandhi, while verbs in embedded clauses do not. Haacke (1999), by contrast, finds that verbal sandhi is purely determined by the linear order of elements in the clause: If the verb is preceded by a tense-marking auxiliary, it will undergo sandhi; if it is followed by such an auxiliary, it will not.

These two descriptions lead us to quite different conclusions about the nature of Khoekhoe sandhi. If Haacke is right, then Khoekhoe sandhi is post-syntactic and left-dominant: The relevant sandhi domain for the verb also includes the tense marker, and so the verb will undergo sandhi whenever it fails to be leftmost in that domain. By contrast, if Brugman is right then the relevant generalization is a purely syntactic one: Certain syntactic configurations (such as embedding) control whether the citation or sandhi form of a word is inserted, making Khoekhoe neither left- nor right-dominant as such.

This paper presents a novel prosodic production experiment designed to adjudicate between these two analyses. The results of this experiment support a hybrid generalization: tense marker position controls verbal sandhi in matrix clauses (as in Haacke 1999), but embedded verbs always resist sandhi (as in Brugman 2009). This complicates the issue of Khoekhoegowab's relevance to the generalizations described in Zhang (2007) about left- and right-dominant systems.

The rest of this paper will proceed as follows. In Section 2, I will present the basic facts of Khoekhoegowab tone sandhi and discuss the generalizations proposed for verbal sandhi proposed by Brugman and Haacke. In 3, I will describe the design & methodology used for a prosodic production experiment aimed at deciding between the prior analyses of Khoekhoegowab verbal sandhi. Section 4 presents the results of this experiment, and Section 5 discusses some implications of Khoekhoegowab sandhi for our typology of tone sandhi and avenues for future research.

2 Background: Khoekhoegowab tone sandhi

All lexical items in Khoekhoegowab are associated with one of six tonal classes[2]; each tonal class is, in turn, associated with a particular tonal melody made up of a sequence of at most two out of the four contrastive tone levels. The word will be produced with this melody, called the "citation melody", in isolation or in certain prosodically strong positions (defined in more detail below). The citation melodies are given in Table 1 along with a near-minimal sextuplet illustrating the contrast.

Table 1: Citation melodies (Brugman 2009).

Melody	Description	Example	Gloss
[1]	Superlow	[!à̗as]	'servant'
[2]	Low	[ǁàas]	'tie'
[12]	Low-rising	[!nà̗às]	'story'
[4]	High	[ǂáas]	'plain'
[5]	Superhigh	[!nā́as]	'tortoise'
[45]	High-rising	[ǂáā́s]	'spittle'

As noted, the citation melody only surfaces in certain prosodic contexts; in most contexts a process of tonal sandhi applies. Sandhi is an opaque tonal substitution process mapping each of the six citation melodies onto another, apparently arbitrary melody. Sandhi can broadly be characterized as a weakening process in the sense that it reduces the number of cross-linguistically marked tonal melodies: The inventory of sandhi melodies has lower register overall than the inventory of citation melodies and contains fewer rising contours (which are cross-linguistically marked, see e.g. Yip 2002). The six citation melodies and their sandhi counterparts are given in table 2. Note that some citation tones (namely the low-rising and low-level tones) are unaffected by sandhi. Elsewhere, the effect of sandhi is unpredictable: Level tones become contours and vice versa; high-register tones sometimes become low-register ones and sometimes do not; some contrasts are neutralized while others are maintained. Sandhi has the effect of neutralizing the contrast between the superlow and high tone classes, and also between the low and high-rising. In at least one case, sandhi involves

[2] Functional items like auxiliary verbs or nominal affixes also have contrastive tone, but that tone system works differently from the tone on lexical vocabulary; see Brugman (2009) for details.

apparent underapplication opacity ('counterfeeding'): Underlying high tone becomes low-falling; but underlying superhigh tone becomes high without continuing on to become low-falling.

Table 2: Sandhi forms.

Citation			**Sandhi**	
Low-rising	[12]	→	[12]	Low-rising
Superlow	[1]	→	[21]	Low-falling
High	[4]	→	[21]	Low-falling
Low	[2]	→	[2]	Low
High-rising	[45]	→	[2]	Low
Superhigh	[5]	→	[4]	High

2.1 Sandhi domains

I have said that the citation melodies appear in prosodically strong positions, while sandhi applies everywhere else. It's time to make that more precise. Within the nominal domain, the generalization is clear: The leftmost item in a DP (or PP) receives citation form, while all other items undergo sandhi[3]. This is illustrated with a set of DPs in (3), repeated from example (2). In (a) the noun surfaces with its citation melody; in (b), only the adjective 'red' takes citation form, while the noun undergoes sandhi; in (c) only the numeral 'six' keeps its citation form while both 'red' and 'pots' undergo sandhi; and in (d) only determiner 'those' keeps citation form while all other words take sandhi.

(3) Sandhi in DPs (citation forms highlighted): Brugman (2009)

a. **súűku**
pots

b. **|ápấ** sùùku
red pots

c. **!nánĩ** |àpa sùùku
six red pots

[3] All observations about the distribution of sandhi in DPs are due to Brugman (2009) and confirmed by my own fieldwork.

d. **ǁnáã̋** !nàni |àpa sùùku
those six red pots

Put another way, each maximal DP (or PP) is mapped onto a single sandhi domain. Within a sandhi domain, the leftmost position is "strong" in the sense that it resists sandhi and retains its lexically-specified form; all words not in that strong position lose their citation form and take on their sandhi form.

The association between the left edge of phrases and citation melody is preserved when the verb is moved to the left perhiphery (and thus winds up at the left edge of the clause): In this context, the verb takes citation melody regardless of what occurs later in the clause. In (4a), the verb *khomai* 'read' takes its citation tone (superhigh [5]) when fronted; (4b) shows a context in which it takes its sandhi tone (high [4]) in its base, clause-final position. This shows that verbs are subject to the same sandhi process affecting the nominal domain, and that when there is no material which could possibly precede the verb in the sandhi domain, the verb resists sandhi just as expected.

