Metrical structure and sung rhythm of the Hausa rajaz

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PHONOLOGICAL ANALYSIS

Metrical structure and sung rhythm of the Hausa rajaz

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The rajaz meter of Hausa is based on syllable quantity. In its dimeter form, it deploys lines consisting of two metra, each usually containing six moras. A variety of metra occur, and the key analytic challenge is to single out the legal metra from the set of logically possible ones. We propose an analysis, framed in MAXIMUM ENTROPY OPTIMALITY THEORY, that does this and also accounts for the statistical distribution of metron types, varying from poem to poem, within the line and stanza. We demonstrate a law of comparative frequency for rajaz and show how it emerges naturally in the maxent framework when competing candidates are in a relationship of harmonic bounding.

Turning to how the verse is sung, we observe that rajaz verse rhythm is typically REMAPPED onto a distinct sung rhythm. We consider grammatical architectures that can characterize this remapping. Lastly, we develop a maxent phonetic grammar to predict the durations of the sung syllables. Our constraints simultaneously invoke all levels of structure: the syllables and moras of the phonology, the grids used for poetic scansion, and the grids used for sung rhythm.*

Keywords: Hausa, meter, rajaz, sung rhythm, maxent, syllable duration

1. INTRODUCTION. Hausa is a major language of the Chadic family, spoken by about 40 million people in northern Nigeria and neighboring countries. Hausa possesses a rich tradition of poetry, based on the distinction between light and heavy syllables. In performance, Hausa poetry is always rendered in song, rather than spoken recitation. This article addresses one particular meter of Hausa called the RAJAZ. Our purpose is to provide a comprehensive account of this meter, covering three related areas: metrical scansion, musical rhythm, and phonetic realization. In forming the analysis, we encounter a variety of theoretical questions and propose answers to them.

First, we address the standard research questions of metrics as applied to rajaz: what is it about a text of Hausa that qualifies it as a legal rajaz line? Given that rajaz shows a striking variety of forms, what is the common basis that underlies them? We tackle these questions using the traditional framework of GENERATIVE METRICS (Halle & Keyser 1966, 1971, Kiparsky 1975, 1977), augmented for explicitness and precision with the framework of MAXENT GRAMMAR (Goldwater & Johnson 2003, Hayes, Wilson, & Shisko 2012).

Our metrical analysis of the rajaz implies a particular rhythm to which we would expect it to be sung. Yet the actual rhythm of the sung rajaz is normally distinct from this expected rhythm. We offer a description of rajaz singing based on the theory of musical rhythm in Lerdahl & Jackendoff 1983, and illustrate it with diverse rhythmic forms in which the rajaz is sung.

Sung rhythm, as rendered in the Lerdahl/Jackendoff theory, is itself a theoretical abstraction—the notes as physically rendered by the singer correspond in their durations only in an indirect way to the note values implied by the rhythmic structure. Thus, there

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The supplemental materials mentioned at various places in the text can be accessed at http://muse.jhu.edu/resolve/69.

is a gap between theoretical and observed durations. To bridge this gap, we develop a phonetic component for the metrical grammar of singing, which translates formal rhythmic structures into quantitative outputs. These outputs are derived not just from the rhythmic structure itself, but also from the phonological content of the syllables and their underlying metrical scansion. In formulating this phonetic component, we employ the model of generative phonetics proposed in Flemming 2001, expressing it in the formalism of maxent grammar.

Our goal, in the end, is a 'soup to nuts' treatment of a single meter, going from abstract pattern to phonetic form.

2. BACKGROUND.

2.1. THE FIELD OF METRICS.

As Kiparsky 1987 pointed out, humanity is a METRICAL species: we all participate in forms of verbal art, specific to our own language and culture, that deploy phonological material (syllables, stress, weight, phrasing) to manifest rhythmic patterns in verse and song. The ability to appreciate these art forms arises effortlessly and unconsciously on exposure to data in childhood, and research indicates both diversity across traditions and shared abstract underlying principles. This implies that it is worthwhile to develop a field of GENERATIVE METRICS, which (as elsewhere in generative grammar) would employ explicit formal representations and principles, make concrete predictions, and aspire to a contentful general theory in which language-specific analyses are couched. The challenge of creating such a theory was first undertaken by (among others) Halle and Keyser (1971) and Kiparsky (1975, 1977) and continues today as an active research tradition; see Blumenfeld 2016 for a recent review.

Generative metrical analysis seeks to make accurate predictions of the intuitive judgments of native participants concerning which kinds of lines (or stanzas, etc.) count as well-formed instantiations of their metrical type. Such intuitions are often gradient: among the set of possible lines in a verse tradition, some form canonical instantiations of their rhythmic type, whereas others are felt to be 'imperfect' to some degree; they are often described as METRICALLY COMPLEX. An adequate analysis should accurately predict the various degrees of complexity.

Complexity is widely thought to be related to CORPUS FREQUENCY: complex lines are rare to a degree dependent on their complexity (Halle & Keyser 1971:157, Hayes, Wilson, & Shisko 2012). Complexity can thus be studied by gathering a representative corpus of verse and developing a grammar that FREQUENCY-MATCHES the corpus, characterizing common types as common, rarer types as rare to the appropriate degree, and absent types as absent. The specific goal undertaken in this section is to develop an explicit frequency-matching analysis of the Hausa rajaz.

2.2. THE HAUSA VERSE TRADITION.

Hausa verse and song involve two interacting traditions, oral and written verse. The rajaz meter is part of the latter tradition. The written tradition originated in the nineteenth century, using Arabic Islamic poetry as a model (Hiskett 1975). During the twentieth century, nativization took place, whereby original Arabic meters were restructured, partly under the influence of the oral tradition. As a result, the putatively Arabic type of poetry departed from its historical origins and must now be understood in its own terms; see Schuh 2011 and references cited there.

For Hausas, poetry is closely equated with song; the Hausa word *waka* designates both. Even written meters like rajaz are composed with the intent that readers will sing what they are reading. Singing is itself a creative process that can remap the implied rhythm of the verse into a variety of different sung rhythms.

2.3. Syllable weight and quantitative meter in hausa. Dozens of meters are used in Hausa (Greenberg 1949, Skinner 1969, Skinner et al. 1974, Galadanci 1975, Hiskett 1975, Muhammad 1979, Schuh 1988a,b, 1989), all of them based on the distinction of heavy and light syllables. Heavy syllables in Hausa are those that are closed (CVC) or contain a long vowel or diphthong (CVV), and light syllables are those that are short-voweled and open (CV). We use the traditional symbols breve (ᴗ) to indicate a light syllable and macron (–) to indicate heavy. No Hausa word begins with a vowel,[1] so the issues that arise in syllabifying /VC#V/ sequences in other languages do not arise for Hausa.

A Hausa meter is defined by a particular arrangement of heavy and light syllables. For instance, the 'catalectic mutadaarik' meter (Schuh 1995) uses the arrangement shown in 1, in which curly brackets surround options exercised variably in particular lines.

(1) The Hausa catalectic mutadaarik meter[2]
{ᵕ_ᵕ} – {ᵕ_ᵕ} – {ᵕ_ᵕ} – ᴗ –
Example:
– – ᴗ ᴗ – – – ᴗ –
Nairàa dà kwabòo saabo-n kuɗii[3]
naira and kobo new-LINKER money
'Naira and kobo, the new money'

The positions with optionality show a systematic equivalence (free variation) between two lights and one heavy. We treat this equivalence using moraic theory (e.g. Hyman 1985, Hayes 1989a), whose fundamental tenet is that a heavy syllable contains two moras and a light syllable one mora. This permits a straightforward computation of the metrical equivalence between ᴗᴗ and – just noted, and (as we will see) has a rather more extensive application in rajaz.

3. The rajaz meter. Our analysis of rajaz is based on an examination of eleven poems, forming a total of 2,476 lines; see Appendix A for titles and sources.

A poem in rajaz normally consists of a series of stanzas. In modern rajaz, these are normally quintains (five lines), with the rhyme scheme *aaaab*, *ccccb*, *ddddb*, and so on. The stanza-final lines turn out to have not just special rhyming properties, but special metrical properties as well.

In the analysis we propose, the rajaz line consists of two parallel sister constituents. Following the terminology for Ancient Greek, which has similar units, we call them metra (sg. metron). The metra of the Hausa rajaz vary considerably, but the great bulk of them (96.5% of the lines in our sample) fall into just five types, given in Table 1 with their corpus counts.

Excepting – – ᴗ –, which is heptamoraic, these metra have exactly six moras (hexamoraic). The five metron types are all well represented, and the most common type

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[1] Words that begin orthographically with a vowel actually begin with a glottal stop.

[2] 'Catalectic' designates truncations in the pattern found at or near the end of a line; for example, catalectic mutadaarik seems like a truncated version of {ᵕ_ᵕ} – {ᵕ_ᵕ} – {ᵕ_ᵕ} – {ᵕ_ᵕ} –, a meter that also exists in Hausa.

[3] 'Naira da kwabo', a song by Haruna Oji promulgating the 1973 change to decimalized currency in Nigeria; recorded off the air.

All verse text is given in Hausa orthography. *y* is [j], *ƙ* is [k'], *c* is [tʃ], *j* is [dʒ], *sh* is [ʃ], *r* is [ɽ], *r̃* is [ɾ] or [r], an apostrophe represents a glottal stop, doubling marks length, and all other symbols have more or less their IPA values. Phonemic high tone is unmarked, and low tone is given with a grave accent.

TYPE	AS METRON 1		AS METRON 2		ALL	
	COUNT	FRACTION	COUNT	FRACTION	COUNT	FRACTION
⏑ – ⏑ –	1,146	0.463	521	0.210	1,667	0.337
– – –	173	0.070	864	0.349	1,037	0.209
– ⏑ ⏑ –	336	0.136	494	0.200	830	0.168
– – ⏑ –	688	0.278	47	0.019	735	0.148
⏑ ⏑ – –	25	0.010	487	0.197	512	0.103
TOTAL	*2,368*	*0.957*	*2,413*	*0.975*	*4,781*	*0.965*

TABLE 1. The five primary metron types.

overall is ⏑ – ⏑ –. However, the metron types are not evenly distributed: – – ⏑ – is almost entirely confined to line-initial position, and ⏑ ⏑ – – is confined to final position. As a first approximation, we can say that when a Hausa poet constructs a line of rajaz, she chooses and concatenates a legal metron 1 and a legal metron 2, following the frequencies given in the chart. However, as we will see, the full picture is more subtle and more principled than this.

The irregular metron types are listed in Appendix B. These form a diverse set, and we suspect that some may represent scribal error. For the sake of realism we include all of them when we train the weights for our grammars (see below), but we do not attempt to predict their relative frequency; we believe a grammar is sufficient simply if it succeeds in predicting them to be rare.

The thirty-second stanza of the poem MHa 'Tutocin Shehu' ('The banners of the Sheikh') by Mu'azu Haɗeja (1955) illustrates all five major metron types.

(2) Stanza 32 of 'Tutocin Shehu'
⏑ – ⏑ – / – ⏑ ⏑ –
Wà.kii.là naa mân.cè wa.ni
maybe I.PERF forget somebody
– – ⏑ – / ⏑ ⏑ – –
Kaa san ha.lii dà tù.nàa.nii
you.PERF know manner with memory
– – ⏑ – / – – –
Bàl.lee kà.mar mìs.kii.nìi
how.much.less as.with poor.person
⏑ – ⏑ – / ⏑ ⏑ – –
Wà.kii.là bàa shi à.nii.nii
maybe give.IMP him tenth.of.penny
⏑ – ⏑ – / ⏑ – ⏑ –
À san dà yai tù.nan.ni.yaa
one.SBJNCT know whether he.does memory
'Maybe I've forgotten somebody,
You know how things are with memory.
How much less for a poor person,
Maybe give him a tenthpenny coin,
And know whether he remembers.'

