Journal of Phonetics 104 (2024) 101323

Contents lists available at ScienceDirect

Journal of Phonetics

journal homepage: www.elsevier.com/locate/Phonetics

The phonetics of vowel intrusion in Sgi Bara

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ARTICLE INFO

Article history:
Received 17 July 2023
Received in revised form 11 March 2024
Accepted 12 March 2024

Keywords:
Intrusive vowels
Vowel reduction
Epenthesis
Contrastiveness
Consonant clusters
Wordhood
Papuan languages

ABSTRACT

We provide a phonetic examination of intrusive vowels in Sgi Bara [jil]. These vowels are inserted in predictable places, and their quality (either [i], [ɨ], or [u]) is also predictable, so they are not considered phonemic. We demonstrate that they differ from phonemic vowels in their duration, being shorter; and in their articulation, being more peripheral; but not in their intensity. We then demonstrate how this phonetic understanding of the difference between intrusive and phonemic vowels can be used to answer phonological questions about Sgi Bara. We offer two case studies: phonologically ambiguous sequences of high vowels, and frequent two-word combinations that may be univerbating. The results confirm the existence of a distinction between intrusive and phonemic vowels.

1. Introduction

Many languages possess vowels which are phonetically present but which pose problems for phonological analysis because they do not behave like phonological segments. Such vowels, which have been called intrusive (Hall, 2006), can occur in different environments, such as at word edges (see Henderson & Dobson, 1994 on Arrernte) or in consonant clusters (as in Sye; Crowley, 1998). Such systems are often considered from a phonological perspective, since they raise interesting theoretical issues for phonological theory. But it is also important to understand these systems phonetically, because although intrusive vowels are often phonetically present, they also differ in important ways from their phonologically real counterparts.

In this paper, we examine the intrusive vowels of Sgi Bara, a Trans New Guinea language of Papua New Guinea. In Sgi Bara, the high vowels [i], [ɨ], and [u] can be inserted to break up certain consonant clusters. These intrusive vowels are optional, but fairly frequent. The clearly phonemic vowels are /i e a o u/, which means that there is a difference between the phonemic high vowels /i u/ and the intrusive ones. We compare these two categories, finding statistically significant differences. We then use that phonetic understanding to examine aspects of the phonology of Sgi Bara that pose analytical challenges, demonstrating how phonetics can inform phonology and *vice versa*.

In the following section, we discuss the concept of intrusive vowels in greater detail. Then we introduce the Sgi Bara language and its phonological inventory (§3), describe our methods (§4) and the results (§5) of our phonetic analysis, and finally discuss its application to phonological analyses (§6) before offering a brief conclusion (§7).

2. Intrusive vowels

In the literature on 'inserted' vowels, phonologists recognize a distinction, most clearly articulated by Hall (2006), between vowels that are epenthetic and those that are intrusive. Epenthetic vowels are those that are visible to the phonological system—that is, they participate in phonological processes such as stress assignment. Intrusive vowels, sometimes also called excrescent vowels (e.g., Levin, 1987), by contrast, are invisible to all phonological processes. This dichotomy is, predictably, too simple, and numerous phenomena do not fit neatly into either category (Blevins & Pawley, 2010; Tabain & Breen,

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https://doi.org/10.1016/j.wocn.2024.101323
0095-4470/

2011; see also Levin, 1987). But it remains a useful tool for typological comparison, and allows us to recognize that vowels may exhibit differing degrees of interaction with phonological processes.

Discussion around inserted vowels, whether epenthetic or intrusive, has centered around a few questions. First there is the question of an articulatory target: are these vowels stored in speakers' mental representations of words, and given their own articulatory gesture? Or are they simply byproducts of other, more purposeful gestural movements that speakers make, emerging merely as a figment of their articulation? Browman & Goldstein (1992), for example, found evidence for an articulatory target in reduced English schwa tokens. Davidson & Stone (2003), however, found no such evidence when they induced English speakers to produce intrusive schwas. Related to the question of articulatory substance is the question of length, and there seems to be consensus that epenthetic and intrusive vowels are shorter than others (cf. Hall, 2011 on Lebanese Arabic and Hocank).

Another topic that has received considerable attention is the "insertion or reduction" question. Essentially, have these vowels been inserted into words where they originally did not exist, or are they erstwhile full vowels that have been reduced? This distinction can be made at the historical level, when describing the diachronic origins of various vowel systems, but also at the synchronic level, when describing phonological models of speech production. Historically, it is clear that systems of vowel epenthesis and intrusion can arise in a wide variety of ways, including insertion (Tabain & Breen, 2011), reduction (Huang, 2018), and others (Blevins & Pawley, 2010). There is no single diachronic pathway to the phenomena under discussion. Synchronically, there is a similarly diverse set of phenomena on display. Reduced vowels in Russian are the result of reduction (Iosad, 2012), but the phenomenon we discuss below is, synchronically at least, clearly insertion. Notably, reduction does not always have to result in more central vowel qualities, but can also be 'centrifugal', yielding the peripheral values *a, i,* and *u* (Harris, 2005).

Related to the question of these vowels' origin is the question of their function: what are they there for? This question is particularly pertinent for intrusive vowels, since such vowels, by definition, do not contrast with anything, including the absence of themselves, and so appear at first blush to be functionally deficient in an important sense. Gestural timing varies from language to language, even in otherwise identical consonant clusters (Pouplier et al., 2020), so it could be supposed that all non-phonemic vowels, even very long ones, are simply due to differing degrees of gestural overlap. But this is scarcely an explanation, and it has been suggested that inserted vowels may provide formant cues for adjacent consonants (Tabain & Breen, 2011). Work on highly complex consonant clusters, which frequently exhibit vowel intrusion, lends credence to this idea (Easterday, 2019).

Vowel intrusion has been recognized as an areal pattern among Papuan languages for some time (Foley, 1986), and has been documented before among members of the Madang family, such as Kalam (Pawley, 1966; Blevins & Pawley, 2010; Pawley & Bulmer, 2011) and Anamuxra (Ingram, 2001). These intrusive vowels are often high, rather than mid. The high central vowel [ɨ] is also common areally, whether it is analyzed as intrusive, as above, or phonemic, as in Kobon (Davies, 1980) and most Sogeram languages (Daniels, 2015).

In this paper we provide a phonetic analysis of intrusive vowels in Sgi Bara, a Trans New Guinea language spoken in Papua New Guinea. We cannot hope to answer all of the questions we raised, but instead make a more modest contribution. The phonetic literature on vowel intrusion is relatively sparse and does not provide clear descriptions of the phonetic properties of these vowels. Therefore, we provide an analysis of the phonetic features of intrusive vowels and those vowels which are analyzed as being phonologically real. In doing so, we hope to provide phonetic evidence in support of addressing these fundamentally phonological questions.

3. The Sgi Bara language

Sgi Bara[1] is spoken in Madang province, Papua New Guinea (PNG), in the northwestern foothills of the Finisterre Range, near Astrolabe Bay (see the map in Fig. 1). The language's speakers, who probably number around 700, primarily live in the three villages of Albu, Dumbu, and Jilim. Communities in northern PNG have been shifting to Tok Pisin for decades (Kulick, 1992), and Sgi Bara is no exception. Young adults are usually still fluent speakers of the language, but children are generally only passively fluent. During approximately three months in Jilim village between 2016 and 2022, Daniels never observed anyone under 15 using the language.