(4) a. **Khőmai** go =b ge Dandagoba ǂkhanisa.
read PST =3MS DECL D. book
"Dandago read the book."
b. Dandagob ge ǂkhanisa go **khómai**.
D. DECL book PST **read**.
"Dandago read the book."

The situation becomes more complex when we consider in situ verbs, however. Previous works on verbal sandhi give contradictory generalizations. Brugman (2009) states that all root-clause (in situ) verbs undergo sandhi, while all embedded clause verbs retain their citation form. That is, for Brugman the distribution of sandhi on the verb is determined purely by the syntax: An Agree relation in the syntax between the complementizer and the verb marks the verb with a feature determining whether it will be spelled out in sandhi or citation form. Later prosodic considerations have no effect.[4]

[4] More specifically, Brugman (2009) argues that embedding complementizers mark their verbs with a "sandhi-resistant" diacritic that prevents them from undergoing sandhi even when prosodic factors would predict it — that is, when the verb is not leftmost in a sandhi domain. This allows her to account for the facts in (4), in which verbs take citation form when topicalized, even in matrix clauses.

By contrast, Haacke (1999) gives a generalization purely based on the linear order of elements. The determining factor, for Haacke, is the placement of tense-marking. Khoekhoegowab marks tense, aspect, and polarity with a set of auxiliaries. These auxiliaries come in two classes. One class of auxiliaries appears postverbally (and generally clause-finally when the verb is in situ); the other class appears before the verb, encliticizing to some XP in the middlefield. In both cases, the tense marking and the verb may be separated by other elements in the clause. For example, (5) and (6) show two coordinated VPs. In (5), the tense marker *tama* 'negative non-future', which belongs to the postverbal class, appears clause-finally, and is thus separated from the first verb *huni* 'stir' by the entire second conjunct. In contrast, (6) shows that the tense marker *go* 'past', which belongs to the preverbal class, may freely encliticize to either the first or the second object, with no change in meaning. If it encliticizes to the second object as in (6a), it is separated from the first verb; if it encliticizes to the first object as in (6b), it is separated from the second verb.

(5) Aob ge mai-e húní́ tsi ǁgan-e áḿ tama.
man DECL pap stir and meat grill NEG.NF
"The man didn't stir the pap or grill the meat."

(6) a. Aob ge mai-e húní́ tsi ǁgan-e go àm.
man DECL pap stir and meat PST grill
"The man stirred the pap and grilled the meat."
b. Aob ge mai-e go hùni tsi ǁgan-e àm.
man DECL pap PST stir and meat grill
"The man stirred the pap and grilled the meat."

Kusmer (2019) argues that the position of the tense marker in Khoekhoegowab is a morphophonological fact rather than a syntactic one.[5] This conclusiono is based on the fact that there is no systematic change in meaning or syntactic structure between clauses bearing preverbal or postverbal tense markers (beyond that attributable to the denotation of the tense marker itself). Put another way, neither the preverbal nor the postverbal class of tense marker forms a morphosyntactic natural class. Tables 3 and 4 give a complete list of all tense markers, separated by class; it can easily be confirmed that there is no one tense, aspect, or polarity feature that defines either class. Instead, the determining factor is a phonological one: Preverbal tense markers are all monomoraic, while postverbal ones are

[5] The facts leading to this conclusion were originally noted by Hahn (2013).

all bimoraic. Kusmer (2019) argues that the preverbal tense markers are postsyntactically-displaced into that position for prosodic reasons, but syntactically originate in the same position as the postverbal markers.

Table 3: Preverbal tense markers .

	IPA	Gloss
a	[ra]	present stative
ra / ta	[ra] / [ta]	imperfect
ge	[ke]	remote past
go	[ko]	recent past
ni	[ni]	future
ta	[ta]	negative non-finite
ga	[ka]	irrealis

Table 4: Postverbal tense markers .

	IPA	Gloss
tama	[tama]	non-future negative
tide	[tite]	future negative
i	[iː]	non-present stative
hâ	[hãː]	perfect

Haacke (1999) states that the tonal melody of the verb is determined by whether tense marking is preverbal or postverbal. Because the position of tense marking is determined postsyntactically, Haacke's analysis thus holds that sandhi is a purely post-syntactic process. His analysis also maintains the characterization of Khoekhoegowab sandhi as "left-dominant": If the verb and the tense marker are assumed to form a sandhi domain together, then the verb can only be leftmost in that domain (and thus resist sandhi) if tense marking is postverbal.

Brugman (2009) and Haacke (1999) thus present very different generalizations for Khoekhoegowab sandhi, with implications for its analysis. These differences are summarized in tables 5 and 6.

In order to resolve the conflict between these generalizations, I conducted a prosodic production experiment, to be described in the next two sections. To preview the results, the final generalization resulting from this experiment is as follows: Root clause verbs undergo sandhi whenever they

Table 5: Brugman's generalization.

	Matrix	Embedded
Preverbal tense	Sandhi	Citation
Postverbal tense	Sandhi	Citation

Table 6: Haacke's generalization.

	Matrix	Embedded
Preverbal tense	Sandhi	Sandhi
Postverbal tense	Citation	Citation

are preceded by a tense marker; embedded clause verbs do not undergo sandhi except in quotative clauses (marked with a special complementizer), where they behave like root verbs. This generalization is summarized in table 7.

Table 7: Results of experiment.

	Matrix	Embedded
Preverbal tense	Sandhi	Citation
Postverbal tense	Citation	Citation

3 Experimental design & methodology

3.1 Speakers

The experimental subjects were 4 native speakers of Khoekhoegowab (3f, 1m), between the ages of 18 & 30. All speakers resided in Windhoek. Two were current UNam graduate students studying Khoekhoegowab; the others were recruited from the author's prior fieldwork consultants.