The reader may have noticed that we have classified the final syllable of the first line, *ni*, as heavy. This reflects our observance of a general principle of Hausa (and indeed other) quantitative meter, called BREVIS IN LONGO: the last syllable of a line metrically counts as heavy, irrespective of its phonological weight. We discuss this principle further in §5.3.

We turn now to a formal account that will cover the distribution of the major metron types, starting with the necessary theoretical background.

4. THEORETICAL BACKGROUND.

4.1. METER AND SCANSION. A key idea in generative metrics has been to posit an abstract structure—the METRICAL PATTERN, or simply 'meter'—which serves as a kind of measuring stick against which concrete lines of verse can be evaluated.

Concerning the form of the metrical pattern, we follow, for example, Hayes 1983, 1989b, Prince 1989, Fabb & Halle 2008, and Blumenfeld 2015 in construing it formally as a GRID, depicting the strength of the individual rhythmic beats, coupled with a hierarchical BRACKETING STRUCTURE. Grid and bracketing are affiliated thus: every nonterminal grid mark has a single bracketed domain of which it is the head. Such structures have been used for the description of three phenomena involving rhythm: verse meter, musical structure (Lerdahl & Jackendoff 1983), and linguistic stress (Liberman & Prince 1977, Halle & Vergnaud 1987, Hayes 1995). Such structures characteristically respect a principle of BINARISM/TERNARISM: constituents are very often binary, secondarily ternary, and very seldom (in verse, perhaps never) any higher order of branching. They also respect a principle of HIERARCHY; that is, they include multiple layers of structure. Verse and music are special in that they also respect the principle of PARALLELISM: sister nodes have identical or closely similar content.

For the Hausa rajaz, let us suppose that the structure of the line is defined as follows (these principles may be considered to be inviolable constraints on metrical structure).

(3) Structure of the rajaz line
  a. A LINE consists of two METRA.[4]
  b. A METRON consists of two FEET.
  c. A FOOT contains THREE GRID COLUMNS.

The prominence relations on the grid are defined as in 4.

(4) Prominence relations in the rajaz line
  a. The second foot of a metron is stronger than the first.
  b. The second position of a foot is the strongest.

We know of no evidence to tell us which metron of the line is the stronger and harmlessly omit the relevant structure from our representations.[5]

A bracketed grid structure that obeys the principles of 3 and 4 is given as Figure 1.

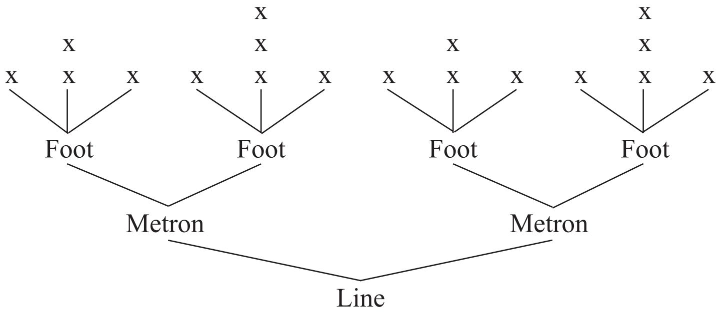

FIGURE 1. The rajaz metrical pattern.

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[4] Rajaz can also be written in trimeter, with three metra, for which this constraint would of course have to be stated differently. In this article we have limited our attention to dimeter.

[5] A referee suggested that the second metron should have greater prominence than the first, on the basis of 'prominence agreement' with the rising prominence contour of the feet (Prince 1989). But Prince's principle seems to us unlikely to be true; see in particular the counterexample in Attridge 1982:117–18.

It can be seen that there are two levels of binary branching (the most common type) and one of ternary, yielding a total of 2 × 2 × 3 or twelve grid columns. In terms of the analysis to come, this is the basis of the factual observation that most lines have twelve moras.

Many poetic traditions show a tendency to match the metrical bracketing of the line with the hierarchical phonological phrasing of the language (see e.g. Hayes 1988). This tendency is robustly attested at the line level in Hausa: as our data indicate, line breaks generally are matched by large phrasal breaks, and large phrasal breaks are confined to line breaks. The matchup of phonological phrasing to metrical bracketing is weaker at the lower levels of structure, metron and foot. At least in some poems, there is an observable weak tendency to echo the bracketing structure at the metron level by placing a phrasal break between the metra of a line, and also to echo the final foot structure by avoiding word breaks between the last two syllables.[6] Thus there is some evidence in support of the bracketing structure posited in Fig. 1. For a more abstract argument for bracketing structure (basically, it rationalizes the periodicity of the grid), see Prince 1989:46.

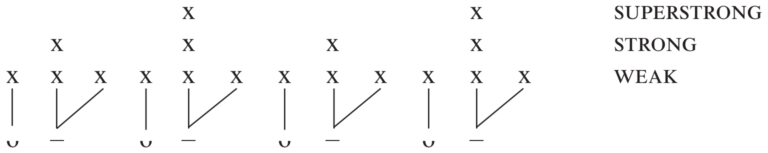
Turning now to the distribution of heavy and light syllables, we first display Fig. 1 without its bracketing, giving each horizontal grid level a label for convenience.

(5) Grid of Fig. 1 alone, with labels for levels

				x						x		SUPERSTRONG
	x			x			x			x		STRONG
x	x	x	x	x	x	x	x	x	x	x	x	WEAK

The key idea for the analysis of quantity is that the propensity to initiate a heavy syllable is related to the strength of the grid column on which it is initiated (see Halle 1970, Prince 1989, Hanson & Kiparsky 1996). The two superstrong columns virtually always initiate a heavy, and the two merely strong columns initiate a heavy as the most common option (see Table 1 above). The eight weak columns initiate either a light syllable or the second mora of a heavy. A 'canonical' line will therefore have an iambic quantitative profile. One such line (the first of 'Tutocin Shehu') is aligned with the grid as in 6.

(6) Scanning the canonical line type



ka noo ta ab du shaa ya boo
Kanòo ta Abdù shaa yàboo
Kano of Abdu receive praise
'Kano of Abdu be praised'

The principal 'noncanonical' metron types (– – –, – ⏑ ⏑ –, – – ⏑ –, ⏑ ⏑ – –) do place their final heavy syllable in the superstrong position, but elsewhere must necessarily involve some degree of weight-strength mismatch, discussed in detail in §5.2.[7]

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[6] Our compilation of phonological breaks for a subset of the poems we study may be viewed in the supplemental materials.

[7] A referee asks why it is criterial to INITIATE a heavy syllable in strong position, as opposed to (say) terminating it there. The question opens up issues too broad to discuss here, but to us the most likely answer comes from 'phonetically based metrics', parallel in approach to phonetically based phonology (e.g. Hayes, Kirchner, & Steriade 2004). Here is some relevant research. Psychologists (e.g. Donovan & Darwin 1979) lo-

4.2. Choice of theoretical framework. Seeking a framework in which to couch the analysis, we first adopt some criteria. Since we seek to model complexity with simple ingredients, we adopt a constraint-based theory, rooted in optimality theory (OT; Prince & Smolensky 1993). The OT research literature has a strong track record in the analysis of complex data with simple constraints. The key to this is to permit the ranking, or some other form of prioritization, of conflicting constraints.

Another desideratum arises from the need to achieve frequency-matching by assigning appropriate probabilities to candidates. Following the introduction of OT, probabilistic variants of OT were proposed, notably by Anttila (1997) and Boersma (1998). However, scholars in computer science (Eisner 2000, Johnson 2002, Goldwater & Johnson 2003) soon suggested that a more mathematically tractable approach with better learnability properties could be obtained by adopting existing ideas in probability theory. The relevant mathematics dates from the nineteenth century and is present in Smolensky's (1986) work in connectionism, itself part of the ancestry of OT. This approach is often now called maxent, abbreviating maximum entropy optimality theory.

There are several reasons to adopt maxent here. Some are practical: it is the only framework affiliated with a learning algorithm backed by mathematical proof; we know for certain when we conduct a maxent analysis that our software will be able to find (within the limits of hardware and computation time) the parameter values for the model that best fit the data.[8] Maxent also lends itself readily to statistical testing, permitting analysts the reassurance that the effects of their constraints are greater than might arise simply by chance (Hayes, Wilson, & Shisko 2012). In addition, maxent when scrutinized emerges as a deeply intuitive and rational way to reason from data to predictions.

Intuitive rationale of maxent. The key formula of maxent is as given in 7.

(7) The maxent formula

$$\Pr(x) = \frac{1}{Z}\exp(-\Sigma_i w_i f_i(x)), \text{ where } Z = \Sigma_j \exp(-\Sigma_i w_i f_i(x_j))$$

$\Pr(x)$	probability of candidate x
$\exp(y)$	e (about 2.72) to the power of y
Σ_i	summation across constraints
w_i	weight of the ith constraint
$f_i(x)$	number of times x violates the ith constraint
Σ_j	summation across candidates.

In prose, 7 says, 'To compute the predicted probability of a candidate, take e to the negated weighted sum of its constraint violations, then divide by the sum of comparable values computed for all candidates'. We dissect the formula for its meaning below.

First, constraints differ in strength by virtue of each one bearing a weight (w_i). The higher the weight of a constraint, the more it lowers the predicted probability of candidates that violate it. Unlike in OT, the probability of a particular candidate is dependent on the combined effect of all the constraints that violate it. This is expressed in the weighted sum $\Sigma_i w_i f_i(x)$ in 7, which is often called the harmony of a candidate; maxent

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cate the perceptual 'moment of occurrence' of a syllable approximately at the start of its first mora (syllable onsets are inert, just as they usually are in phonology). Moreover, the human auditory system responds very strongly at this location (Wright 2004). Concerning why heavy syllables should gravitate to rhythmically strong positions, see the detailed studies of the phonetics of syllable weight in Gordon 2006 and Ryan 2011.

[8] A convergence proof exists for noisy harmonic grammar (Boersma & Pater 2016), but it covers only nonstochastic cases.

is indeed one species of the more general approach of HARMONIC GRAMMAR (Legendre et al. 1990, Legendre et al. 2006, Potts et al. 2010, Pater 2016).

The fact that the harmony contributions of all constraints get added together means that the theory predicts CONSTRAINT GANGING: violation of multiple constraints, or multiple violations of one constraint, can outweigh the effect of a single higher-weighted constraint (Jäger & Rosenbach 2006). In maxent, ganging is an automatic behavior of the system, a fact that differentiates it (and other forms of harmonic grammar) from OT, where ganging is achieved only as a special effect (conjoined constraints; Smolensky 1995).[9] We believe that automatic ganging not only is well supported empirically (e.g. Zuraw & Hayes 2017) but also accords with common sense about how evidence is martialed to arrive at conclusions: ideally, we weigh all of the evidence.

The exponentiation operator in 7, exp(y), also has a commonsense basis, as its effect is to require a great deal of evidence in order to approach certainty. For instance, to shift the predicted probability of a candidate downward from 50% to 49.001%, one needs to assign it only 0.040 units of additional harmony, but the same shift going from 1% to 0.001% requires 6.92 units. Further, 7 includes the denominator Z, which sensibly requires that lower probability be assigned when strong competing candidates are present.

In sum, maxent strikes us as deeply in accord with the way rational beings weigh evidence in making choices: the explanatory factors are given different degrees of importance, all of the evidence is considered, a greater degree of evidence is needed in approaching certainty, and options are less plausible when they compete with strong alternatives.