Sgi Bara belongs to the large Trans New Guinea family (Pawley & Hammarström, 2018), within which it is a part of the 108-language Madang branch (Z'graggen, 1975a, Daniels, to appear) and then the 31-member Rai Coast subgroup (Z'graggen, 1980). Sgi Bara was first surveyed by John Z'graggen in 1969 (1971: 104), but only briefly. He surveyed the area again in more detail in the early 70′s (1975b: 13), and eventually published a wordlist of around 350 items for each of the Rai Coast languages (1980).

This wordlist was the only documentation of Sgi Bara when Daniels began fieldwork in 2016. He visited Jilim village twice in 2016, once in 2018, and once in 2022, each time staying between two and four weeks. He and the community have recorded over 14 hours of naturalistic Sgi Bara speech (primarily monologic narratives, but also some procedural and expository monologues, as well as dialogues and dramatic reenactments), of which over 4.6 hours have been transcribed and translated into Tok Pisin. It is from this corpus of naturalistic speech that we have selected recordings for analysis.

The consonant inventory that we assume for Sgi Bara is given in Table 1. In cases where the orthographic symbol we use differs from the IPA symbol, the orthographic symbol is given in <angled brackets>.

Most of the contrasts are straightforward to establish. There are a couple issues, which we point out here for the sake of completeness, but which we essentially ignore for now. One is the contrast between *h* and *h*^{w}. These phonemes only occur word-initially. Most tokens of [h] trigger the intrusive vowel [u], but a few do not, so for now we are positing two phonemes to account for the contrast. Because of the uncertainty around these phonemes, though, we are excluding [h]-initial words

[1] Also called Jilim (e.g., Z'graggen 1975a; 1975b; 1980), ISO 693–3 code [jil].

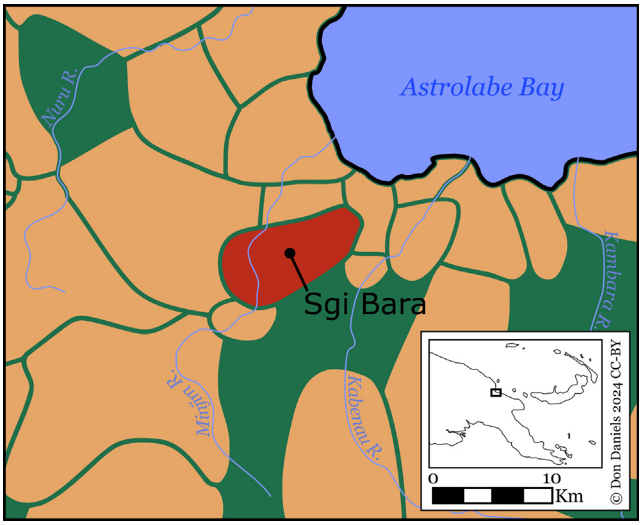

Fig. 1. Map of Sgi Bara and the surrounding languages.

from our phonetic analysis below. Another issue is whether to posit *w* and *y* as separate phonemes or as allophones of the high vowels. This issue also remains unclear, so we are excluding glide-initial words from our analysis.

The vowel inventory consists of the five cardinal values, as shown in Table 2. One other vowel phone, [ɨ], occurs in some words, but we do not consider it phonemic.

In what follows, it will be important to understand the phonotactic constraints on Sgi Bara words. Sequences of vowel height in a word can be rising, as in (1a), or level, as in (1b). Falling sequences are exceedingly rare—there are only three clear instances, shown in (1c), and all involve a sequence of mid vowel and *a*.

(1)	a.	*mareŋ* 'forest'	b.	*qamam* 'fish'	c.	*ŋgera* 'type of bamboo'
		raboŋ 'cover'		*dedeŋ* 'shadow'		*kesa* 'type of banana'
		ŋalub 'head'		*hobob* 'fence'		*woga* 'type of banana'
		argim 'rib'		*moñeŋ* 'woman'		
		mbolu 'sacred flute'		*kulu* 'night'		
		koli 'thunder'		*hilum* 'male'		

It is, however, possible for high vowels to precede non-high vowels in a word. The catch is that their vowel quality is completely predictable, and producing them is optional; for these reasons, we do not consider them phonemic. We call these vowels intrusive, and they always occur between the first two consonants of a word-initial consonant cluster. The rules for their occurrence are shown in (2), with illustrations in (3).

Table 2
Sgi Bara vowels.

	front	central	back
high	i		u
mid	e		o
low		a	

(2)
- a. If C2 is the palatal glide *y* the intrusive vowel is [i] (3a)
- b. If C2 is bilabial the intrusive vowel is [u] (3b)
- c. If C2 is anything else then
    - d. If the following vowel is front the intrusive vowel is [i] (3c)
    - e. If the following vowel is back the intrusive vowel is [u] (3d)
    - f. If the following vowel is *a* the intrusive vowel is [ɨ] (3e)

(3)	a.	*qyan*	[qijan]	'strangler fig'
		byel	[bijel]	'share'
	b.	*kmim*	[kumim]	'dry'
		gbar	[gubar]	'jaw'
		dwem	[duwem]	'bird of paradise'
		smbleŋ	[sumbleŋ]	'dawn'
	c.	*sle*	[sile]	'before'
		mnŋgi	[minŋgi]	'later'
		snjweŋ	[sindʒweŋ]	'cockroach'
		ñqre	[ɲiʁre]	'fig type'
	d.	*qñoŋ*	[quɲoŋ]	'shake'
		qsqo	[qusʁo]	'play'
		bjrub	[budʒrub]	'root'
		mndqor	[mundʁor]	'winged bean'
	e.	*ŋgdab*	[ŋgɨdab]	'son'
		gday	[gɨdaj]	'one'
		mblmal	[mbɨlmal]	'tree type (*Syzygium furfuraceum*)'
		ñŋglaŋ	[ɲiŋglaŋ]	'wavy'

There are a few exceptions to these rules. One is that words that begin with one of the glides /w/ or /y/ may optionally be articulated with the vowel that corresponds to that glide, rather than with the vowel predicted in (2). This alternate pronunciation appears to be the more common alternative. In (4) we show some words that are predicted to contain [u] (4a), [i] (4b), and [ɨ] (4c), but in which these intrusive vowels alternate with a vowel that is triggered by the preceding glide.

(4)	a.	*yma*	[juma] ~ [jima]	'tree type (*Myristica hollrungii*)'
		yqo	[juʁo] ~ [jiʁo]	'leave'
	b.	*wsi*	[wisi] ~ [wusi]	'now, today'
		wli	[wili] ~ [wuli]	'food, thing'
	c.	*yqaŋ*	[jɨʁaŋ] ~ [jiʁaŋ]	'feces'
		wqay	[wɨʁaj] ~ [wuʁaj]	'NEG'

Table 1
Sgi Bara consonants.

	bilabial	alveolar	alveo-palatal	velar	uvular	glottal
vl. stop	p	t		k	q	
vd. stop	b	d	dʒ <j>	g		
prenas. stop	mb	nd	ndʒ <nj>	ŋg		
nasal	m	n	ɲ <ñ>	ŋ		
vl. fricative		s				h
round fricative						h^w
trill		r				
approximant	w	l	j < y>			

If /r/ is the second consonant of a three-consonant cluster, the intrusive vowel sometimes follows it, rather than preceding it as expected. Some examples are provided in (5).