3.2 Stimuli

The primary experimental manipulation was the position of tense marking. 15 pairs of sentences differing only in the position of tense marking were

constructed, yielding 30 total test items. All of the sentences used the verbs listed in Table 8; these verbs were selected to be mostly sonorant[6] (to aid in F0 tracking) and to have either High or High-Rising citation melodies, which are the two melodies showing the most detectable change under sandhi. Sample pitch tracks for each verb, all taken from the same speaker, are presented in figure 1. In addition to the test items, 12 filler pairs (24 items) were added, which differed only in whether the direct object of the verb had scrambled past another XP; fillers thus superficially resembled test items in showing only word-order differences. Between fillers and test items, there were 54 items in total.

Table 8: List of verbs in experimental items.

Verb	Gloss	Citation		Sandhi	
oa ā om	‘return’ ‘cry’ ‘build’	High	[4]	Low-falling	[21]
mû huni am	‘see’ ‘stir’ ‘grill’	High-rising	[45]	Low	[2]

The test items were further subdivided into 6 **syntactic frames**, 3 matrix and 3 embedded: Matrix declarative clauses (7); matrix constituent Question clauses (8); Relative clefts (9);[7] Nominalized embedded SOV clauses (10); Quotative embedded SOV clauses (11); and matrix VP Coordination clauses (12).[8]

[6] /huni/ ‘stir’ is often produced as [uni].

[7] Brugman (2009) analyses these OVS sentences as a kind of TP fronting. My analysis of them as relative clause clefts hinges on three facts. First, the subject obligatorily undergoes sandhi in this context, as though the noun is not leftmost within its own phrase; this implies that the preceding material (i.e. the embedded clause) is contained within the DP. Second, OVS word order is ungrammatical when the subject is immediately preceded by a demonstrative. This is unexpected if OVS is derived by TP fronting, but expected if the OV constituent is a subject relative clause within the DP — determiners precede DP-internal relatives. Finally, this word order has a unique pragmatic meaning: it is used to convey that the subject is new information while the rest of the clause is given, parallel to cleft structures in other languages.

[8] In examples (7) – (11), the first subexample has a tense marker in preverbal position while the second has a tense marker in postverbal position. In example (12), [a] has the tense marker preceding both verbs; [b] has it preceding only the second; and [c] has it fully postverbally.

The **VP coordination** syntactic frame had one systematic difference from the others: Because there were two verbs, tense marking could be in three locations: Before both verbs (12)[a]; between the verbs (12)[b]; or after both verbs (12)[c]. Because of this, test items in this syntactic frame were constructed in triplets (rather than pairs as described above); in the final analysis, each verb was treated as a separte trial and coded as either preverbal or postverbal.

(7) MATRIX

a. Khoeb ge oms |kha **go** oa.
man DECL home to **PST** return
"The man went home."

b. Khoeb ge oms |kha oa **tama**.
man DECL home to return **NEG.NF**
"The man didn't return home."

(8) QUESTION

a. ǁNa tarasa **go** tae-e am?
that woman **PST** what grill
"What did that woman grill?"

b. ǁNa tarasa tae-e am **tama**?
that woman what grill **NEG.NF**
"What didn't that woman grill?"

(9) RELATIVE

a. Oms |kha **go** oa khoeb ge.
home to **PST** return man DECL
"It was that man who returned home."

b. Oms |kha oa **tama** khoeb ge.
home to return **NEG.NF** man DECL
"It was the man who didn't return home."

(10) NOMINALIZED

a. Mî ta ge ra Dandagob **go** oms |kha oa sa.
say I DECL IMP D. **PST** home to return -COMP
"I am saying that Dandago returned home."

b. Mî ta ge ra Dandagob oms |kha oa **tama** sa.
say I DECL IMP D. home to return **NEG.NF** -COMP
"I am saying that Dandago didn't return home."

(11) QUOTATIVE

a. Mî ta ge ra arib ge |hôasa **go** mû ti.
say I DECL IMP dog DECL cat **PST** see C.QUOT
"I am saying that the dog saw the cat."

b. Mî ta ge ra arib ge |hôasa mû **tama** ti.
say I DECL IMP dog DECL cat see **NEG.NF** C.QUOT
"I am saying that the dog didn't see the cat."

(12) COORDINATION

a. Aob ge mai-e **go** huni tsi ǁgan-e am.
man DECL pap **PST** stir and meat grill
"The man stirred the pap and grilled the meat."

b. Aob ge mai-e huni tsi ǁgan-e **go** am.
man DECL pap stir and meat **PST** grill
"The man stirred the pap and grilled the meat."

c. Aob ge mai-e huni tsi ǁgan-e am **tama**.
man DECL pap stir and meat grill **NEG.NF**
"The man didn't stir the pap or grill the meat."

These 6 syntactic frames were selected to fully distinguish between the two prior analyses. Most embedded clauses in Khoekhoegowab are nominalized; the contrast between the **matrix** and **nominalized** frames is thus crucial. Under Brugman's analysis, all items in the **matrix** frame should undergo sandhi, while no items in the **nominalized** frame should; under Haacke's analysis the items with preverbal tense marking in both frames should show sandhi, while the items with postverbal tense marking should not.

The other syntactic frames are present in order to test variations on the two analyses. Matrix declaratives in Khoekhoegowab always have a second-position clitic marking the clause type (Hagman 1977); embedded clausess do not have such a marker. A possible variation on Brugman's analysis is to hypothesize that it is the presence or absence of such a marker that correlates with verbal sandhi, not the clause type itself. Matrix questions in Khoekhoegowab typically lack a clause-type marker (and thus superficially resemble embedded clauses); by contrast, quotative embedded clauses, which take a special complementizer only available under verbs of reported speech, exceptionally do take a clause-type marker (and thus superficially resemble matrix clauses). If it is the clause-type marker that controls verbal sandhi, we predict the **quotative** frame to uniformly undergo sandhi and the **question** frame to uniformly fail to do so.