HARMONICALLY BOUNDED SEMI-WINNERS. Formula 7 assigns some positive degree of probability to every single candidate. For most ‘losing’ candidates this probability is so low (like, say, 10^{-30}) that most people will consider the value an acceptable approximation to zero. Sometimes a significant degree of probability is assigned to candidates that are HARMONICALLY BOUNDED (i.e. incur a proper superset of the constraint violations of some other candidate; Prince & Smolensky 1993:156). This probability is never higher than that assigned to the bounding candidate, assuming nonzero weights, but it can sometimes be nontrivial (Jesney 2007).

The possibility that harmonically bounded candidates can receive substantial probability is one that sets maxent apart from other approaches. A variety of analyses have made use of this property (Hayes & Wilson 2008, Hayes & Moore-Cantwell 2011, Hayes, Wilson, & Shisko 2012), and indeed it is essential in the analysis to follow.

Summing up, the reasons we adopt maxent are (i) its computational advantages in finding the optimum grammar and statistically testing it, (ii) its close correspondence with intuition concerning the role of evidence in arriving at conclusions, and (iii) its unique behavior in permitting harmonically bounded candidates sometimes to receive substantial probability.

Maxent is here deployed in an ‘inputless’ architecture, in which all that we are interested in is the probabilities assigned to the members of GEN (i.e. the complete candidate set). Nothing is derived from anything; we only want to know which candidates are legal metrical entities and to what degree. This architecture has been employed before, both in the study of phonotactics (Hayes & Wilson 2008) and in metrics (Hayes & Moore-Cantwell 2011, Hayes, Wilson, & Shisko 2012). Abandoning metrical underly-

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[9] Maxent does not HAVE to gang; in particular, every classical OT grammar has a maxent translation, which can be created by choosing very large weight differences to reflect OT strict ranking; see Prince & Smolensky 1993:§10.2.2.

ing forms avoids arbitrary and perhaps unfruitful decisions, and it lets us focus on the simple question of what is metrically legal.

5. A FIRST-PASS ANALYSIS.

5.1. CHOOSING A GEN. Turning to the analytic task posed by Hausa, we first make the assumption that GEN consists of all possible strings of the symbols /⏑/ and /–/: that is, of every string of syllable weights. Thus (just as in phonology), GEN is vast, indeed infinite. However, it turns out that we can work safely with an ersatz GEN that is finite, indeed manageably small. First, we model the two metra of the line separately, using a diacritic annotation indicating whether we are dealing with an initial or final metron. This is because, as our investigations have indicated, there are no statistically significant dependencies between the two metra of a line (the choice of the second metron does not depend on the choice for the first, and vice versa). Then, for each metron, we adopt as GEN a list consisting of all possible sequences of – and ⏑ up to five syllables, as well as the lightest six-syllable sequences, ⏑ ⏑ ⏑ ⏑ ⏑ ⏑ and its *brevis in longo* variant ⏑ ⏑ ⏑ ⏑ ⏑ –. This list is given in Table 2.

1 SYLLABLE	2 SYLLABLES	3 SYLLABLES	4 SYLLABLES	5 SYLLABLES		6 SYLLABLES
⏑	⏑ ⏑	⏑ ⏑ ⏑	⏑ ⏑ ⏑ ⏑	⏑ ⏑ ⏑ ⏑ ⏑	– ⏑ ⏑ ⏑ ⏑	⏑ ⏑ ⏑ ⏑ ⏑ ⏑
–	⏑ –	⏑ ⏑ –	⏑ ⏑ ⏑ –	⏑ ⏑ ⏑ ⏑ –	– ⏑ ⏑ ⏑ –	⏑ ⏑ ⏑ ⏑ ⏑ –
	– ⏑	⏑ – ⏑	⏑ ⏑ – ⏑	⏑ ⏑ ⏑ – ⏑	– ⏑ ⏑ – ⏑	
	– –	⏑ – –	⏑ ⏑ – –	⏑ ⏑ ⏑ – –	– ⏑ ⏑ – –	
		– ⏑ ⏑	⏑ – ⏑ ⏑	⏑ ⏑ – ⏑ ⏑	– ⏑ – ⏑ ⏑	
		– ⏑ –	⏑ – ⏑ –	⏑ ⏑ – ⏑ –	– ⏑ – ⏑ –	
		– – ⏑	⏑ – – ⏑	⏑ ⏑ – – ⏑	– ⏑ – – ⏑	
		– – –	⏑ – – –	⏑ ⏑ – – –	– ⏑ – – –	
			– ⏑ ⏑ ⏑	⏑ – ⏑ ⏑ ⏑	– – ⏑ ⏑ ⏑	
			– ⏑ ⏑ –	⏑ – ⏑ ⏑ –	– – ⏑ ⏑ –	
			– ⏑ – ⏑	⏑ – ⏑ – ⏑	– – ⏑ – ⏑	
			– ⏑ – –	⏑ – ⏑ – –	– – ⏑ – –	
			– – ⏑ ⏑	⏑ – – ⏑ ⏑	– – – ⏑ ⏑	
			– – ⏑ –	⏑ – – ⏑ –	– – – ⏑ –	
			– – – ⏑	⏑ – – – ⏑	– – – – ⏑	
			– – – –	⏑ – – – –	– – – – –	

TABLE 2. GEN for the analysis of one rajaz metron.

Our computations indicate that this is a ‘safe’ GEN, as it includes every logically possible weight sequence under a certain length, and we can show that any candidate beyond these lengths would be prevented by powerful constraints from receiving any appreciable probability.[10]

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[10] Here are the details. There are two dangers in using a short GEN like Table 2. First, there might be unlisted candidates that receive substantial probability without our being aware of it (Karttunen 2006). Second, under the infinite GEN demanded by the theory (all strings of ⏑ and –), the normalizing factor Z used in maxent analysis might turn out to be infinite—which wipes out the analysis entirely (Daland 2015). To make sure we have no undetected viable candidates, we created a larger GEN including all ninety-three strings of up to seven moras; when we used this in modeling (see below), no candidate in the expanded set got more than 0.00026 probability, and longer candidates do even worse. Regarding the problem of infinite Z, Daland observes that the key to avoiding it is to include a constraint of the type *STRUC, penalizing any sort of structure. For us, the applicable constraint is 9 below, *SQUEEZE, which penalizes every mora above six added to a candidate. In our analyses, the weight of *SQUEEZE is at least 3.78 in every poem. We calculate that under this value, the aggregate probability of candidates added as we let them grow longer shrinks far faster than the number of candidates added; as Daland shows, this keeps us safe from the infinite-Z problem.

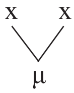
5.1. Constraints. Hayes, Wilson, and Shisko (2012:697) suggest that metrics is fundamentally based on this principle: construct lines whose phonological structure evokes the meter. In this view, the meter (here, Fig. 1) is viewed as a specifically rhythmic pattern.[11] The syllables of the phonological representation have properties that dictate within narrow limits how they will be deployed to evoke the meter effectively.

In the case of a quantitative meter like rajaz, we will often find close durational matching, with the mora serving as the unit of timing. In this spirit, our first family of constraints is defined to establish one-to-one correspondence between moras and grid columns. *Stretch says that it is bad to align a mora with more than one grid column, and *Squeeze says it is bad to align a grid column with more than one mora. Example violations appear in 10.

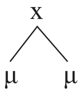
(8) *Stretch: For every grid column greater than one to which a mora is associated, assess a penalty.

(9) *Squeeze: For every mora greater than one to which a grid column is associated, assess a penalty.

(10) a. Violation of *Stretch



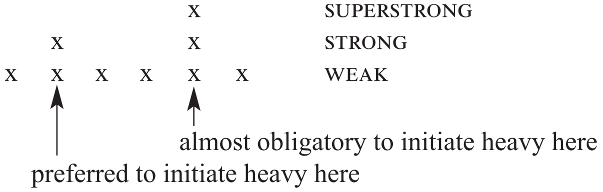
b. Violation of *Squeeze



We also assume, without bothering to formulate them, inviolable constraints that ban unassociated (‘floating’) moras and unassociated grid columns.[12] In conjunction with the metrical template in Fig. 1, *Stretch and *Squeeze enforce the fundamental hexamoraic character of the rajaz metron (for heptamoraic metra and their distribution, see below).[13]

As noted above, there are two places where heavy syllables most often occur in the rajaz: they are almost obligatorily initiated in the fifth, superstrong, position of the metron, and they are statistically predominant in the second, merely strong, position.

(11) Distribution of heavy syllables in the metron



We take this to be an instance of prominence alignment, in the sense of Prince & Smolensky 1993:150. Just as in stress systems, where the constraints typically align heavy syllables with stress and light syllables with stresslessness, so also in quantitative meter heavy syllables are aligned with strong beats and light syllables with weak. Naturally, the superstrong positions would be expected to align even more strictly with

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[11] For alternative views see Blumenfeld (2015) and Riad (2017), who favor accounts treating metrics more or less as extended phonology. Although little here hinges on these differences of conception, we note in passing that the hexamoraic metron of rajaz, impeccable in the Lerdahl/Jackendoff (1983) theory of rhythm we assume, would have to be considered very dubious taken as a phonological entity.

[12] In fact, empty grid columns do occur widely in the tradition of Hausa oral verse, but not in the written genre discussed here.

[13] Since our GEN consists simply of strings of ᴗ and –, we are ignoring the candidates that misalign grid slots and moras gratuitously—for example, in having the same number of moras and grid slots but misassociating them anyway, thereby violating *Stretch and *Squeeze. Since *Stretch and *Squeeze are powerful constraints, such candidates will receive very low probability and may safely be ignored.

heavy syllables than the merely strong ones. The constraints that are needed for rajaz are given in 12.

(12) Constraints defined by prominence alignment of weight and grid strength
- a. Strong is Long: Assess a penalty for any strong (or stronger) grid column that does not initiate a heavy syllable.
- b. Superstrong is Long: Assess a penalty for any superstrong grid column that does not initiate a heavy syllable.
- c. Long is Strong: Assess a penalty for any heavy syllable that is not initiated in a strong (or stronger) grid column.

The constraint Long is Superstrong is of course a logical possibility, but turns out to be of no use to the analysis and is therefore omitted; see discussion below. Table 3 gives the grid alignments of the five basic metron types and their violations of Strong is Long and Long is Strong.

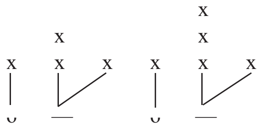
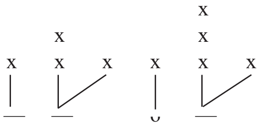
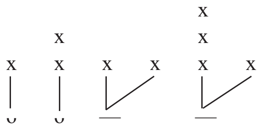
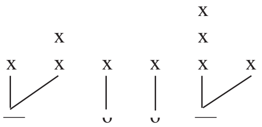
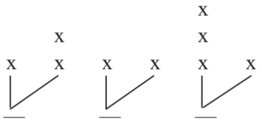
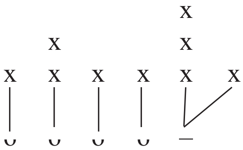
	Strong is Long	Long is Strong
	0	0
	0	0 1st heavy treated as ‘as if’ light; see below
	1 from grid column 2	1 from 1st heavy
	1 from grid column 2	1 from 1st heavy
	1 from grid column 2	2 from 1st and 2nd heavy

Table 3. Sample violations of Strong is Long and Long is Strong.

Later on, when we establish the constraint weights, it will emerge that Superstrong is Long is a very powerful constraint (accounting for the near-obligatory appearance of – at the end of each metron), and Strong is Long is a noticeably powerful constraint (accounting for the overall preference for iambicity). Long is Strong turns out to play a subtle role, but this will only be seen when we move on to more detailed grammars for individual poems; it militates against – – –, which uniquely among the five types violates Long is Strong twice.

There is one way not yet covered in which the six positions of the grid could be filled while still obeying Superstrong is Long, namely by picking nothing but light syllables in the nonsuperstrong positions.