(5)	*grmo*	[guɾmo] ∼ [gɾumo]	‘slit-gong drum’
	krndum	[kuɾndum] ∼ [kɾundum]	‘cardamom’
	prqa	[pɨɾʁa] ∼ [pɾɨʁa]	‘arrive’

Finally, word-initial /hʷ/ triggers following [u] when the next segment is a consonant; this phenomenon is the reason for positing a contrast between /h/ and /hʷ/. Examples are given in (6).

(6)	*hʷleŋ*	[huleŋ]	‘ask’
	hʷyi	[huji]	‘yesterday’
	hʷñaŋ	[huɲaŋ]	‘rest (v.)’

A final feature that distinguishes intrusive vowels is that they are optional. Essentially all of the intrusive vowels shown above can be omitted, and often will be during fast speech. In our sample, 345 of 689 tokens that could have contained intrusive vowels did not. As described below (§4.3), our threshold for distinguishing the presence versus the absence of a vowel was three repeating periods in the waveform. By this criterion, almost exactly 50% of words that could contain an intrusive vowel actually do.

There are a number of reasons for considering these vowels intrusive, as opposed to either epenthetic or phonological. We counter arguments that they might be phonological first, and then turn to arguments for considering them epenthetic. The main reason for supposing that these vowels might be phonological starts with the observation that it is not just their *quality* that is predictable, but also their *placement*. The fact that intrusive vowels only occur between the first two consonants of a word suggests that this slot is, in some sense, stored in speakers’ mental representations as potentially containing an intrusive vowel. And if these vowels are (or might be) stored in mental representations, one might be tempted to consider them phonemic. But that leap is not justified. Speakers store a great deal of phonetic detail in their phonological representations (Pierrehumbert, 2001), including allophonic variation. What we have here is essentially allophonic variation between zero and a vowel, where the conditions under which a zero may be realized as a vowel can be stated precisely, as in (2). The fact that intrusive vowels occur in predictable places is not evidence for their phonemic status, any more than the predictability of aspiration on English voiceless stops is evidence that the aspiration is a phonemic /h/.

Is it possible that these vowels are epenthetic? We do no think so. Recall that epenthetic vowels are vowels that are inserted in a predictable way, but, once inserted, are visible to the phonological system (Hall, 2006). We have two reasons for supposing that these vowels are intrusive. The first is stress assignment in words containing vowels of unequal height. Our understanding of stress is still incomplete, but it is nevertheless clear that stress is weight sensitive. The heaviest vowel on the scale low > mid > high receives stress, meaning that intrusive vowels are never stressed, and are never even relevant for determining where stress should fall.[2] The second reason is the behavior of the durative prefix. This morpheme is reduplicative, copying the first vowel of the word and all the consonants to the left of it. Crucially, the intrusive vowels are ignored in this process. For example, when attaching to *mn-ŋemb* ‘stay-PL.FPST.SAME.SBJ’, it is realized as *mnŋe∼mn-ŋemb*. So we find no evidence that these vowels interact with the phonological system, and thus consider them intrusive, not epenthetic. But we recognize that this is primarily a phonological question, not a phonetic one. And as we are primarily concerned with a phonetic analysis of these vowels at present, we leave a fuller phonological interpretation for future work.

It is worth pointing out that consonant clusters can occur in other places in a Sgi Bara word. If a word contains two phonemic vowels, there may be a cluster between them, as in *komblom* ‘neck’, *baqrum* ‘dollarbird’, or *asbu* ‘spy (v)’. These clusters do not contain intrusive vowels. Clusters may also occur word-finally. Every lexical root ends in a maximum of one consonant, but clusters of up to four consonants may be created via the addition of suffixes and enclitics. Final clusters do not generally have intrusive vowels, although sometimes a consonant will be accompanied by an audible release. The phonetic behavior of these clusters remains a topic for future reasearch. A few examples are given in (7).

(7)	*a.*	*kndam=y* hurt=1SG.PRS.SS ‘I hurt and . . .’	*b.*	*teb=sg* plant=1PL.PRS.SAME.SBJ ‘we plant and. . .’
	c.	*ka<w>n=d=g* knock.off<3SG.OBJ>=SG.RPST=DIFF.SBJ ‘s/he knocked it off and. . .’	*d.*	*ŋalub=s=ql* head=INS=FOC.2PL.FUT ‘with *your head*’

Lastly, note that both word-initial and word-final consonant clusters exhibit unexpected sonority sequences, as with the final clusters in *kndamy* and *ŋalubsql* in (7), or the initial clusters in *krndum* ‘cardamom’, *wsi* ‘now, today’, and *ñŋglaŋ* ‘wavy’.

In the rest of this paper, we investigate the phonetic properties of the intrusive vowels described in (2). Do they differ acoustically from vowels that are phonemically present? If so, how? And can those differences be leveraged to answer other phonological questions? But first, we must describe our methods.

4. Methods

In this section, we outline the data and methodology that we used for this study. We discuss the speakers that we recorded (§4.1), the recordings that we made (§4.2), and then detail our methods of acoustic (§4.3) and statistical (§4.4) analysis.

4.1. Speakers

The acoustic data presented in this paper features seven native speakers of Sgi Bara (although some supplementary data was used for the case study described in §6.1 below). All speakers grew up in the Jilim village community and are fluent speakers of both Sgi Bara and Tok Pisin. Raga Yamu also knows Sa [pup] and Soq [mdc], Kaimbu Mobya knows Sa, and Barbara Kaus knows Agarabi [agd]. The only speaker with any formal education is Miriam Yambanji, who finished grade 6. Demographic information about the speakers is given in

[2] Stress assignment in words containing multiple vowels of the same height remains a topic for future research.

Table 3. Note that for most speakers, their age at the time of recording had to be guessed.

4.2. Recordings

Vowel acoustics were obtained from narratives recorded in February and September 2016 and February 2018. Each speaker was recorded with an Olympus LS-14 recorder connected to either a headset microphone (the Sennheiser ME 3-ew) or a lapel microphone (the ME 2) at a sampling rate of 96 kHz. Speakers presented monologues of their choice and were recorded by Daniels in Jilim village, in a variety of outdoor locations. The researcher could not control for occasional background noises, such as distant conversations or chirping birds, though these did not interfere with the acoustic analyses presented below. The Sgi Bara corpus currently contains 266 such recordings, totaling 14 hours and 50 minutes. Of these, 85 recordings (4 hours and 46 minutes) have been transcribed and translated into Tok Pisin. A subset of these recordings, selected for speaker diversity, served as the primary source material for the current study, including three narratives from women and four from men. The combined duration of the selected recordings is 23.5 minutes. Details about each recording are given in Table 3.

4.3. Acoustic analysis

Formants, intensity, and duration of the vowel tokens were measured and analyzed using the computer software Praat (Boersma & Weenink, 2022). The spectrogram settings were set to the standard settings; the range of frequencies displayed was 0–5000 Hz, the duration of the analysis window was 0.005 seconds, and the dynamic range for deciBels was 70 dB.