The VP coordination frame serves to disambiguate two interpretations of Haacke's generalization. In one interpretation, the presence of a tense-

marker from the preverbal class that triggers sandhi on the verb regardless of their actual relative positions. In the other interpretation, it is the linear order of tense marker and verb that matters, not the class to which the tense marker belongs. If the former analysis is correct, preverbal tense markers will trigger sandhi on the first verb even when they linearly follow it; if the latter analysis is correct, preverbal tense markers will only trigger sandhi on that verb when they linearly precede it.

Finally, the relative cleft frame serves to confirm that it is embedded clauses in general, rather than nominalized clauses in specific, that resist sandhi under Brugman's analysis.

A full list of all stimuli, including fillers, is presented in the appendix.

3.3 Procedure

Sentences were presented on a laptop screen; only one sentence was on screen at time, and speakers could advance to the next sentence at their own pace. Each speaker saw all 54 sentences in a random order, and were then instructed to take a short break, after which this was repeated with a different randomized order such that each speaker saw each item twice. The entire procedure took between 15 and 30 minutes, depending on speaker.

Speakers were asked to read each sentence aloud as naturally as possible. The sentences were all recorded on a Zoom H5 recorder using a Shure SN10A-CN head-mounted microphone.

3.4 Analysis

After recording, individual items were segmented and then force-aligned using the Montreal Forced Aligner (McAuliffe et al. 2017), which was trained on a dataset of the author's fieldwork elicitation encompssing roughly 4.5 hours of transcribed Khoekhoegowab speech from 8 speakers. After alignment, the TextGrid boundaries of each verb were hand-adjusted in Praat (Boersma & Weenink 2001) and a script was used to extract the audio of each verb token into its own file; in this process, 5 tokens were rejected because the resulting recording was inaudible due to the speaker reducing the verb.[9] The remaining 283 tokens were coded for tense position (preverbal or postverbal) and syntactic frame. Tokens from the VP coordination frame were coded based on whether the tense marker linearly preceded the verb

[9] Speakers frequently partially devoiced the vowel of the verb when it was clause-final; the 5 rejected items all had a fully devoiced vowel.

in question, not whether the tense marker was drawn from the preverbal or postverbal class. For example, in (13) the first verb *huni* 'stir' was coded as having postverbal tense marking because *go* 'past' linearly follows it, even though *go* is from the preverbal class. (*Am* 'grill' was coded as preverbal, as normal.)

(13) Aob ge mai-e huni tsi ǁgan-e **go** am.
man DECL pap stir and meat **PST** grill
"The man stirred the pap and grilled the meat."

To exclude the possibility of confirmation bias in my own transcriptions, I used the following procedure to code the results: Three phonetically-trained naive transcribers (all native English speakers with no prior experience Khoekhoegowab) were asked to sort the tokens into "high" (citation form) and "low" (sandhi form). Transcribers were given the tokens sorted by speaker and lexical item, with all information about syntactic frame and tense-marker position removed, so as to blind them to the experimental manipulation. Additionally, I hand selected two tokens of each surface tone contour used in the experiment (High-rising, Low, High, & Low-falling) that I felt were protypical examples, to serve as reference points for the transcribers. To provide one additional datapoint, I performed the same blind transcription.

There was broad agreement between the transcribers; the transcriptions overall showed a Fleiss' Kappa[10] of 0.77, indicating substantial agreement. What disagreement exists is likely due to the effects of voice quality obscuring perceptions of tone; in particular, Speaker 3 spoke predominantly in breathy voice, while Speaker 4 spoke primarily in creak.

In order to confirm that the transcribers were attending to the intended phonetic differences, the smoothed mean pitch tracks in Figure 2 were created. A Praat script was used to extract F0 at 20 evenly-spaced points across each verb. For the purpose of constructing these graphs, individual recordings were treated as having undergone sandhi only if a majority of transcribers marked that item as "low"; all others were treated as having citation form. Loess smoothing was used to construct an average pitch track across all items. From this, it can be seen that transcribers are in fact distinguishing the citation and sandhi forms: For both tone classes the citation forms (HR and H) are distinctly higher than the sandhi forms (L and LF);

[10] Fleiss' Kappa is a measure of inter-transcriber agreement; see Fleiss (1971). It generalizes the widely-used Cohen's Kappa to datasets with more than 2 transcribers.

HR does show a distinctive final rise, while H is level. Both the L and LF forms fall only slightly, but are still distinguishable by level.

4 Results

Having confirmed that transcribers were distinguishing the relevant tone classes, the hypotheses discussed above were tested against these blind transcriptions using a logistic regression model. The dependent variable was whether a given observation was transcribed as "low" (i.e. "sandhi"); the model looked for fixed effects of syntactic frame (6 levels: Matrix, Question, Coordinated, Quotative, Nominalized, & Relative) and tense marker position (2 levels: Pre and Post), plus interactions between these.

(14) **Model:** `Sandhi ~ Frame * Position`

In order to distinguish the various alternatives to Brugman's generalization, a custom contrast matrix (Bruin 2011) was used for the syntactic frame variable to make the following comparisons:

(15)
a. Group mean of Matrix, Question, Coordinated, & Quotative ('matrix-like' clauses) vs. group mean of Nominalized & Relative
b. Mean of Matrix vs. mean of Question
c. Mean of Matrix vs. mean of Quotative
d. Mean of Matrix vs. mean of Coordinated
e. Mean of Nominalized vs. mean of Relative

This model allows us to distinguish between 3 competing hypotheses (and some subcases):

(16)
a. **Hypothesis A: Haacke's generalization**
The verb undergoes sandhi iff...
(i) ...it is preceded by tense-marking.
Prediction: Main effect of Position; no main effect of Frame[d].
(ii) **A′:** ...it is associated with a tense-marker from the "preverbal" class.
Prediction: Main effects of Position and Frame[d].
b. **Hypothesis B: Brugman's generalization**
The verb undergoes sandhi iff...