(13)



This candidate occurs in verse, but is quite rare (see Appendix B). To near-exclude it, we appeal to a ban on long sequences of light syllables, a ban that is pervasive in Hausa meters (Greenberg 1949, Schuh 2014). We express this as a constraint penalizing a sequence of three lights.

(14) *Triple Light: *⏑ ⏑ ⏑

Empirical support for such a constraint is found in the Hausa mutadaarik meter (Schuh 1989, 1994). This basically anapestic meter allows feet like ⏑ ⏑ – and – –, but also the rarer variant – ⏑ ⏑, which shows that the right edge of the foot can be ⏑ ⏑. Yet ⏑ ⏑ ⏑ ⏑ is extremely rare as a mutadaarik foot, and – ⏑ ⏑ is never followed by ⏑ ⏑ –: it may only be followed by –. These observations are straightforwardly accounted for by *Triple Light, for which a ⏑ ⏑ ⏑ ⏑ sequence incurs two violations. Ancient Greek anapests work just the same (Raven 1962:54).

Within rajaz, *Triple Light accounts for the near-absence of the ⏑ ⏑ ⏑ ⏑ – metron type. As 13 shows, this metron is favored by Long is Superstrong, a constraint we have dispensed with. If Long is Superstrong is to be included in the analysis, it must be made far weaker than *Triple Light.

The constraints *Stretch, *Squeeze, Superstrong is Long, Strong is Long, and *Triple Light, along with the template of Fig.1, give us the basic overall patterning of the data, with *Stretch and *Squeeze accounting for fundamental hexamoraicity of metra and Superstrong is Long, *Triple Light, and Strong is Long accounting for the distribution of heavy syllables.

Beyond this, it is necessary to account for the asymmetries in the populations of the five types across the two metra, documented above in Table 1. To review, ⏑ ⏑ – – is rare as an initial metron, occurring there only 1% of the time. We have no basis for understanding why the rajaz essentially forbids lines to begin with ⏑ ⏑, though factually this is so. It is not a property of Hausa meter in general (Schuh 1989, 1994); for instance, the catalectic mutadaarik noted in 1 begins thus. For rajaz we simply stipulate a ban on line-initial ⏑ ⏑, as given in 15.[14]

(15) *Line-Initial ⏑ ⏑: *$[_{\text{Line}}$ ⏑ ⏑

The other asymmetry of metron distribution in rajaz requires us to make a brief excursus into 'as if' phenomena in quantitative meter.

5.3. Brevis in longo and other 'as if' phenomena. A pervasive phenomenon in quantitative metrics is brevis in longo ('a short in place of a long'). It works like this: for the last syllable in the line, the actual phonological quantity does not matter, and any light in this position is counted as heavy. This is true, for instance, in Greek (Raven 1962:26), Latin (Raven 1965:30), Sanskrit (Fabb 2002:175), and Arabic (Elwell-Sutton 1986). The pattern holds as well for Hausa: we have found no systematic patterning that is based on the actual phonological weight of final syllables; rather, they are consistently treated as if they were heavy. Indeed, although we have not systematically investigated this, our impression is that line-final length distinctions are actually neutralized

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[14] Violations of *Line-Initial ⏑ ⏑ and *Triple Light are underrepresented even in prose (§6.6), but the effect is modest and is insufficient to explain the rarity of verse lines that violate them.

phonetically in singing: short vowels are sung long; the normal phonetic [ʌ] vowel quality of short /a/ is replaced by [a], and long and short vowels of the same phonemic quality can rhyme with each other.

Brevis in longo is by far the most pervasive 'as if' phenomenon in quantitative metrics, and we simply treat it as such.[15]

(16) *Brevis in longo*: Treat every line-final syllable as heavy.

In practical terms, *brevis in longo* implies the cancellation of all violations of STRONG IS LONG and SUPERSTRONG IS LONG that would otherwise occur when a light syllable occurs line-finally. For purposes of analysis, *brevis in longo* permits us a convenient shortening of GEN for line-final metra: it is harmless to leave out the vacuous candidates ending in ᴗ, since the constraints we are employing will prefer the versions where final ᴗ is treated as –. We implemented this in our GEN given above in Table 2.

We invoke a distinct 'as if' principle as the basis of our treatment of the aberrant heptamoraic – – ᴗ – metron. Recall from Table 1 that we consider this metron type to be fully legal, but only in line-initial position. We suggest that the requirement that metra be hexamoraic is fundamental in rajaz, and that line-initial heptamoraic metra arise as a consequence of a license optionally allowing an initial heavy to be treated as light. From this and other principles emerges the prediction that initial – – ᴗ – should be the only legal heptamoraic metron—all others are ruled out by independently needed constraints. Thus, for example, we might expect heptamoraic – ᴗ – – to occur line-initially, but this would count as a version of ᴗ ᴗ – –, which is impossible line-initially because of *LINE-INITIAL ᴗ ᴗ. All other logical possibilities for licensing a heptamoraic metron are ruled out by *SQUEEZE.

The practice of letting an initial heavy stand in for a light has precedents elsewhere. In Hausa, the catalectic mutadaarik described above in 1 is basically ᴗ ᴗ – / ᴗ ᴗ – / ᴗ ᴗ – / ᴗ –, but the first foot may alternatively be rendered – ᴗ – (Schuh 1995). Persian works like Hausa mutadaarik, in that heavy may replace light in the initial position of any meter that begins ᴗ ᴗ (Elwell-Sutton 1976:86). Greek iambic trimeter is like Hausa rajaz, but more general: – – ᴗ – metra may be substituted for basic ᴗ – ᴗ – anywhere in the line (Raven 1962:27).

In our analysis, the substitution of heavy for initial light is governed by a constraint, INITIAL HEAVY-FOR-LIGHT, that militates against heavy-for-light substitution in initial position.

(17) INITIAL HEAVY-FOR-LIGHT: Assess a violation when a heavy syllable substitutes for a light in initial position.

In fact, it is something of a stretch to call 17 a constraint, as some Hausa poets actually prefer to invoke the substitution. In the analysis to follow, we give INITIAL HEAVY-FOR-LIGHT a special status by letting it assume a negative weight, unlike any of the other constraints. When INITIAL HEAVY-FOR-LIGHT has a negative weight, a violation actually makes a candidate better, as in Flemming 2004.[16] This permits us to analyze the practice of poets who prefer the substitution.

6. MAXENT MODELING. In our maxent modeling, we make separate copies of GEN—one for initial metra, one for final—and annotate them for the frequencies with which

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[15] We are agnostic concerning the formal implementation of 'as if' constraints like 16. One possibility is to construct a parallel representation of the weight pattern, licensed by its connection to phonology and referred to by the metrical constraints.

[16] As a referee points out, negative weights are controversial; they could be avoided here by adding a constraint that is violated whenever initial heavy-for-light substitution is NOT present.

each candidate occurs in the data corpus, as well as for the constraint violations. Standard algorithms then assign weights to the constraints in a way that best fits the data. We first demonstrate how highly weighted constraints pick out the five basic metron types from GEN as the most common. We then turn to detailed quantitative modeling of the distribution of metron types across line position, stanza position, and poem.

6.1. Capturing the five major metron types. To show how the five major metron types emerge from the constraint system laid out above, we adopt an idealized system in which these are the only legal types. For simplicity, we ignore frequency differences and just assume that all types are of equal frequency in those contexts where they are legal. We fit the weights to assign such frequencies, and to approximate zero frequencies for all noncanonical metron types.

The five basic metron types are singled out by a five-constraint grammar, as follows.

(18) A first-pass metrical grammar: singling out the dominant metron types

Constraint	Weight
*Stretch (8)	100
*Squeeze (9)	100
Superstrong is Long (12b)	100
*Line-Initial ⏑ ⏑ (15)	100
*Triple Light (14)	100

We adopt 100, an extremely high value, for each constraint weight; under the maxent math this suffices to give any candidate that violates a constraint a probability vanishingly close to zero (for instance, line-initial ⏑ ⏑ – –, which violates only *Line-Initial ⏑ ⏑, gets a probability of 9.3×10^{-45}). In the tableaux below, we record such values as zero.

The tableaux given in 19 are abbreviated versions of computationally implemented tableaux (available in the supplemental materials) that evaluate all of the candidates in the GEN of Table 2. Where a candidate is marked 'etc.', this means that any other candidate that shares its constraint violation will likewise be assigned a near-zero probability.

(19) Tableaux for first-pass grammar

	*Squeeze	*Stretch	Superstrong is Long	*Line-Initial ⏑ ⏑	*Triple Light	Predicted frequency
Weights:	100	100	100	100	100	
1st metron						
☞ ⏑ – ⏑ –						0.25
☞ – – ⏑ –						0.25
☞ – ⏑ ⏑ –						0.25
☞ – – –						0.25
⏑ – – –, etc.	*					0
⏑ – –, etc.		*				0
⏑ – – ⏑, etc.			*			0
⏑ ⏑ – –, etc.				*		0
⏑ ⏑ ⏑ ⏑ –, etc.					**	0

(Tableaux 19. *Continues*)

	*Squeeze	*Stretch	Superstrong is Long	*Line-Initial ⏑ ⏑	*Triple Light	Predicted frequency
Weights:	100	100	100	100	100	
2nd metron						
☞ ⏑ – ⏑ –						0.25
☞ – ⏑ ⏑ –						0.25
☞ – – –						0.25
☞ ⏑ ⏑ – –						0.25
– – ⏑ –, ⏑ – – – –, etc.	*					0
⏑ – –, etc.		*				0
⏑ – – ⏑, etc.			*			0
⏑ ⏑ ⏑ ⏑ –, etc.					**	0

What we have so far, then, is a demonstration that a subset of the constraints we have laid out suffices to single out the five basic metron types, limiting them where appropriate to the first (– – ⏑ –) or second (⏑ ⏑ – –) metron position. In this simple system, all legal candidates are violation-free, and a maxent grammar assigns them equal (.25) probability.[17]

6.2. Variation by poem and stanza position. The bigger analytical challenge is not just to derive the five basic metron types, but to offer a nuanced, frequency-matching analysis of all the data in our corpus. The 2,476 lines of our corpus come from eleven different poems, no two of which show exactly the same pattern (even when they are by the same poet). Moreover, within a poem the last line of the five-line stanza often has a different pattern of metron types from the first four lines.

In Table 4 and Table 5, we give a fuller presentation of our data, giving the percentage frequency of each of the five primary metron types for each of the eleven poems, which are identified by title and author initials (for full details see Appendix A).

Within each poem, we consider two distinctions: whether a metron is the first or the last of its line, and whether the line in which it is located is final or nonfinal in its stanza. Hence there are 5 × 11 × 2 × 2 = 220 data points. Data are percentages, calculated by dividing the number of metra of a particular type by the number of stanza-final or non-stanza-final lines in the poem. For example, AAA ‘Cuta ba Mutuwa ba’ has sixty-seven stanzas, hence 4 × 67 = 268 non-stanza-final lines; of these 181 have ⏑ – ⏑ – as their first metron, that is, 67.5% of the total; this is the first value given in Table 4. Data do not sum to 1 across rows because we do not include any of the noncanonical metra. For HGU ‘Gidan Audu Baƙo Zu’ we analyze only the non-stanza-final lines; in this poem the last line of each stanza is an invariant refrain (*Mù jee gidan zuu kalloo* ‘Let’s go to the zoo and see’), and it would be pointless to submit to statistical analysis a corpus consisting essentially of just a single line.

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[17] Equal probability is indeed the maximum entropy solution, which hints at the name given to this framework.