Four categories of vowel token were excluded from analysis. As mentioned, vowels next to glides or *h* were not included. We also did not include vowels from Tok Pisin loanwords. While these undergo some measure of phonological adaptation and often conform to Sgi Bara articulatory patterns, all speakers in our sample are natively fluent in Tok Pisin. As such, their loanword tokens may differ systematically from their production of native Sgi Bara lexemes. The third excluded category is vowels from disfluent speech. And lastly, we excluded a certain category of prosodically lengthened vowel: Sgi Bara speakers occasionally attach a clitic to the end of a phrase, which serves a discourse function. This clitic is usually articulated with a significantly lengthened vowel. These vowels differ in their acoustic qualities from lexical and intrusive vowels and are therefore excluded. All other lexical and intrusive vowels were included in analyses unless otherwise noted.

The remaining vowel tokens were then manually segmented and labeled in Praat. Recall that intrusive vowels only occur in word-initial consonant clusters. In each recording, words that contained an initial consonant cluster were identified and segmented into phones. The boundaries at the word and phonetic level were all aligned at the nearest zero crossing in the Praat TextGrid. To distinguish between acoustic transitions between phonemes and the presence of an intrusive vowel, we used the following criterion: there must be three clearly repeating periods in the waveform between C1 and C2.

After the recordings had been segmented and labeled, the formants, intensity, and duration of each vowel were extracted using Praat scripts. Vowel duration (in msec) was log-transformed for plotting and analysis. In the data presented below, formant values and intensity were sampled at the temporal midpoint of the vowel.

The total number of vowel tokens in the data is 1607: 1225 lexical vowels (235 /i/, 487 /e/, 234 /a/, 176 /o/ and 93 /u/) and 353 intrusive ones (192 [i], 59 [ɨ] and 102 [u]). Intrusive vowels were recorded from 155 words, most of which only have one instance in the data set. 10 words have between 6 and 18 instances in the data set, suggesting a typical Zipfian frequency distribution. The number of vowels analyzed for each speaker are given in Table 4.

4.4. Statistical analysis

To analyze our data, we use linear mixed-effects regression models. In general, the phonetic property was the dependent variable and vowel status (i.e., real or intrusive) was included as a fixed factor. Vowel, word, and speaker were included as random intercepts, unless otherwise noted. Significance of predictors was determined via model comparisons of the full model with a model that did not include the fixed factor. Models that deviate from this structure are described in more detail below.

5. Results

As described above, we analyzed a variety of spectral and duration measures associated with production of vowels. Specifically, we measured vowel duration (§5.1), intensity (§5.2), and the first and second formants (§5.3). Below, we outline results for each of these measures in turn. We begin by focusing on the categories of vowels that are clearly phonologically real and those we suspect to be intrusive vowels. We restrict our initial comparison to intrusive vowels of the type shown in (3).[3] Following this, we explore how this phonetic analysis may help us understand and motivate phonological analyses of other vowel types.

5.1. Vowel duration

Fig. 2 shows the vowel duration for real and intrusive vowels. It is clear that intrusive vowels are shorter than real vowels.

The statistical analysis bears out this observation. Inclusion of vowel status significantly improves model fit (β = 0.198, t = 13.57, χ^2 = 172.12, p <.001).

One factor to consider is that these results may be driven by the fact that the intrusive vowels include [ɨ], which may be quite reduced, but the real vowels do not. Instead, the real vowels include [a], which may be produced with a longer duration. To assess this possibility, we investigate only productions of [i] and [u] from both categories; the results are shown in Fig. 3. This subsetting resulted in 294 intrusive vowels and 466 real vowels. Even investigating just these vowels, we see a similar pattern. When these vowels are produced in a

[3] We excluded vowels conditioned by glides in C2 position, such as in *dwem* 'bird of paradise', due to the difficulty of measuring the boundary between the intrusive vowel and the following glide.

Table 3
Primary speaker and recording information.

Speaker	Sex	Age	Recording	Date	Dur.	Microphone
Raga Yamu	M	66?	A Man Turns Into a Pig	2016–02-17	4:00	Sennheiser ME 3-ew
Kaimbu Mobya	M	66?	Bush Band	2016–09-06	2:40	Sennheiser ME 3-ew
Margaret Kaus	F	41?	Lake	2016–02-24	1:18	Sennheiser ME 2
Philip Sombru	M	44?	My Mountain	2016–09-08	5:07	Sennheiser ME 3-ew
Miriam Yambanji	F	42	My Husband Left Me	2016–09-06	2:04	Sennheiser ME 3-ew
Joseph Bal	M	45	They Killed My Father	2016–02-22	3:47	Sennheiser ME 3-ew
Barbara Kaus	F	46?	Zombie Wife	2016–02-17	4:34	Sennheiser ME 3-ew

Table 4
Number of vowels per speaker.

Speaker	Lexical vowel tokens	Intrusive vowel tokens
Raga Yamu	198	62
Kaimbu Mobya	137	31
Margaret Kaus	141	48
Philip Sombru	252	52
Miriam Yambanji	137	30
Joseph Bal	102	39
Barbara Kaus	258	91

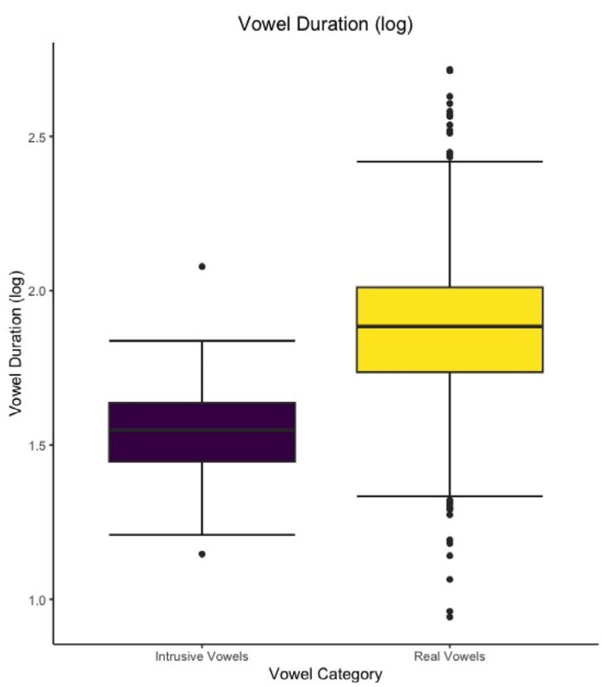

Fig. 2. Vowel duration (log) for intrusive (n = 353) and real vowels (n = 1400).

phonologically contrastive context they are longer than when produced in a phonologically predictable one. Although the pattern from Fig. 2 is reduced in Fig. 3, it is still robust.

As above, the statistical analysis bears out this observation. Inclusion of vowel status significantly improves model fit (β = 0.197, t = 11.54, χ^2 = 118.62, p <.001).

It is interesting to note that, in general, the duration of real vowels is far more variable than the duration of intrusive vowels. Real vowels are also far less restricted in the positions where they can occur. That is, both prosodically and phonotactically, real vowels can occur in more locations. It is possible that this variability in position increases the potential variability in vowel duration as well.