(i) ...it is in a matrix-like clause.
Prediction: Main effect of FRAME[A]

(ii) **B′:** ...it is in a clause with a second-position clause type marker.
Prediction: Main effect of FRAME[B]; no main effect of FRAME[C].

c. **Hypothesis C: Hybrid**
The verb undergoes sandhi iff it is both preceded by tense marking and in a matrix-like clause.
Prediction: Main effect of POSITION and interaction between POSITION & FRAME[A].

The results of the model are presented in Table 9.

Table 9: Significant coefficients.

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-2.3326	0.2100	-11.107	< 2e-16	***
Pos[Pre]	3.2699	0.2837	11.524	< 2e-16	***
Frame[a]	0.5480	0.5539	0.989	0.32252	
Frame[b]	0.5312	0.5371	0.989	0.32268	
Frame[c]	0.6855	0.3925	1.747	0.08069	
Frame[d]	-0.3645	0.4258	-0.856	0.39189	
Frame[e]	2.8904	1.0522	2.747	0.00601	**
Frame[a]:Pos[Pre]	3.9183	0.7060	5.550	2.86e-08	***
Frame[b]:Pos[Pre]	0.3840	0.7898	0.486	0.62684	
Frame[c]:Pos[Pre]	0.3645	0.8402	0.434	0.66436	
Frame[d]:Pos[Pre]	0.7444	0.6075	1.225	0.22048	
Frame[e]:Pos[Pre]	-0.1030	1.3010	-0.079	0.93689	

The significant main effect of position is compatible with Hypothesis A (Haacke's generalization). The positive coefficient indicates that preverbal tense-marker position does correlate with higher rates of sandhi on the verb. That there is no main effect of FRAME[D] supports Hypothesis A over Hypothesis A′ — it is the absolute position of the tense marker with respect to the verb that matters, not which positional class it belongs to.

The lack of significance for a main effect of FRAME[A] (which compares matrix-like syntactic frames to embedded ones) is incompatible with Hypothesis B (Brugman's generalization): If sandhi were conditioned by the

embedded status of the clause, this coefficient should be significantly positive. Similarly, the lack of a main effect of FRAME[B] is incompatible with Hypothesis B′.

However, there is also a significant interaction between Frame[a] (which compares "matrix-like" syntactic frames to embedded clauses) and tense marker position. The positive coefficient indicates that transcribers were significantly more likely to mark a verb as having undergone sandhi if it was in a matrix-like syntactic frame and had preverbal tense-marking. This is compatible with Hypothesis C, the hybrid model: preverbal tense markers trigger sandhi on the verb only in matrix-like clauses; embedded clauses systematically resist sandhi, regardless of tense marker position.

The significance of FRAME[E] (NOMINALIZED vs. RELATIVE) is due to a confound in the experimental design. Examples of both these syntactic frames are repeated below, with the verb highlighted. Note that in the RELATIVE case, the verb is significantly closer to the start of the utterance than in the NOMINALIZED case. This means that downdrift (see e.g. Connell 2001) has had longer to apply in the NOMINALIZED case; in other words, the overall F0 range of verbs will be both smaller and lower in the NOMINALIZED case than the RELATIVE one. This likely lead to more verbs being transcribed as low (i.e. having undergone sandhi) regardless of ground truth.

(17) a. RELATIVE:
Oms |kha go **oa** khoeb ge.
home to PST **return** man DECL
"It was that man who returned home."

b. NOMINALIZED:
Mî ta ge ra Dandagob go oms |kha **oa** sa.
say I DECL IMP D. PST home to **return** -COMP
"I am saying that Dandago returned home."

Overall, then, the results of the model support the hybrid model Hypothesis C: In most embedded clause types, verbs resist sandhi; elsewhere, verbs undergo sandhi exactly when preceded by tense marking.

5 Discussion

Khoekhoegowab sandhi, at first glance, appears to be left-dominant in the sense discussed by Zhang (2007): Within some domain, the leftmost item

retains its underlying tone while all other items undergo sandhi. However, Khoekhoegowab is typologically unusual within this class: left-dominant sandhi systems most typically involve spreading of the leftmost tone over the non-leftmost elements; Khoekhoe sandhi instead involves paradigmatic melodic substitution, which is typically characteristic of right-dominant systems.

Khoekhoegowab verbs present a problem for the characterization of this sandhi process as left-dominant. The experiment reported here shows that verbal sandhi obeys the generalization repeated in Table 10. In matrix clauses, verbal sandhi is plausibly left-dominant: If the verb and its tense marking are taken to form a sandhi domain[11], then the verb will only be leftmost in that domain when it precedes the tense marker. However, this apparent relationship is disrupted in embedded clauses: In most embedded clause types, verbs resist sandhi regardless of the position of tense. This draws into question the relevance of Khoekhoegowab sandhi to the typology discussed in Zhang (2007) and elsewhere.

Table 10: Results of experiment (repeated from Table 7) .

	Matrix	**Embedded**
Preverbal tense	Sandhi	Citation
Postverbal tense	Citation	Citation

5.1 Variation

The data reported here expands on previous descriptions of Khoekhoegowab prosody in another respect: All previous descriptions have said that Khoekhoe sandhi is categorical[12], while the results of this experiment leave open the possibility that it is variable: No two transcribers agreed on 100% of the tokens.

Some of this variability is certainly due to transcriber error. All transcribers were non-Khoekhoegowab-speaking, and thus it is highly likely that

[11] For example, as the result of a constraint requiring Extended Projections to be prosodically phrased together (as proposed by López 2009)), or as the result of a constraint requiring argument-selection relations to be maintained in prosody (as proposed by Clemens 2019).