POSITION IN STANZA	POEM	TOTAL LINES	⏑ – ⏑ – (%)	– – ⏑ –	– ⏑ ⏑ –	– – –	⏑ ⏑ – –
NONFINAL	AAA ‘Cuta ba Mutuwa ba’	268	67.5	6.3	19.4	0.4	0.0
	AAA ‘Jihar Kano’	60	96.7	0.0	1.7	0.0	0.0
	AAA ‘Ƙoƙon mabarata’	208	97.6	0.0	0.0	0.0	0.0
	ADS ‘Tabarƙoƙo’	136	35.3	43.4	14.7	0.0	0.0
	AYG ‘Karuwa’	156	23.1	24.4	22.4	21.8	3.8
	HGU ‘Gidan Audu Baƙo Zu’	140	37.2	43.4	22.2	14.2	0.9
	IYM ‘Harshen Hausa’	176	30.7	39.8	14.8	10.2	1.1
	IYM ‘Roƙon Ubangiji’	160	39.4	46.3	6.3	3.8	1.9
	MHa ‘Tutocin Shehu’	308	44.2	26.9	19.2	6.2	0.3
	TTu ‘Harshen Hausa’	76	26.3	53.9	10.5	5.3	0.0
	TTu ‘Kanari’	320	26.6	54.4	9.1	7.8	1.3
FINAL	AAA ‘Cuta ba Mutuwa ba’	67	64.2	4.5	28.4	0.0	0.0
	AAA ‘Jihar Kano’	15	86.7	13.3	0.0	0.0	0.0
	AAA ‘Ƙoƙon mabarata’	52	88.5	7.7	1.9	0.0	0.0
	ADS ‘Tabarƙoƙo’	34	50.0	23.5	14.7	0.0	0.0
	AYG ‘Karuwa’	39	38.5	20.5	20.5	10.3	5.1
	HGU ‘Gidan Audu Baƙo Zu’	—	—	—	—	—	—
	IYM ‘Harshen Hausa’	44	45.5	45.5	2.3	4.5	0.0
	IYM ‘Roƙon Ubangiji’	40	50.0	25.0	7.5	5.0	7.5
	MHa ‘Tutocin Shehu’	77	39.0	13.0	16.9	23.4	1.3
	TTu ‘Harshen Hausa’	19	36.8	47.4	15.8	0.0	0.0
	TTu ‘Kanari’	80	30.0	11.3	23.8	30.0	2.5

TABLE 4. Data for eleven rajaz poems: metron 1.

POSITION IN STANZA	POEM	TOTAL LINES	⏑ – ⏑ –	– – ⏑ –	– ⏑ ⏑ –	– – –	⏑ ⏑ – –
NONFINAL	AAA ‘Cuta ba Mutuwa ba’	268	0.4	0.0	0.0	86.6	10.4
	AAA ‘Jihar Kano’	60	1.7	5.0	93.3	0.0	0.0
	AAA ‘Ƙoƙon mabarata’	208	1.0	1.4	97.1	0.0	0.0
	ADS ‘Tabarƙoƙo’	136	22.1	9.6	27.9	21.3	6.6
	AYG ‘Karuwa’	156	19.2	0.0	20.5	34.0	25.0
	HGU ‘Gidan Audu Baƙo Zu’	140	6.2	0.9	7.1	46.1	60.3
	IYM ‘Harshen Hausa’	176	27.8	1.7	15.3	22.7	29.5
	IYM ‘Roƙon Ubangiji’	160	18.1	2.5	12.5	41.3	23.8
	MHa ‘Tutocin Shehu’	308	27.6	1.3	13.3	32.5	23.4
	TTu ‘Harshen Hausa’	76	6.6	2.6	13.2	32.9	40.8
	TTu ‘Kanari’	320	10.9	0.6	9.1	38.8	40.0
FINAL	AAA ‘Cuta ba Mutuwa ba’	67	0.0	0.0	0.0	97.0	3.0
	AAA ‘Jihar Kano’	15	66.7	0.0	26.7	0.0	0.0
	AAA ‘Ƙoƙon mabarata’	52	65.4	0.0	28.8	0.0	0.0
	ADS ‘Tabarƙoƙo’	34	0.0	0.0	23.5	70.6	5.9
	AYG ‘Karuwa’	39	74.4	2.6	7.7	5.1	7.7
	HGU ‘Gidan Audu Baƙo Zu’	—	—	—	—	—	—
	IYM ‘Harshen Hausa’	44	0.0	0.0	0.0	77.3	20.5
	IYM ‘Roƙon Ubangiji’	40	97.5	2.5	0.0	0.0	0.0
	MHa ‘Tutocin Shehu’	77	80.5	9.1	0.0	3.9	3.9
	TTu ‘Harshen Hausa’	19	0.0	0.0	0.0	73.7	21.1
	TTu ‘Kanari’	80	93.8	3.8	1.3	0.0	0.0

TABLE 5. Data for eleven rajaz poems: metron 2.

To visualize the data, the reader may find it useful at this point to turn ahead to the graphs of Figs. 5–15, where the data are plotted as the black lines.

It should be clear that there is quite a bit of stylistic variation, and that a poet often treats the stanza-final line differently from the others. For instance, in TTu ‘Kanari’, ᴗ – ᴗ – occurs in 30% of the 'second metron, non-stanza-final line' category, but for the 'second metron, stanza-final line' its frequency is dramatically higher, 93.8%.

The analysis to follow covers first metron 1, then metron 2.

6.3. Analysis of metron 1. Scrutiny of the data indicates that, while poets exercise quite a bit of arbitrary choice in the second metron, their practice is far less arbitrary in the first metron. Let us look at the aggregate frequency figures for the major metron types. We refer to the two metron types ᴗ – ᴗ – and – – ᴗ – as iambic since, as Table 3 showed, they are the only ones that (making use of 17, Initial Heavy-for-Light) perfectly realize the iambic structure of the metron.

In the data of Tables 4 and 5 we find that the iambic category is always the most common. Then, with few exceptions, – ᴗ ᴗ – is always more frequent than – – –. The relative preferences for all of the data are shown in Figure 2; in the data labels, 'f' means 'stanza-final' and '~f' means 'non-stanza-final.'

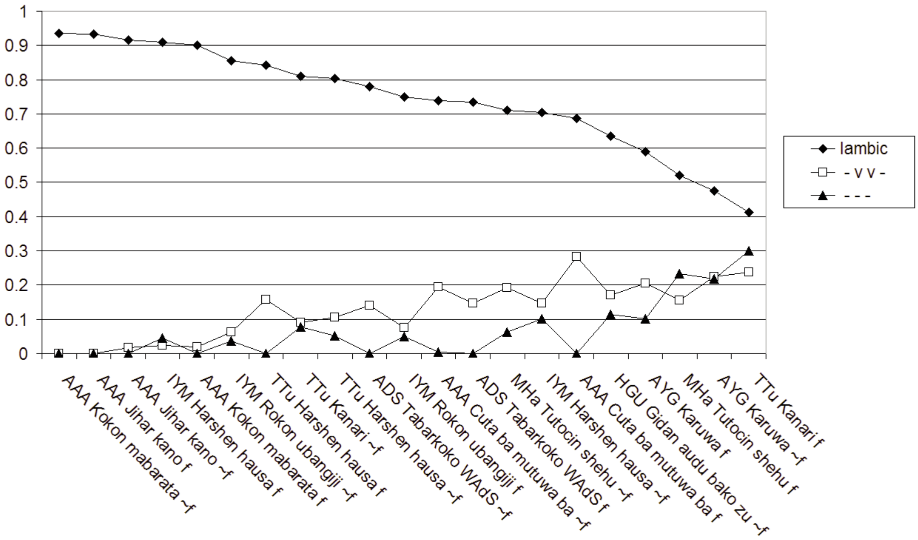

Figure 2. Relative preference for iambic, – ᴗ ᴗ –, and – – – as the first metron.

Such systematic patterning suggests that a structural principle underlies the regularities, and we offer here an analysis based on the natural constraints of prominence alignment discussed above. We have already established that Superstrong is Long is a very powerful constraint, which helps define the basic inventory of legal metra. Our study has also found that Long is Superstrong would be a very weak constraint at best, and we have not included it in the analysis. The remaining prominence-alignment constraints are Strong is Long and Long is Strong, which for most poets turn out to be neither very strong nor very weak—hence they play a role in governing differences of relative frequency and thus of metrical style. In 20 we give the violations of the three relevant metron types (iambic, – ᴗ ᴗ –, and – – –) for these two constraints.

(20) Violations of Strong is Long and Long is Strong

	Strong is Long	Long is Strong
Iambic (ᴗ – ᴗ – / – – ᴗ –)		
– ᴗ ᴗ –	*	*
– – –	*	**

Tableau 20 displays a pattern known to be important in OT: harmonic bounding. The metron – – – has every violation that – ⏑ ⏑ – has, plus an additional violation of Long is Strong; and if we abstract away from Initial Heavy-for-Light (irrelevant, for reasons to be explained), then – ⏑ ⏑ – has every violation that ⏑ – ⏑ – and – – ⏑ – have, plus violations for Long is Strong and Strong is Long. In OT, if candidate *x* harmonically bounds candidate *y*, then *y* can never win, no matter how the constraints are ranked (Prince & Smolensky 1993:156). As noted in §4.2, maxent enforces a similar principle: if candidate *x* harmonically bounds candidate *y*, then *y* can never be assigned a higher probability than *x*; and indeed unless all of the constraints that distinguish *x* from *y* have zero weight, *y* must be assigned a lower probability than *x*. To explain the relative differences seen in Fig. 2, all we need to assume is that Strong is Long and Long is Strong have nonzero weights. If this line of analysis is right, then in the first metron the frequencies are a direct reflection of the degree to which various metra deviate from the ideal specified by the metrical grid.

This is not to say that all of the poets work the same in metron 1; Fig. 2 already shows that they do not. Rather, they use a variety of weights for the crucial constraints Strong is Long and Long is Strong, which produce highly varying outcomes. Yet with few exceptions, these outcomes respect the implicational pattern we have observed; see Table 6.

	Weight of Long is Strong	Weight of Strong is Long
AAA ‘Cuta ba Mutuwa ba’	1.5	0.0
AAA ‘Jihar Kano’	0.0	3.9
AAA ‘Ƙoƙon mabarata’	0.2	3.9
ADS ‘Tabarƙoƙo’	0.0	1.5
AYG ‘Karuwa’	0.3	0.0
HGU ‘Gidan Audu Baƙo Zu’	0.3	0.3
IYM ‘Harshen Hausa’	0.5	0.4
IYM ‘Roƙon Ubangiji’	0.3	1.2
MHa ‘Tutocin Shehu’	0.5	0.4
TTu ‘Harshen Hausa’	0.5	0.4
TTu ‘Kanari’	0.2	0.4

Table 6. Weights of Long is Strong and Strong is Long for eleven poems.

Turning now to the two iambic metra, ⏑ – ⏑ – / – – ⏑ –, the picture is rather different: these trade off, such that using one more means using the other less. The scattergram in Figure 3 illustrates this.

The slope of the regression line is very close to −1, indicating trade-off. We suggest that within the rajaz system as a whole, ⏑ – ⏑ – and – – ⏑ – are in free variation, but for different combinations of poem and stanza position, one or the other is preferred. This follows in our analysis from our having given an exceptional status to the constraint Initial Heavy-for-Light (17), letting it take on negative or positive weights. A priori it is neither a good thing nor a bad for this substitution to be used. From this perspective, ⏑ – ⏑ – and – – ⏑ – are variants of the same candidate (they are identical in their remaining constraint violations), with a relatively arbitrary allocation of the combined frequency.

Summing up so far, we suggest that although Hausa poets are free to exert idiosyncratic preferences (among the legal metra) in the final metron position, they abide by principled markedness constraints, based on prominence alignment, for the initial metron. The only real idiosyncrasy in the first metron is a poet-specific choice for favoring or disfavoring initial heavy-for-light substitution.