It is important to recall, however, that intrusive vowels also appear in a bimodal distribution: either they are present or they

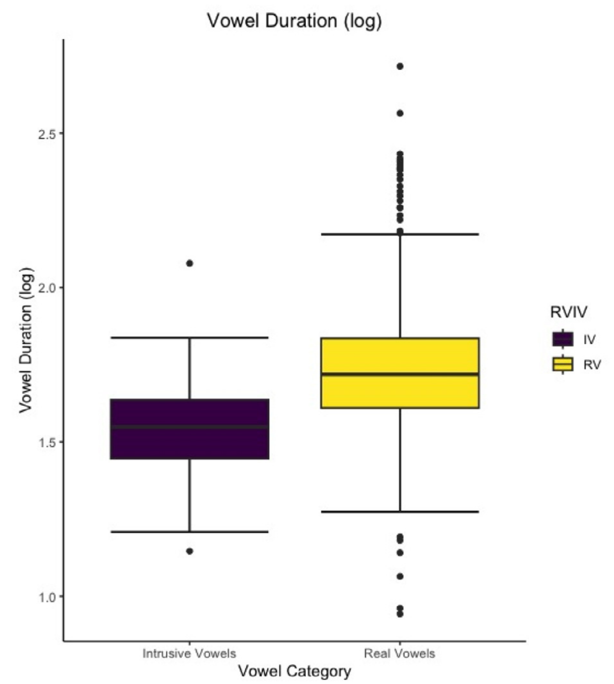

Fig. 3. Vowel duration (log) for intrusive (n = 353) and real [i] and [u] (n = 464).

are entirely absent. This is another way in which they differ from real vowels. Such optionality also fits within the "intrusive vowel" category in Hall's (2006) typology.

One might question whether the increased variability for real vowels, and indeed our observed difference between intrusive and real vowels, is attributable to the fact that real vowels occur in more positions within words than intrusive vowels, which are limited to occurring between initial consonants. Therefore, we investigated two subsets of our high vowels. The first is a subset of real vowels that occur in initial syllables (113 real vowels). The second is a subset of that subset, comparing only situations where the flanking consonants are matched to those flanking consonants surrounding intrusive vowels (36 real vowels). These are not matched one-to-one with intrusive vowels. Instead, they include all real vowels that occur with the same flanking consonants as intrusive vowels. Fig. 4 shows the first subset (between initial consonants) and Fig. 5 shows the second subset (matching the flanking consonants).

It is clear from these figures that the overall pattern still holds. Real vowels are longer, and more variable, than intrusive vowels, even when limited to word-initial contexts. However, we caution against over-interpretation of Fig. 5, as the number of vowels included for real vowels is quite small. Nevertheless, a mixed effects model on only the initial syllable vowels demonstrates that this effect is significant, even with the smaller number of vowels (β = 0.16, t = 9.86, χ^2 = 88.46, p <.001; though note we removed word as a random effect, as it resulted in a singular model fit). Our sample size was too small to conduct a statistical analysis of the cases where the consonant structures are matched, but we believe that our results are not driven (solely) by the restricted location of intrusive vowels and the relative flexibility of real vowels, but rather by phonological aspects of these vowels.

Note also that, especially in Figs. 2–4, real vowels exhibit significantly more duration outliers. We assume that these outliers are prosodically lengthened in some way, although we concede that phrase- and utterance-level prosody are not yet understood for Sgi Bara. Nevertheless, the observation that real vowels are often prosodically lengthened, while intrusive vowels are not, also corroborates our phonological analysis. This is because it suggests that real vowels are phonologically available to host higher-level prosodic stress—whatever that stress may be—while intrusive vowels are not visible to the phonological system in the same way.

We turn now to an analysis of intensity in Sgi Bara vowels.

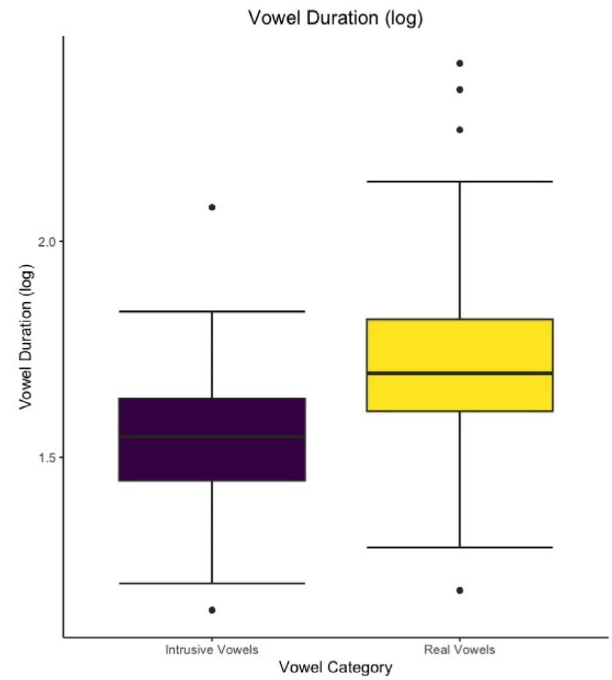

Fig. 4. Vowel duration (log) for intrusive (n = 353) and real [i] and [u] between initial consonants (n = 110).

5.2. Intensity

Fig. 6 shows the intensity for the real and intrusive vowels. It is clear that, unlike duration, there are no differences in the intensity of real and intrusive vowels. As above, the statistical analysis bears out this observation (χ^2 < 2, p >.05).

A motivation for this may be the preponderance of voiced consonants in word-medial position. The voiceless consonants /p t k h h^w/ only occur word-initially, and /q/ in phrase-medial position is voiced and spirantized to [ʁ]. The only voiceless phone that reliably occurs word-medially is [s], which means that word-medial consonants are almost always voiced. As for word-initial consonants, although they can be voiceless, they usually are not; the token frequencies of the voiceless consonants /p t k s h h^w/ in word-initial position are not especially high, and they represent only about one-third of the phoneme inventory. This means that both intrusive and real vowels are most commonly surrounded by voiced segments, which may affect their intensity. One way to investigate this idea would be to examine words with /s/ in second position, such as *qsqo* 'play' or *ssu* 'paint'. However, we leave that for future work.

Again, it is interesting to note that, as in the case of vowel duration, the real vowels demonstrate more variability in intensity than the intrusive vowels. And again, it is possible that because real vowels can appear in more positions, we observe more variability in their phonetic realization.

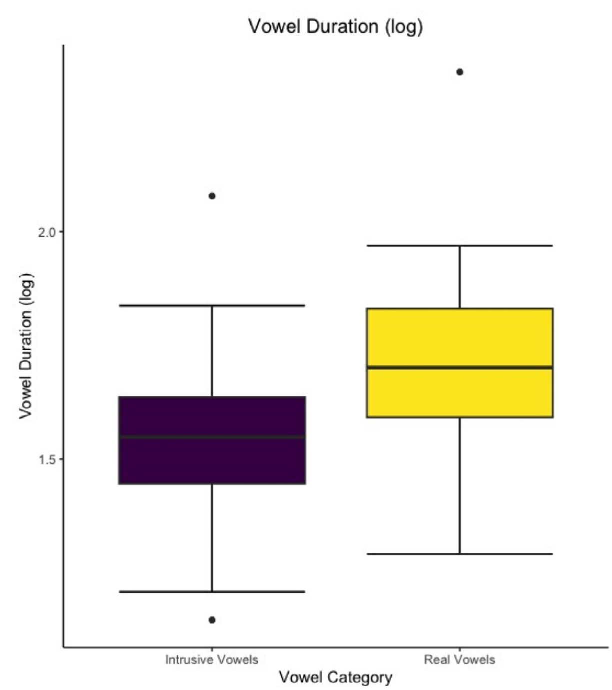

Fig. 5. Vowel duration (log) for intrusive (n = 353) and real [i] and [u] between initial matching consonants (n = 36).