[12] Brugman (2009) does acknowledge variability in one limited respect: nouns preceded by a relative clause sometimes anomalously resist sandhi. Verbal sandhi, though, is said to be categorical.

the transcriptions are not perfectly accurate to the true phonological form of the token. That is, there certainly some tokens which have phonologically undergone sandhi but which were transcribed as having citation form, and vice versa.

But transcriber error cannot fully explain the variability in the data. For example, Figure 3 presents the F0 pitch tracks for two tokens of the same verb from the same speaker in the same condition (one from each block) — in both cases, the sentence in (18). Even if we allow for variability in F0 range between utterances, the two tokens here have different contours; it seems likely that one is High-Rising (citation form) while the other is Low (sandhi form). This seems to be a case of intra-speaker variability in verbal sandhi.

(18) Aob ge mai-e go huni tsi ǁgam-e **am**.
man DECL pap PST stir and meat **grill**
"The man stirred the pap and grilled meat."

There are a variety of known sources of variation that this experiment was not designed to control for. For example, speech rate is known to affect prosodic phrasing, with higher speech rates being associated with fewer prosodic boundaries (Fougeron & Jun 1998). It's possible that, at slower speech rates, speakers may insert a prosodic break before the verb, allowing it to retain citation form (by virtue of being at a left edge) even when the syntactic structure would normally lead to a different prosodic structure. It's also possible that this variation is either disfluency (i.e. the speaker simply misspoke) or an effect of the experimental task (for example, list intonation).

However, the experimental results do show that the generalizations reported here are strong trends and seem to reflect the normal case. As such, further research is required to determine the sources and extent of variation in Khoekhoegowab tone sandhi.

Appendix: Experimental stimuli

MATRIX:

(19) Khoeb ge oms |kha **go** *oa*.
man DECL home to **PST** *return*
"The man returned home."

(20) Khoeb ge oms |kha *oa* **tama**.
man DECL home to *return* **NEG.NF**
“The man didn’t return home.”

(21) Khoeb ge oms |kha **go** **-ro** *oa*.
man DECL home to **PST** **-IMP** *return*
“The man was returning home.”

(22) Khoeb ge oms |kha *oa* **hâ**.
man DECL home to *return* **PERF**
“The man has returned home.”

(23) |Gôab ge mai-e **go** *huni*.
boy DECL pap **PST** *stir*
“The boy stirred the pap.”

(24) |Gôab ge mai-e **go** **-ro** *huni*.
boy DECL pap **PST** **-IMP** *stir*
“The boy was stirring the pap.”

(25) |Gôab ge mai-e *huni* **tama**.
boy DECL pap *stir* **NEG.NF**
“The boy didn’t stir the pap.”

(26) |Gôab ge mai-e *huni* **hâ**.
boy DECL pap *stir* **PERF**
“The boy has stirred the pap.”

NOMINALIZED:

(27) Mî ta ge ra [Dandagob **go** oms |kha *oa* -sa.]
say I DECL IMP D. **PST** home to *return* -COMP
“I am saying that Dandago returned home.”

(28) Mî ta ge ra [Dandagob oms |kha *oa* **tama** -sa.]
say I DECL IMP D. home to *return* **NEG.NF** -COMP
“I am saying that Dandago didn’t return home.”

(29) Mî ta ge ra [|gôab **go** mai-e *huni* -sa.]
say I DECL IMP boy **PST** pap *stir* -COMP
“I am saying that the boy stirred the pap.”

(30) Mî ta ge ra [|gôab mai-e *huni* **tama** sa.]
say I DECL IMP boy pap *stir* **tama** -COMP
“I am saying that the boy didn’t stir the pap.”

COORDINATION:

(31) Aob ge [mai-e *huni*] tsi [ǁgan-e **go** *am*.]
man DECL pap *stir* and meat **PST** *grill*
“The man stirred the pap and grilled the meat.”

(32) Aob ge [mai-e **go** *huni*] tsi [ǁgan-e *am*.]
man DECL pap **PST** *stir* and meat *grill*
“The man stirred the pap and grilled the meat.”

(33) Aob ge [mai-e *huni*] tsi [ǁgan-e *am* **tama**.]
man DECL pap *stir* and meat *grill* **NEG.NF**
“The man didn’t stir the pap or grill the meat.”

(34) Khoedages ge [omsa *om*] tsi [ǁgam-e **go** *ā*.]
K. DECL house *build* and water **PST** *drink*
“Khoedage built the house and drank water.”

(35) Khoedages ge [omsa **go** *om*] tsi [ǁgam-e *ā*.]
K. DECL house **PST** *build* and water *drink*
“Khoedage built the house and drank water.”

(36) Khoedages ge [omsa *om*] tsi [ǁgam-e *ā* **tama**.]
K. DECL house *build* and water *drink* **NEG.NF**
“Khoedage didn’t build the house and drink water.”

Relative:

(37) [Oms |kha **go** *oa*] khoeb ge.
home to **PST** *return* man DECL
“It was the man who returned home.”

(38) [Oms |kha *oa* **tama**] khoeb ge.
home to *return* **NEG.NF** man DECL
“It was the man who didn’t return home.”

(39) [Mai-e **go** **-ro** *huni*] |gôab ge.
pap **PST** **-IMP** *huni* boy DECL
“It was the boy who stirred the pap.”

(40) [Mai-e *huni* **hâ**] |gôab ge.
pap *huni* **PERF** boy DECL
“It is the boy who has stirred the pap.”

Quotative:

(41) Mî ta ge ra [arib ge |hôasa **go** *mû* ti.]
say I DECL IMP dog DECL cat **PST** *see* C.QUOT
“I am saying that the dog saw the cat.”