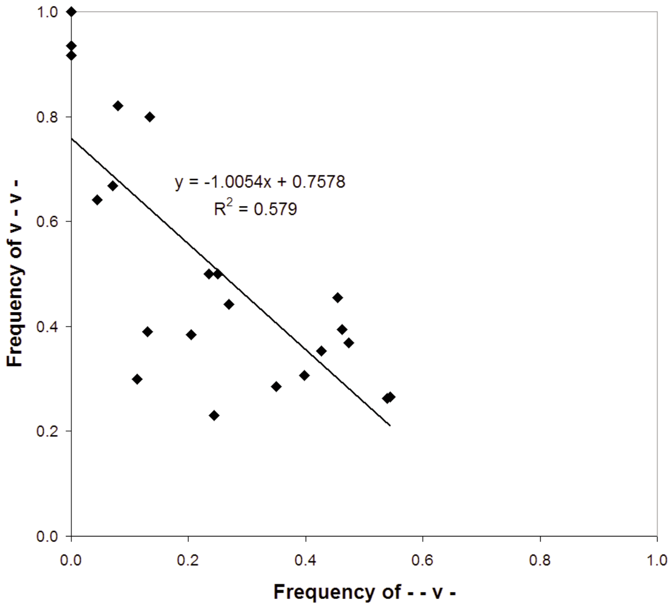

Figure 3. Trade-off for ⏑ – ⏑ – and – – ⏑ – in the first metron.

6.4. Analysis of metron 2. Metron 2 stands out for its greater degree of poem-to-poem idiosyncrasy; a graph analogous to Fig. 2 for metron 2 (see the supplemental materials) forms a tangle of lines, not the clean pattern seen in Fig. 2. Individual poets rather idiosyncratically 'boost' the frequency of particular types in the metron 2 position, and (as observed above) they often treat the second metron of stanza-final lines differently from the second metron of non-stanza-final lines. (In contrast, the first metron of stanza-final lines is reassuringly similar to the first metron of non-stanza-final lines; compare the first and third lines in the graphs of Figs. 5–15 below.) Often the stanza-final metron adheres to a particular type with very high frequency; see the rightmost figures in the graphs.[18]

As far as why poets pick particular metra to serve as line endings in particular poems, we can only speculate. Three possible reasons follow.

Refrains. One possibility is the use of refrains. Two of our poems happen to be about the Hausa language and employ a refrain; specifically, the last word of every stanza is *Hausa* 'Hausa'. Naturally enough, this means that the last metron of the stanza must be either ⏑ ⏑ – – or – – –. However, the distributions of refrains can only form a small part of the explanation for the distribution of line-final metra; in our corpus refrains are not ubiquitous, and in any event they affect only stanza-final position.

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[18] Our referees queried how the rajaz data relate to the commonly suggested principle of closure in metrics, sometimes expressed as 'beginnings are free, endings strict' (Kiparsky 1968, Hayes 1983, Ryan 2016). Our checking of this point (see the supplemental materials) indicates that metra at the ends of lines and stanzas are not especially strict in the sense of closely matching the metrical template, but they are more predictable in the sense that poets use fewer options there (mathematically: endings have lowered entropy). A parallel from English folk verse (Hayes & MacEachern 1998:497) is the prevalence of metrical laxness in refrains, which occur couplet- or quatrain-finally and have zero entropy. Conceivably, metrical closure could be reinterpreted as favoring lowered entropy at endings; on this view, increasing metrical strictness at endings is only the most common way to lower entropy.

Sung rhythm. Another possible reason for poets to idiosyncratically prefer particular final metra might be the influence of sung rhythm. We assess the explanatory value of this idea (limited, it turns out) in §7 below.

Quantitative clausulae. We suggest that metrical systems can impose quantitative constraints at or near the ends of lines that are not fundamentally integrated into the overall quantitative system. The most striking case of which we are aware is the Serbo-Croatian folk epic meter (Jakobson 1933, Zec 2008). This is fundamentally not a quantitative meter at all; it is basically a trochaic pentameter with strong requirements of matching between prosodic breaks and foot edges. Yet it also incorporates what Jakobson calls a quantitative clausula, a small stretch at the right edge of the line that imposes quantity requirements on syllables. Specifically, of the ten syllables of the line, syllables 7, 8, and 9, if accented, are required to be light, light, and heavy, respectively. Such a pattern is remarkable as it seems to have nothing to do with the trochaic binary foot structure of the verse.

Quantitative clausulae do not even have to occur in poetry: a long-standing research tradition detects clausulae as a stylistic element, found at the ends of sentences and major phrases, in the prose writing of Greek and Latin authors; see Baum 1986.

Our interest lies in the possibility of quantitative clausulae in ordinary systems of quantitative meter. For instance, here is the formula for a common meter of Persian (the meter, like Hausa rajaz, is based on hexamoraic units).

(21) A Persian meter (Elwell-Sutton 1976:102)
⏑ – ⏑ – / {ᵕ _ ᵕ} – – / ⏑ – ⏑ – / {ᵕ _ ᵕ} –

This is the simplest statement of the pattern, but it neglects the fact that the first {ᵕ _ ᵕ} position is realized as – only 3% of the time, whereas the second {ᵕ _ ᵕ} position is realized as – 35% of the time (Elwell-Sutton 1976:128–29). We suggest that among the other constraints of the system (for which see Elwell-Sutton 1976, Hayes 1979, Deo & Kiparsky 2011) Persian includes a quantitative clausula constraint, – – Clausula. If the data gathered by Elwell-Sutton (1976:127–34) are representative, this constraint plays a major role in the Persian metrical system: realization of {ᵕ _ ᵕ} as – is always frequent when – – Clausula is satisfied as a result, and never frequent otherwise. A comparable pattern occurs in the Greek and Latin dactylic hexameter; a pattern discussed by Ryan (2011:442) suggests that this meter strongly respects ⏑ ⏑ – – Clausula. In sum, it appears that quantitative—or even fundamentally nonquantitative—systems can impose extra quantitative requirements at domain endings.

What of Hausa rajaz? We have found that we can model our data fairly accurately if we set up a total of four quantitative clausula constraints, which resemble those just given. Three of them are applicable at the ends of lines, and one at the ends of stanzas.

(22) Quantitative clausula constraints for rajaz
a. – – Clausula
b. – – – Clausula
c. ⏑ ⏑ – Clausula
d. – – – Clausula, Stanza-Final

We also employ a fifth constraint, which is a just a contextualized version of Strong is Long (12a), affiliated to the last metron of the stanza.

(23) Strong is Long (SIL)—Last Metron of Stanza: Assess a penalty for any strong (or stronger) grid column that does not initiate a heavy syllable, when occurring in the last metron of a stanza.

In principle, this could be an additional clausula type (– ⏑ –), but we prefer to express this in authentic structural terms, paralleling the general Strong is Long constraint.

Constraint 22a, – – CLAUSULA, is a more general version of 22b, – – – CLAUSULA, since any line ending in – – – ends in – – as well. This has an empirical consequence, since if – – CLAUSULA has a high weight it will boost the frequency of lines ending – – – just as much as it boosts lines ending in ᴗ ᴗ – –. Inspection of the graphs in Figs. 5–15 below indicates that in general, when a poet favors ᴗ ᴗ – – line-finally, (s)he also favors – – –. It is to capture this tendency that we adopt – – CLAUSULA rather than the more specific ᴗ ᴗ – – CLAUSULA.

6.5. FULL MODEL. Adding the five constraints of 22–23 to the eight already presented, we now have the tools to produce a complete model of the data for each poem. The eleven spreadsheets with which we carried out our calculations (one for each poem) are given in the supplemental materials. We included all four GEN functions (line-initial/line-final, stanza-nonfinal/stanza-final), with the candidates from Table 2, along with the violations for each constraint. We also included the frequencies of each metron type in every position; these appear in Tables 4–5 above. Our spreadsheets calculated predicted candidate probabilities from the weights and violations, using the standard maxent math. We also included cells with formulas to compute the log likelihood of the data; maximizing this likelihood is a standard measure for good model fit. Lastly, we used the Solver plugin in Microsoft Excel to find the weights that would maximize the log likelihood. As a check we also calculated the weights with the Maxent Grammar Tool (Wilson & George 2009), obtaining very similar results.

Weights were required to be positive (i.e. act as penalties), with the single exception of INITIAL HEAVY-FOR-LIGHT, which represents a neutral choice and was allowed to go negative, covering the minority of poets who actually prefer initial – – ᴗ – to ᴗ – ᴗ –. For the two poems titled 'Harshen Hausa', which use the word *Hausa* as a stanza-final refrain, we included an ad hoc constraint REFRAIN: HAUSA, violated by candidates for the stanza-final metron that fail to end in – –.

WEIGHTS OBTAINED. We first give in Table 7 the weights that our procedure yielded for each poem.

	*STRETCH	*SQUEEZE	INITIAL HEAVY-FOR-LIGHT	*LINE-INITIAL ᴗ ᴗ	*TRIPLE LIGHT	LONG IS STRONG	SUPERSTRONG IS LONG	STRONG IS LONG	SIL—LAST METRON OF STANZA	– – – CLAUSULA	– – – CLAUSULA, STANZA-FINAL	ᴗ ᴗ – CLAUSULA	– – CLAUSULA	REFRAIN: HAUSA
AAA 'Cuta ba Mutuwa ba'	3.4	5.9	2.6	2.8	0.6	1.5	3.5	0.0	0.0	3.7	1.5	0.0	4.6	
AAA 'Jihar Kano'	4.1	7.8	3.0	0.6	2.4	0.0	11.3	3.9	3.1	0.0	0.0	6.2	0.7	
AAA 'Ƙoƙon mabarata'	4.1	8.7	3.6	1.6	5.6	0.2	0.1	3.9	3.6	0.1	4.4	7.0	0.3	
ADS 'Tabarƙoƙo'	2.3	3.8	0.1	1.4	0.7	0.0	2.3	1.5	0.0	0.8	2.1	1.4	0.5	
AYG 'Karuwa'	3.6	5.4	0.4	2.1	1.6	0.3	3.7	0.0	2.7	0.6	0.0	0.4	0.5	
HGU 'Gidan Audu Baƙo Zu'	3.9	3.8	−0.1	2.5	2.3	0.3	3.4	0.3	0.0	0.0	17.4	0.5	2.7	
IYM 'Harshen Hausa'	3.3	4.8	−0.2	2.8	2.3	0.5	3.4	0.4	0.0	0.4	1.5	0.2	0.8	2.7
IYM 'Roƙon Ubangiji'	4.0	5.2	0.1	1.4	1.2	0.3	2.9	1.2	12.2	0.9	0.0	0.8	1.4	
MHa 'Tutocin Shehu'	3.6	4.2	0.7	2.4	1.4	0.5	3.3	0.4	2.9	0.8	0.0	0.0	0.6	
TTu 'Harshen Hausa'	4.3	4.4	−0.6	4.0	0.9	0.5	3.6	0.4	0.6	0.3	1.2	1.1	2.4	8.3
TTu 'Kanari'	5.2	5.4	−0.3	2.9	1.7	0.2	3.9	0.4	5.5	0.2	0.0	0.3	1.7	

TABLE 7. Results of maxent modeling: weights.

In digesting these numbers it is useful to sort the constraints by median weight, as in Table 8.

constraint	median weight
*Squeeze	5.2
*Stretch	3.9
Superstrong is Long	3.4
SIL—Last Metron of Stanza	2.7
*Line-Initial ⏑ ⏑	2.4
*Triple Light	1.6
– – – Clausula, Stanza-Final	1.2
– – Clausula	0.8
⏑ ⏑ – Clausula	0.5
Strong is Long	0.4
– – – Clausula	0.4
Long is Strong	0.3
Initial Heavy-for-Light	0.25

Table 8. Constraints sorted by median weight.