5.3. Vowel quality

Fig. 7 shows the vowel formant values for the real and intrusive vowels. Examining this figure, it appears that the intrusive vowels are produced more peripherally than the real vowels. Note again that all intrusive vowels are high vowels, so the most relevant comparisons are [i] and [u]. Specifically, both intrusive [i] and [u] vowels are more peripheral in the F2 dimension than real vowels. Intrusive [i] is also more peripheral in the F1 dimension than real [i].

To investigate potential differences, we compare F1 and F2 separately for [i] and [u]. Vowel type significantly improves model fit when investigating F1 (β = 35.492, t = 9.444,

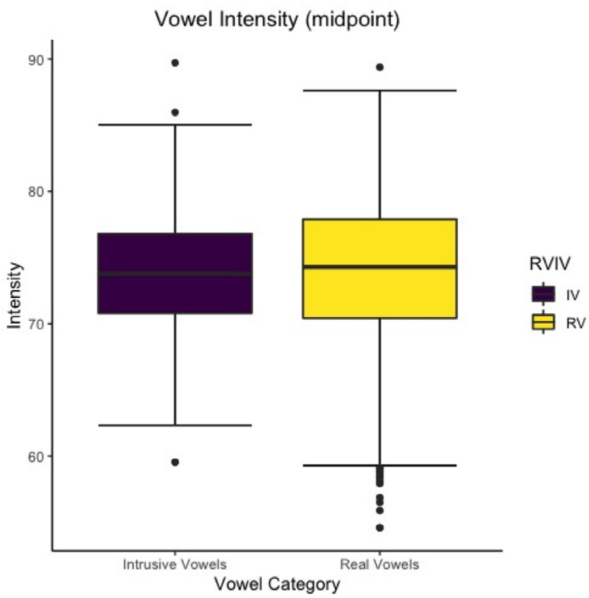

Fig. 6. Vowel intensity (in dB SPL) for intrusive (n = 353) and real vowels (n = 1400).

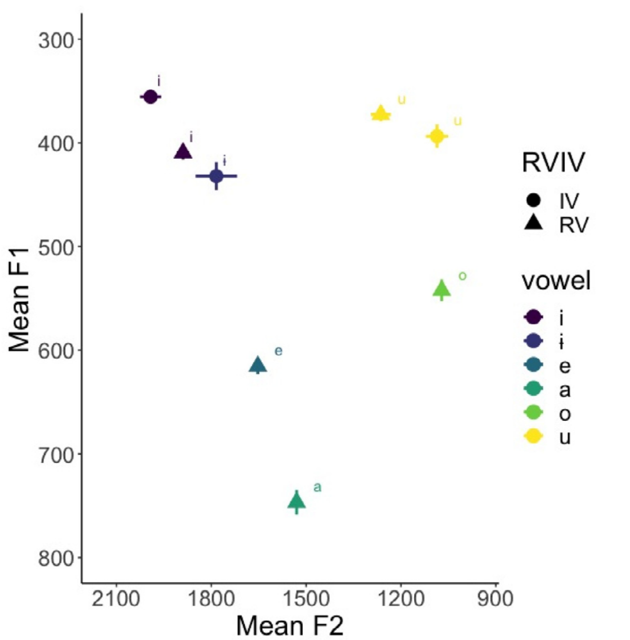

Fig. 7. F1 and F2 at midpoints of real and intrusive vowels. (Bars around the points indicate standard error for each vowel.).

χ^2 = 14.155, p <.001). However, for F2, vowel type does not significantly improve model fit (β = 29.82, *t* = 0.825, χ^2 = 0.684, p =.408). This is likely because the influence on F2 is different for [i] and [u]. An analysis of the individual vowels also does not reveal statistically significant differences.[4] While it is possible that again our results are driven by the relatively restricted locations of intrusive vowels, we do not believe this is the case, given our results for vowel duration. Our sample size, unfortunately, was too small to do meaningful comparisons for F1 and F2 for our restricted subset, but we do not anticipate our results are driven by this issue.

One may wonder why the intrusive vowels are more peripheral than the lexical vowels. There are a number of possible explanations. The first is that speakers are aiming for a more peripheral target. Another explanation is that the qualities of the consonants surrounding the intrusive vowels may restrict the ability to reduce vowel height, for example. Unfortunately, given the current data set, it is not possible to disentangle the two possiblities. What is most interesting, though, is that there is not a clear pattern of reduction, which one might expect for intrusive vowels which are also optional.

In sum, then, the phonological analysis is borne out by the phonetic observations: phonologically predictable vowels, which we call intrusive, are a separate category from phonologically contrastive vowels, which we call real. They are shorter in duration and more peripheral in the vowel space. They are not distinct in terms of intensity, but that may be ascribable to the fact that word-medial consonants are almost always voiced in Sgi Bara. Given that these vowels are distinguishable on phonetic grounds, we can now turn our attention to phonologically more ambiguous contexts and ask whether the vowels they contain are real or intrusive.

6. Discussion

In §3 we presented phonological evidence that Sgi Bara intrusive vowels are not phonemic. Their appearance is predictable from their phonological environment, and so there is no reason to posit their existence as phonemes. This analysis was supported by the phonetic study in §5. Now we examine some phonologically ambiguous contexts to illustrate how this phonetic understanding can be used to improve phonological analysis. We begin by examining sequences of high vowels in §6.1, and turn to phonological wordhood in §6.2.

6.1. High vowel sequences

In (3) above we gave examples of words in which a real high vowel triggers an intrusive one, such as *mnŋgi* [minŋgi] 'later' and *bjrub* [budʒrub] 'root'. However, there are also similar words in which the first vowel appeared more prominent during fieldwork than typical intrusive vowels, and was initially transcribed as stressed. Such words include *nini* '3PL' and *kulu* 'night'. These words pose a problem of phonological analysis.

Recall that Sgi Bara words can contain vowel sequences of equal height. If both vowels are high, they can either be identical or different. Some examples are given in (8): sequences of different vowels in (8)a, and identical ones in (8)b.

(8)	a.	*muñi*	[muɲi]	'louse'	b.	*nini*	[nini]	'3PL'
		yuri	[juri]	'week'		*gilim*	[gilim]	'rat'
		kuji	[kudʒi]	'genitals'		*digi*	[digi]	'border'
		timun	[timun]	'Brahminy kite'		*kulu*	[kulu]	'night'
		hilum	[hilum]	'male'		*kujgum*	[kudʒgum]	'tree fern'
		gimbu	[gimbu]	'how many'		*budu*	[budu]	'dirtiness'

[4] Note that [ɨ] is more front in the vowel space than we might expect. We believe this may be due to coarticulation effects, since many tokens of this vowel come from words that begin with the affricate /j/. Future work could directly examine the quality of this vowel.

For the words in (8)a, there is no question that the first vowel is phonologically real, because it is not the vowel that is predicted by the insertion rule in (2) above. That is, if *muñi* 'louse' were really /mñi/ phonologically, we would expect it to be realized as [miɲi] phonetically, but it is not.