(42) Mî ta ge ra [arib ge |hôasa *mû* **tama** ti.]
say I DECL IMP dog DECL cat *see* **NEG.NF** C.QUOT
"I am saying that the dog didn't see the cat."

(43) Mî ta ge ra [ne khoes ge ǁgan-e **go** *am* ti.]
say I DECL IMP this woman DECL meat **PST** *grill* C.QUOT
"I am saying that this woman grilled the meat."

(44) Mî ta ge ra [ne khoes ge ǁgan-e *am* **hâ** ti.
say I DECL IMP this woman DECL meat *grill* **PERF** C.QUOT
]

"I am saying that this woman has grilled the meat."

QUESTION:

(45) ǁNa tarasa **go** tae-e *am*?
that woman **PST** what *grill*
"What did that woman grill?"

(46) ǁNa tarasa tae-e *am* **tama**?
that woman what *grill* **NEG.NF**
"What didn't that woman grill?"

(47) ǁNa |gôaba **go** **-ro** tae-e *ā*?
that boy **PST -IMP** what *drink*
"What did that boy drink?"

(48) ǁNa |gôaba tae-e *ā* **hâ**?
that boy what *drink* **PERF**
"What has that boy drunk?"

FILLER:

(49) ǁAri =b ge ne khoeba ǁnaba ǂna tama.
yesterday =3MS DECL this man there dance NEG.NF
"This man didn't dance there yesterday."

(50) ǁAri =b ge ǁnaba ne khoeba ǂna tama.
yesterday =3MS DECL there this man dance NEG.NF
"This man didn't dance there yesterday."

(51) Nesi =b ge ariba |hôasa nâ tide.
now =3MS DECL dog cat bite NEG.FUT
"Now the dog will not bite the cat."

(52) Nesi =b ge |hôasa ariba nâ tide.
now =3MS DECL cat dog bite NEG.FUT
“Now the dog will not bite the cat.”

(53) Netsē =b ge khoeba oms |kha go oa |khi.
today =3MS DECL man home to PST return come
“Today the man came back home.”

(54) Netsē =b ge oms |kha khoeba go oa |khi.
today =3MS DECL home to man PST return come
“Today the man came back home.”

(55) ǁNaba =s ge tarasa !gâise go -ro ǁnae.
there =3FS DECL woman well PST -IMP sing
“The woman was singing well there.”

(56) ǁNabas ge !gâise tarasa go -ro ǁnae.
there =3FS DECL well woman PST -IMP sing
“The woman was singing well there.”

(57) Netsē =b ge axaba !haese ǂû hâ.
today =3MS DECL boy quickly eat PERF
“Today the boy has eaten quickly.”

(58) Netsē =b ge !haese axaba ǂû hâ.
today =3MS DECL quickly boy eat PERF
“Today the boy has eaten quickly.”

(59) Tsī =b ge |gôaba |hūsa go mû.
and.then =3MS DECL boy spider PST see
“And then the boy saw the spider.”

(60) Tsī =b ge |hūsa |gôaba go mû.
and.then =3MS DECL spider boy PST see
“And then the boy saw the spider.”

(61) Dandagob ge ǂkhanisa ǁîb |gôasa khomai -ba hâ.
D. DECL book his daughter read -APPL PERF
“Dandago has read the book to his daughter.”

(62) Dandagob ge ǁîb |gôasa ǂkhanisa khomai -ba hâ.
D. DECL his daughter book read -APPL PERF
“Dandago has read the book to his daughter.”

(63) Khoedages ge ǁgau!na-aoba ǁnaba ra !hoa-u.
K. DECL teacher there IMP talk.to
“Khoedage is talking to the teacher over there.”

(64) Khoedages ge ǁnaba ǁgau!na-aoba ra !hoa-u.
K. DECL there teacher IMP talk.to
“Khoedage is talking to the teacher over there.”

(65) Tita ge ǂkhanisa ǁkhawa ra xoa.
I DECL book again IMP write
“I am writing a book again.”

(66) Tita ge ǁkhawa ǂkhanisa ra xoa.
I DECL again book IMP write
“I am writing a book again.”

(67) |Hôas ge ariba netsē mû tama.
cat DECL dog today see NEG.NF
“The cat didn’t see the dog today.”

(68) |Hôas ge netsē ariba mû tama.
cat DECL today dog see NEG.NF
“The cat didn’t see the dog today.”

(69) ǁNa |gôa-i ge khoe-e ǂanebega-se nâ tama.
that child DECL someone on.purpose bite NEG.NF
“That child bit someone on purpose.”

(70) ǁNa |gôa-i ge ǂanebega-se khoe-e nâ tama.
that child DECL on.purpose someone bite NEG.NF
“That child bit someone on purpose.”

(71) ǁGau!na-aos ge ne axaba netsē !hoa-u tide.
teacher DECL this boy today talk.to NEG.FUT
“The teacher didn’t talk to this boy today.”

(72) ǁGau!na-aos ge netsē ne axaba !hoa-u tide.
teacher DECL today this boy talk.to NEG.FUT
“The teacher didn’t talk to this boy today.”