The top six constraints include the five principal constraints of the analysis that served as the sole constraints in the sketch of §6.1 (i.e. *Stretch, *Squeeze, Superstrong is Long, *Line-Initial ⏑ ⏑, *Triple Light). These constraints generally have substantial weights—these are hardly at 100, as we set them in the sketch analysis, but this time we are dealing with real data, with the exceptional lines included. The few cases where these constraints do not have high weights can be shown to be the result of other strong constraints taking over their work. The one constraint not in the core group of five is Superstrong is Long—Last Metron of Stanza, which, interestingly, is often at zero, but where it gets a positive weight tends to get a very large one. The remaining 'minor' constraints responsible for individual style tend to have lower weights and vary considerably from poem to poem.

Assessing the model for accuracy. To assess a particular grammar, it is useful to produce a scatterplot, matching the observed frequency for every element in the four GEN functions against the frequency that the model predicts for it. For 'Tutocin Shehu', such a plot is given in Figure 4.

The scattergram suggests the analysis is on the right track: the data points cluster near the diagonal, with which the fitted regression line virtually coincides. Most of the 190 data points plotted (which represent every member of all four GEN functions) sit very close to (0,0), forming a cluster, which means that the unobserved candidates are properly being assigned probabilities close to zero (avoidance of overgeneration). Contrariwise, no candidates with substantial representation are being assigned a probability close to zero (undergeneration). Essentially similar scatterplots are obtained for the other poems.

The plots can be inspected for outliers (points far from the diagonal), which sometimes suggest possible improvements to the grammar. For instance, for 'Tutocin Shehu' there are data points at (35 predicted, 19 observed) and at (9 predicted, 18 observed), both fairly far off the diagonal. Both represent – – – as metron 1; (35, 19) is for stanza-nonfinal position, (9, 18) for stanza-final lines. Nothing in our constraint set distinguishes metron 1s from each other by stanza position (our grammar for 'Tutocin Shehu' predicts the same fraction for – – – in both contexts). We could complicate the grammar by adding constraints to make the relevant distinction, but any such constraints strike us as unprincipled and fail to help grammar accuracy in any other context. It seems better to accept these minor outliers as unexplained, perhaps simply random. Similar considerations hold for the outliers for the analyses of other poems.

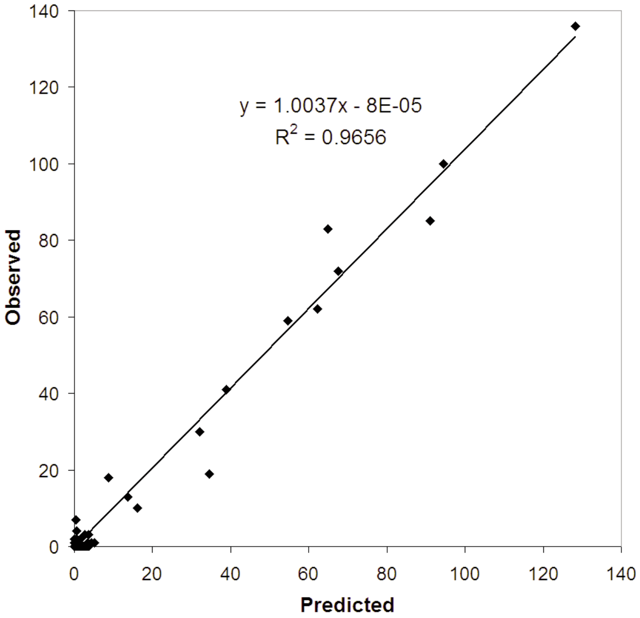

FIGURE 4. Scattergram for 'Tutocin Shehu': predicted vs. observed metron counts.

Lastly, we can assess how the system is describing variation across poets by looking at line graphs comparing predicted (gray) vs. observed (black) values for the four principal metron types of both first and second metra. A series of eleven graphs doing this for each poem is provided in Figures 5–15.

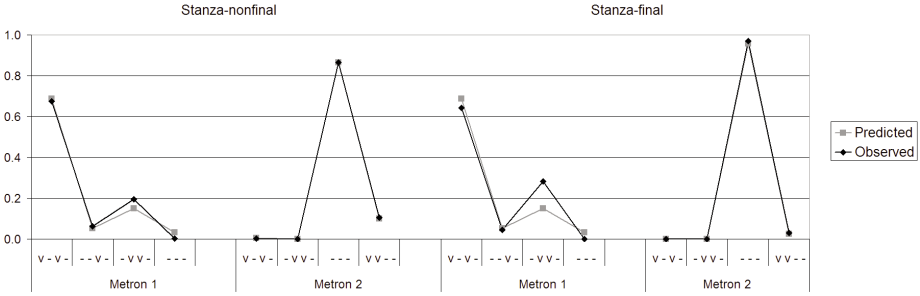

FIGURE 5. AAA 'Cuta ba Mutuwa ba': predicted vs. observed values (major metron types).

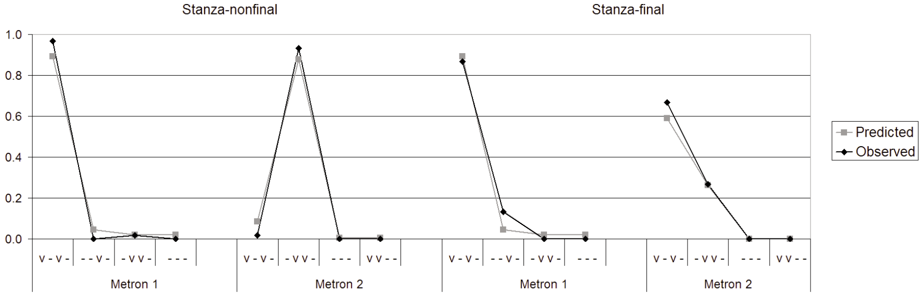

FIGURE 6. AAA 'Jihar Kano': predicted vs. observed values (major metron types).

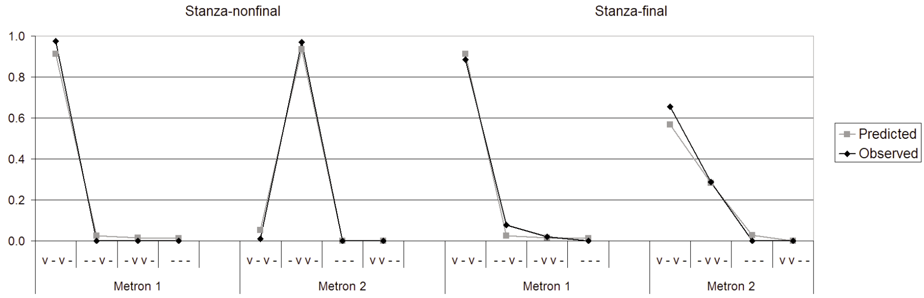

Figure 7. AAA ‘Ƙoƙon mabarata’: predicted vs. observed values (major metron types).

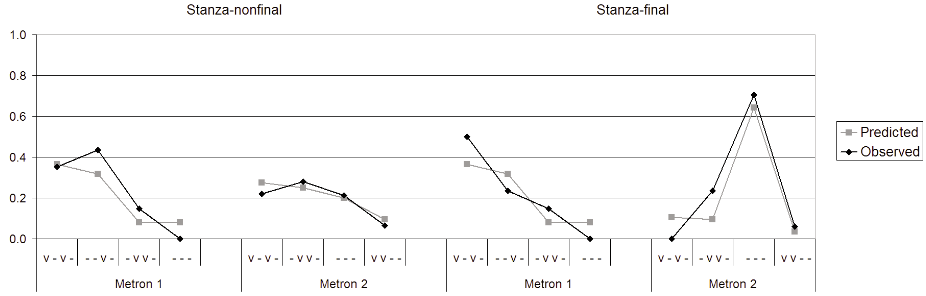

Figure 8. ADS ‘Tabarƙoƙo’: predicted vs. observed values (major metron types).

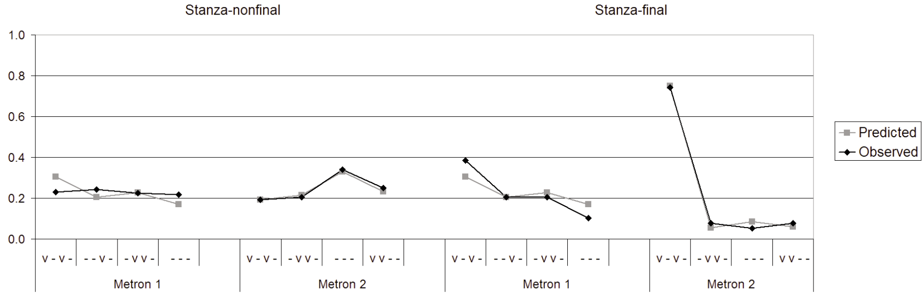

Figure 9. AYG ‘Karuwa’: predicted vs. observed values (major metron types).

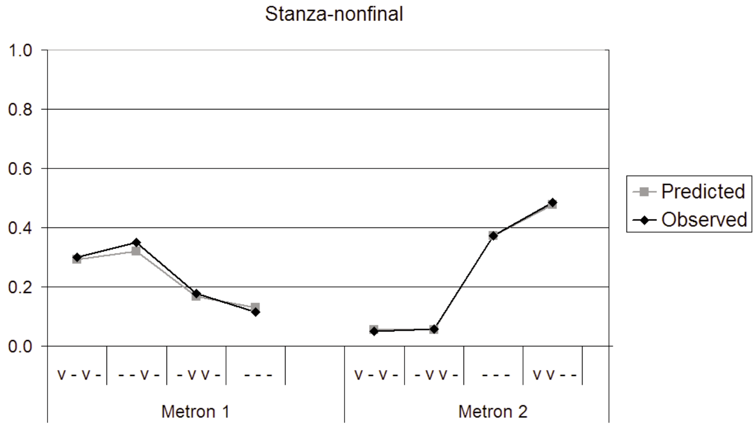

Figure 10. HGU ‘Gidan Audu Baƙo Zu’ (last line is always refrain):
predicted vs. observed values (major metron types).

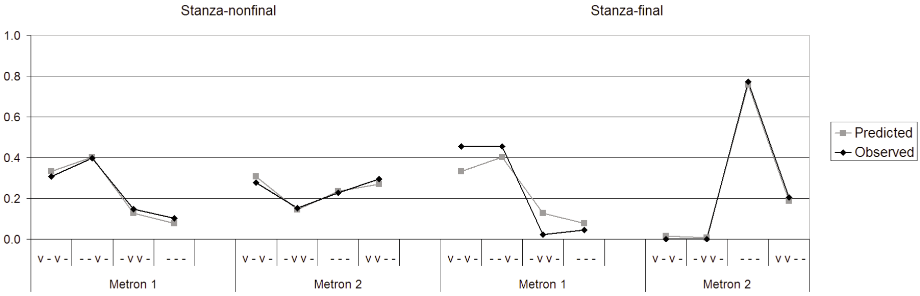

FIGURE 11. IYM 'Harshen Hausa': predicted vs. observed values (major metron types).

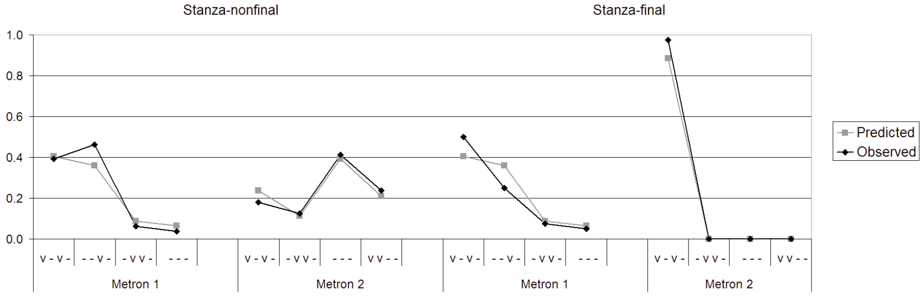

FIGURE 12. IYM 'Roƙon Ubangiji': predicted vs. observed values (major metron types).