However, we do encounter a degree of phonological ambiguity for the words illustrated in (8)b. For each of these words, two phonological analyses are viable. To take the pronoun *nini* '3PL' as an example, it can be analyzed as /nini/, with two phonologically real vowels, or as /nni/, realized as [nini], with the first vowel considered intrusive. There is little to distinguish these analyses phonologically, since both are consistent with our analysis of other aspects of Sgi Bara phonology. It may be possible to distinguish them on the basis of optionality, since intrusive vowels are optional and phonologically real ones are not. But it is still unknown whether all intrusive vowels behave the same with respect to the optionality of their insertion, and in rapid speech, real vowels—especially high ones—can also be quite reduced. However, we might expect the vowels in words like *nini* and *kulu* to be distinguishable on phonetic grounds. The first vowel is either real or intrusive, and since we were able to distinguish these categories in Section 5, we can hope to distinguish them here.[5]

There are two questions we can ask. First, for each individual word like *nini* '3PL' or *kulu* 'night', we can ask whether the first vowel is real or intrusive. The second question we can ask is whether all words like those in (8)b pattern alike—in other words, whether there is a potential contrast between, say, *kulu* and *klu*. We address the first question here, but leave the second for future research.

In order to collect enough tokens of individual lexemes to perform a statistical analysis, we had to expand the data set somewhat. We collected extra tokens of *kulu* 'night' and *nini* '3PL' from additional recordings. These recordings consisted of four more narratives and one dramatic performance ("Butt Shut"). One speaker, Barbara Kaus, is also represented in the primary data; the other four are not. Their demographic information, and information about their recordings, is given in Table 5.

We examined 7 tokens of *kulu* 'night' and 27 tokens of *nini* '3PL'. During fieldwork, both of these words appeared to Daniels to contain prominent first vowels, and thus seemed to make for an interesting comparison with more clearly intrusive vowels. We compared these data only to lexical [i] and [u]. The results from the comparison are given in Fig. 8.

Note that there is a clear difference between these two words: the first vowel of *kulu* appears to behave like an intrusive one, while the first vowel of *nini* behaves like a real one. The observation of *kulu* behaving more like an intrusive vowel than a real one bears out a statistical analysis. In a non-paired t-test, *kulu* is significantly different from the real vowels (t = 5.0823, p <.003), but not significantly different from intrusive vowels (t = -0.287, p =.78). Interestingly, *nini* appears to differ from both real and intrusive vowels in the statistical analysis, (t = -4.69, p <.001 and t = -9.01, p <.001, respectively). However, crucially, it also differs from *kulu* (t = 3.623, p <.01). This underscores the importance of phonetic investigation to confirm phonological analyses, since it appears that *kulu* 'night' is more accurately represented as *klu*.

It also, interestingly, reinforces the division that we propose between phonologially real vowels and intrusive ones, since one word, *kulu*, clearly falls into one of the two categories. At the same time, the results for *nini* suggest that there may be some gradience in Sgi Bara vowel realization: although it falls closer to the real-vowel end of the continuum, it does pattern in an intermediate way. So the behavior of these two words lends support to an analysis that regards Sgi Bara vowels as falling into two broad camps, with largely different phonological and phonetic behavior, but with some gradient behavior in between.

This also points the way for future work, which could examine more individual lexemes to determine whether they have intrusive or real vowels. It would also be interesting to see whether there is any pattern to the distribution of intrusive versus real high vowels before identical high vowels. For instance, the fact that the vowel in *nini* behaves more like a real vowel may be partly due to the fact that it is surrounded by two identical consonants; it may be that sequences like *nn* are dispreferred.[6]

We turn now to another case where the phonetic understanding achieved in §5 provides us with a more complete understanding of Sgi Bara phonology.

6.2. Phonological wordhood

Another analytical puzzle that our phonetic analysis can help with involves phonological wordhood. Many Sgi Bara verb inflections take two forms: they can be suffixed to the verb, or they can be a separate phonological word, which we call an auxiliary. For example, the singular far past is marked by either the suffix *–ed* or the auxiliary *ged*. Similarly, the future is marked by either the suffix *–a* or the auxiliary *qa-*; these are then followed by another suffix that indexes the person and number of the subject. The choice of which kind of inflection to take usually depends on verb class, so *hay-* 'chop' takes the suffixes (*–ed* and *–a*) and *so* 'go' takes the auxiliaries (*ged* and *qa-*). Table 6 illustrates these morphemes combining with suffix-taking verbs and auxiliary-taking verbs. The table also illustrates another kind of inflection for completeness: the singular recent past, which is marked by an invariant clitic *=d*. Verbs that take suffixes often exhibit their own allomorphic variation, as illustrated with *tel* 'put' and its allomorph *tl-*.

The fact that auxiliaries are separate syntactic words is demonstrated by the fact that certain adverbs can intervene between the verb and the inflection, as with *lil* 'two' in (9).

(9)	*Yi*	*so*	*lil*	*ged.*	
	1SG	go	two	SG.FPST	
	'I went twice.'				(Elicited)

[5] One reviewer points out that *nini* is also a function word, and may be prosodically reduced as a result. While we recognize that word class is a potential confound to this study, we actually do not expect the status of *nini* as a pronoun to cause significant reduction. Sgi Bara exhibits frequent ellipsis of nominal referents, and consequently, pronouns are more likely to surface when their referent is salient in some way. We expect this salience to be reflected in the prosody as well.

[6] They are not completely disallowed, however. This is demonstrated by forms like *pnnaŋ* 'hit (PL object)' and *prra* 'tear (v.)'.

Table 5
Supplementary speaker and recording information.

Speaker	Sex	Age	Recording	Date	Microphone
Andrew Yamu	M	55	Butt Shut	2016–02-24	Sennheiser ME 3-ew
Caspar Yamu	M	67	I Went to Bougainville	2018–06-08	Sennheiser ME 2
Korom Jalum	M	52	Life in the Future	2016–09-09	Sennheiser ME 3-ew
Daniel Yagas	M	34	Fought About a Woman	2016–02-25	Sennheiser ME 3-ew
Barbara Kaus	F	46?	Cheese	2016–02-19	Sennheiser ME 3-ew

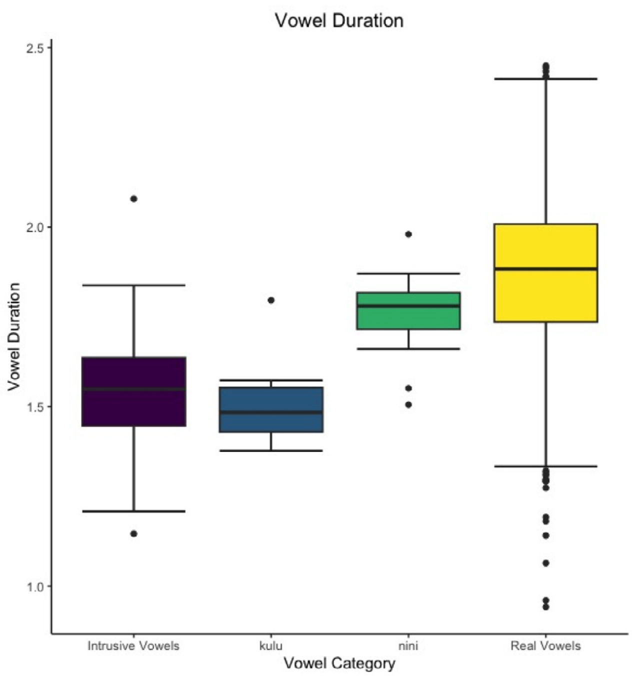

Fig. 8. Duration of *kulu* 'night' and *nini* '3PL' compared with real and intrusive vowels ([i] and [u] only).