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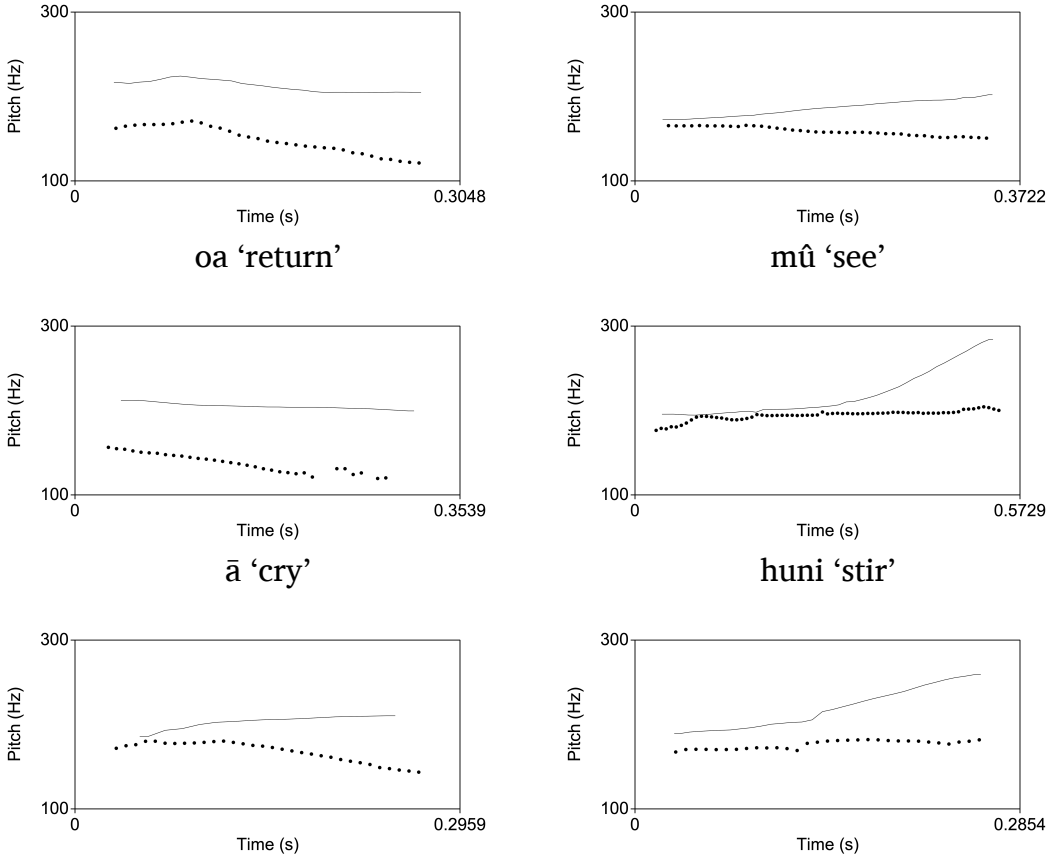

Figure 1: Sample pitch tracks for all six verbs, taken from the same speaker. Solid lines are citation form; dotted lines are sandhi form. Verbs in the left column alternate between [4] & [21]; verbs in the right column alternate between [45] & [2].

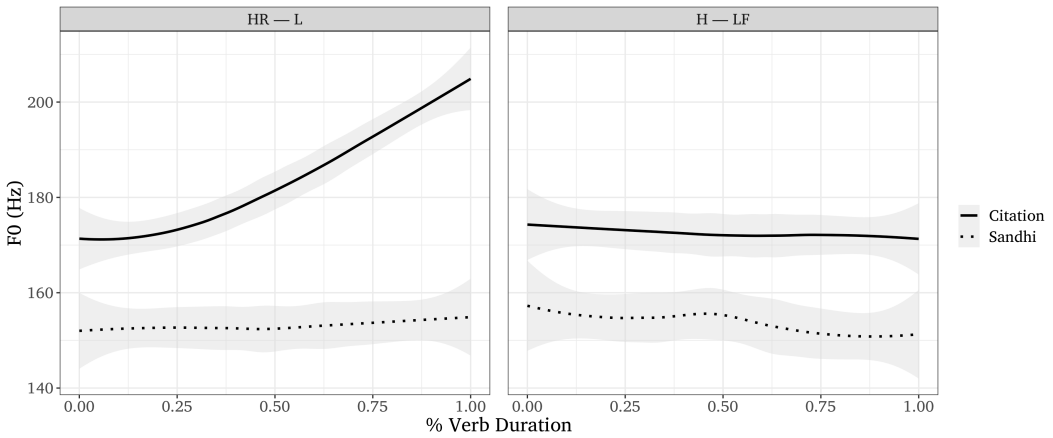

Figure 2: Mean pitch tracks.

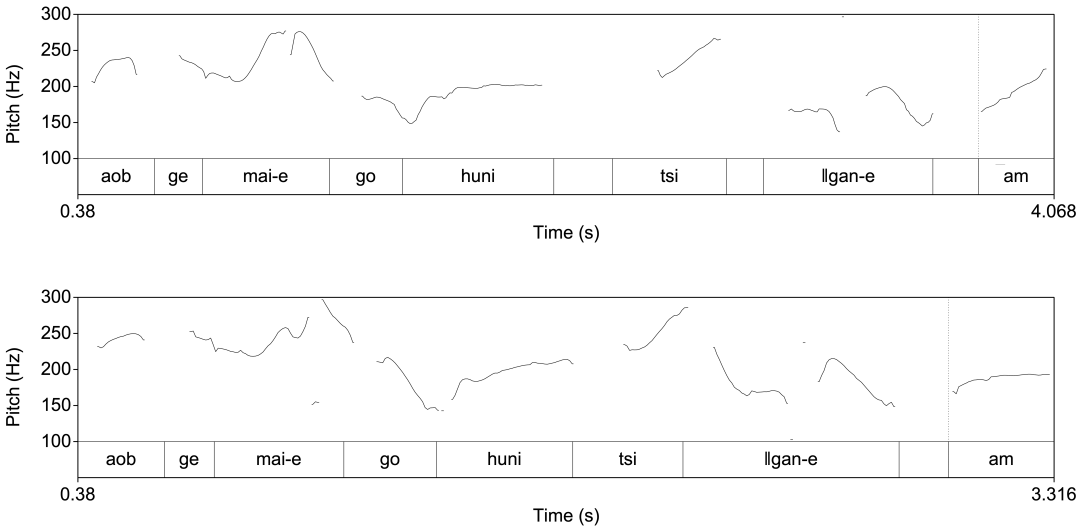

Figure 3: Pitch tracks for two tokens of (18) from the same speaker, showing variation in tone of /am/ ‘grill’.