However, most of the time the sequence *so ged* is not interrupted by another word: the Sgi Bara corpus contains 73 tokens of *so ged* compared to 12 tokens of *so X ged*. Moreover, native speaker intuitions suggest that *so ged* is a single word. One speaker, Jacob Caspar, has transcribed a considerable number of recordings. In his transcripts, totaling 125 minutes, he never transcribed *so ged* as two words, but transcribed it as a single word *soged* 33 times.

This suggests that high-frequency combinations like a verb and its auxiliary may be univerbating and becoming a single phonological word. But observant readers will note a problem with this proposal: some of the verb-plus-auxiliary combinations in Table 6 would be illicit words according to the phonological rules we have proposed. For example, *gruged* should not be allowed, since *u* cannot precede *e*. The only allowable phonological string would be *grged*, which would be realized variably as [gɨrged] or [grɨged]. Similarly, *briqaw* is not allowed; before *a* we expect intrusive [ɨ], realized as [bɨrʁaw] or [brɨʁaw].

To what extent are these combinations two phonological words, then, and to what extent are they one? We can answer this question by seeing whether the high vowels in sequences of a verb plus its auxiliary behave like real high vowels, which is what we would expect if they are inside a separate phonological word from the auxiliary.

We focus this discussion on two-word combinations which, if they univerbated, would form a permissible word under our current analysis. We analyzed 18 tokens of the verb *kri*, which serves as a marker of completive aspect: 8 tokens of *kri gemb* 'COMPL SG.FAR.PAST.SAME.SUBJECT' and 10 tokens of *kri ŋemb* 'COMPL PL.FAR.PAST.SAME.SUBJECT'. Note that, under our analysis, if these pairs of words univerbated, they would not be *phonologically* permissible wordforms, but only phonetically permissible. According to our analysis, a word realized as *krigemb* would be analyzed as being underlyingly *krgemb*, with an intrusive first vowel. But it may also be the case that *krigemb* is still two phonological words: *kri gemb*. In that case, we would expect the *i* to be realized more like a real vowel.

The results of our analysis are given in Fig. 9.

This figure shows that, in this case, the phonetic results corroborate the phonologically-driven analysis that *kri* is a separate word from *gemb* and *ŋemb*. The [i] in the *kri gemb* and *kri ŋemb* sequences has a duration that is similar to the real vowels, but not to intrusive vowels. These observations are echoed in the mixed model comparing the two *kri* forms to intrusive and real vowels. The two *kri* forms differ from intrusive vowels ($\beta = -0.31$, $t = -5.357$) but not from real vowels ($\beta = 0.07$, $t = 1.34$; model comparison: $\chi^2 = 175.99$, $p < .001$).

This suggests that native-speaker intuitions about wordhood are not reflected in vowel duration. In transcripts produced by native speakers, we observed 6 tokens of *krigemb*, transcribed as a single word, and no tokens of *kri gemb*, transcribed as two. (The stories transcribed by native speakers happened not to contain any sequences of *kri ŋemb*.) An interesting potential confound is that *kri* has *r* in second position, and we excluded such consonant clusters from our overall analysis because of their variability. (Recall that words like /grmo/ 'slit-gong drum' can be articulated [gurmo] or [grumo].) However, it seems unlikely that /r/ is preventing *kri gemb* from

Table 6
Sgi Bara inflection allomorphy.

		SG.FAR.PAST	FUT-3SG	SG.RECENT.PAST
Suffixes	*tel* 'put'	*tl-ed*	*tl-a-w*	*tel=d*
	hay 'chop'	*hay-ed*	*hay-a-w*	*hay=d*
Auxiliaries	*so* 'go'	*so ged*	*so qa-w*	*so=d*
	bri 'arrive'	*bri ged*	*bri qa-w*	*bri=d*
	gru 'run'	*gru ged*	*gru qa-w*	*gru=d*

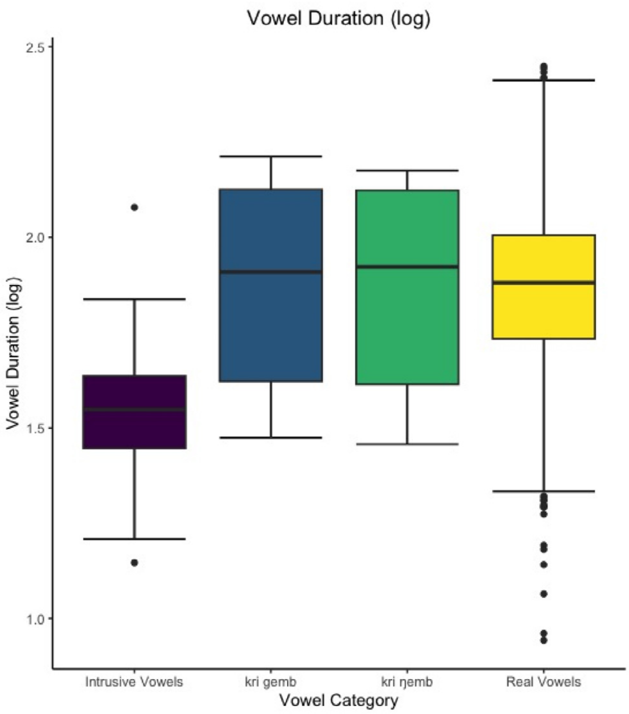

Fig. 9. Duration of *kri* compared with real and intrusive vowels.

univerbating, since sequences like *grmo* are perfectly licit according to Sgi Bara phonotactics. Rather, we conclude that sequences like *kri gemb* are, for the moment, remaining two separate words. Native-speaker intuitions about wordhood are possibly motivated by the frequency with which these morphemes cooccur, rather than by the articulatory qualities of the first vowel.

This small case study illustrates the way that phonetic data can be used to inform phonological analysis. It was unclear whether sequences like *kri gemb* and *kri ŋemb* were best analyzed as consisting of one word or two. Phonological consideration suggested they were two words, but native speakers consistently treated them as one.[7] By conducting a careful phonetic analysis of clearer cases and comparing them with *kri gemb* and *kri ŋemb*, we can see which group these sequences pattern with, and gain more insight into wordhood in Sgi Bara.

7. Conclusion

The results of our current investigation demonstrate that intrusive vowels in Sgi Bara are quantitatively different from real vowels in the language in a variety of acoustic dimensions. Further, our results suggest that this phonetic analysis can be used to answer phonological questions in the language, such as how to analyze sequences of high vowels, or how to understand phonological wordhood. Taken together, the results demonstrate the utility of acoustic–phonetic analyses for understanding minoritized and underresourced languages, and point to the importance of this type of analysis in understanding a variety of functions in these languages.

[7] And so did Daniels, when he began fieldwork.

Funding

This research was supported by NSF grant BCS-2048220.

CRediT authorship contribution statement

Don Daniels: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Zoë Haupt:** Writing – original draft, Data curation. **Melissa M. Baese-Berk:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Acknowledgements

Aspects of this research were presented at the 13th Austronesian and Papuan Languages and Linguistics Conference, the 51st meeting of the Australian Linguistics Society, and to audiences at the University of Oregon. The authors gratefully acknowledge helpful feedback from all three venues, as well as from three anonymous reviewers and the editorial team. We also express our gratitude to the Jilim community for their extraordinary hospitality and generosity during Daniels's fieldwork.

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