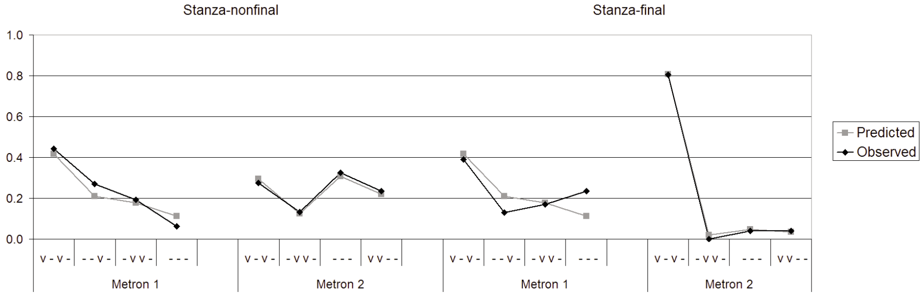

FIGURE 13. MHa 'Tutocin Shehu': predicted vs. observed values (major metron types).

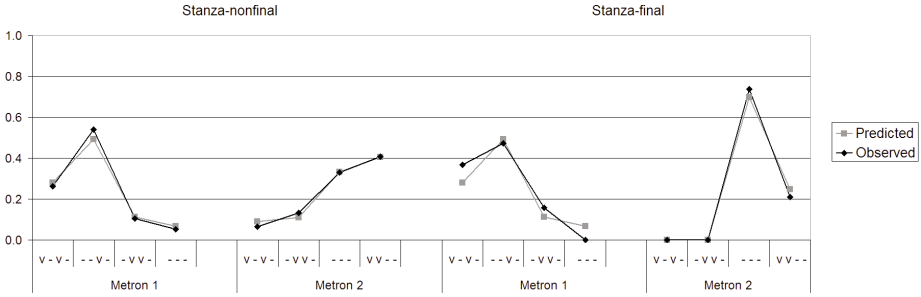

FIGURE 14. TTu 'Harshen Hausa': predicted vs. observed values (major metron types).

The fit is in general rather good, with the worst case being TTu 'Kanari' (Fig. 15). This poem has the largest apparent difference between stanza-final and stanza-nonfinal metron 1, and also includes the largest exception to the pattern of harmonic bounding

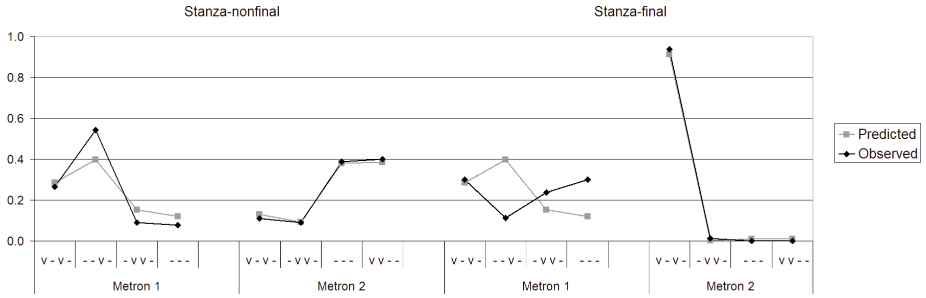

Figure 15. TTu ‘Kanari’: predicted vs. observed values (major metron types).

noted in §6.3. Note that these deviations are found in stanza-final lines, where the overall numbers are smaller and statistical fluctuations are more expected.

We leave the analysis in its current state, judging that the fit to data is fairly good.

6.6. Rigor.

Statistical significance. For all of the constraints in the analysis, we applied the likelihood ratio test (Wasserman 2004:164), which gives the probability of the null hypothesis that the observed data of a given poem would arise under a system lacking the constraint in question. Note that we cannot expect all constraints to test as statistically significant for all rajaz poems, since many of them are used here only to define particular stylistic variants. To give the worst case first, Long is Strong tests as significant ($p < 0.005$) for only two poems, AAA ‘Cuta ba Mutuwa ba’ and MHa ‘Tutocin Shehu’. At the other end of the scale, the fundamental constraints *Stretch and *Squeeze test as highly significant ($p < 0.001$) for all eleven poems. The other constraints fall somewhere between these two extremes; for full details, see the supplemental materials.

Restrictiveness. Our referees asked if this is a restrictive analysis: could the constraints, suitably weighted, describe any data whatsoever? The remedy for this worry is to conduct trials designed to test this possibility. It emerges that everything depends on having the right constraints, just as in analyses expressed in classical OT.

To see this, we tried setting the constraint weights to derive output patterns we anticipated would be underivable, keeping the constraint set the same. We did this first for an imaginary pseudo-poem in which every hemistich takes the form – – –. What happened was that under the best-fit weights, – – – in metron 1 received only 0.333 probability, not the desired 1.[19] In other words, the grammar proved very poor at fitting the impossible data pattern. The reason for this has already been given (§6.3): – – – is harmonically bounded, and there is no way that the weighting can give it priority over its bounding rivals ⏑ – ⏑ – and – ⏑ ⏑ –, which under our weighting also received a probability of 0.333. Inspecting the weights tells us why: the constraints that discriminate between – – –, ⏑ – ⏑ –, and – ⏑ ⏑ – all got weights of zero, and given the relation of harmonic bounding, this is the best the system can do. Similarly, trying to get the system to learn the pattern of all – ⏑ ⏑ – likewise produces failure—indeed, the very same result as before. This is because the only constraint on which – ⏑ ⏑ – beats the seemingly inferior – – – is Long is Strong, but as 20 shows, ⏑ – ⏑ – also beats – ⏑ ⏑ – at this

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[19] In metron 2, high-weighted – – – Clausula, not surprisingly, did indeed give – – – the probability of 1.

constraint, meaning that its weight, along with that of Strong is Long, must be zero in the best-fit model.

Lastly, if we try training the system on something outlandish, for example lines of the form / ⏑ ⏑ ⏑ ⏑ / ⏑ ⏑ ⏑ – /, it fails spectacularly, assigning very little probability to the intended output and similar probability to a great variety of other candidates that perform inherently better on the constraints. Again, the relevant weights come out as zero, the best weighting available.[20]

Prose sample. One other possibility to consider is that the characteristic sequences of the rajaz are merely those that predominate phonologically in the Hausa language, by virtue of its lexical or syntactic characteristics. We can address this question with the so-called 'Russian' method (Bailey 1975, Tarlinskaja 1976, Gasparov 1980, Hall 2006): we extract poetry-like sequences from ordinary prose, then test their metrical properties. We did this for a created sample of 140 lines extracted from the prose exercises in Cowan and Schuh's (1976) Hausa textbook (all materials and analyses are in the supplemental materials). In our pseudo-lines, the first metra were created from hexamoraic sentence-initial sequences, and the second metra from hexamoraic sentence-final sequences. This is realistic, since most lines in rajaz begin and end at a prosodic break (§4.1). We analyzed this corpus as if it were poetry.

The results were revealing. First, a great number of sentences (25.5% of the total) simply would not yield hexamoraic metra without splitting a syllable. For example, if a sentence begins ⏑ – – – … , we can take either ⏑ – – as our metron 1 or ⏑ – – –, but neither of these is hexamoraic. Real rajaz verse is not like this; all but a few irregular lines permit a parse into two discrete hexamoraic metra, which is what our analysis predicts.[21] We excluded these untreatable cases from subsequent analysis.

Addressing the remaining pseudo-lines, we found that the hexamoraic structures were widely distributed among the logically possible types, and—most significantly—that by far the most frequent metron type was the harmonically bounded – – –. For the reason just given, this makes an accurate analysis impossible.

In sum, there is no reason to think that the patterns of the rajaz are the consequence of the natural weight patterns of Hausa text; to the contrary, we might say that prose, favoring – – –, is biased toward the less metrical, so that the rajaz poet must work against the language to achieve her ends.

7. Performing the rajaz in song. We have thus far treated the rajaz solely as a form of poetry: our metrical grammar establishes legal correspondences between phonological representations and an abstract rhythmic structure. As already mentioned, however, the standard way to render a Hausa poem audible is to sing it. Singing tends to employ rhythms distinct from those in the abstract metrical grid (Schuh 1995). We discuss four such cases, then address their theoretical implications. Our work follows ear-

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[20] Metron 2 is of course far less constrained than metron 1, and it is empirically necessary for the constraints to be set up so that any of the four legal types {⏑ – ⏑ –, ⏑ ⏑ – –, – ⏑ ⏑ –, – – –} can dominate under some weighting (see Table 5). However, even here the situation is not 'anything goes'. For instance, – – ⏑ –, legal as metron 1, cannot be derived as metron 2 without allowing a whole raft of other outcomes. Further, certain metron 2 patterns are incompatible with particular metron 1 patterns: ⏑ ⏑ – – cannot dominate in metron 2 if – ⏑ ⏑ – dominates in metron 1; and if metron 1 is exclusively ⏑ – ⏑ –, it is impossible to make the four metron 2 outcomes equiprobable.

[21] The reasoning is that powerful Superstrong is Long forces the last two grid positions of the first metron to be filled with a heavy syllable; thus the metron break automatically coincides with a syllable break.

lier studies of the relationship of text meter and sung rhythm, including Hayes & Kaun 1996, Kiparsky 2006, Dell & Elmedlaoui 2008, Proto & Dell 2013, and Dell 2015.

We examined four recordings covering a subset of the poems studied above. For details and sound files, see the supplemental materials.

Essential to our purpose is the theory of musical rhythm developed in Lerdahl & Jackendoff 1983, which employs bracketed grids rather like those we use for representing meter as the basis for structural representation of musical rhythm. We used such grids in creating our musical transcriptions of Hausa singing; they represent the two authors' shared perception of the musical material.

Two caveats are in order. First, our own musical training is Western and we cannot claim necessarily to be hearing the music as an experienced Hausa listener would. Second, our transcriptions are idealized in that we abstract away from minor deviations from strict rhythm. These deviations are probably expressive; certainly the sung performances are rhythmically far more interesting than a metronomic rendering would be.

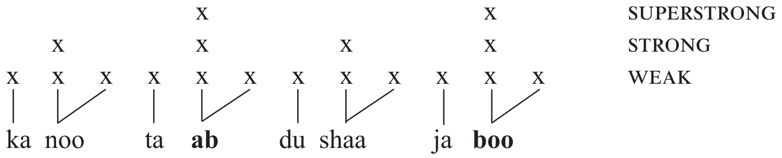
A full account of Hausa singing would address the question of whether lexical tone is matched to musical melody. We consider this question open; for discussion of possible correspondence see Richards 1972 and Leben 1985.

7.1. Patterns in the data.

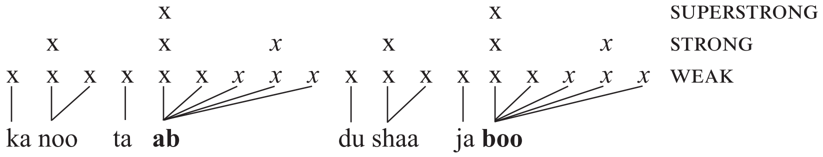
MHa 'Tutocin shehu'. In a recorded sung rendition of 'Tutocin Shehu' by Abubakar Ladan (not the poet), the rhythm is what in Western music would be called 9/8 time; the bottom two rows of the grid are in triple rhythm. The singing grid for this rhythm (24b) might be imagined as a simple augmentation of the basic meter, shown aligned with the same text in 24a. The 'extra' grid columns are shown in italics. As can be seen, the basic alignment of syllables to the grid is the same, except that the superstrong syllables are greatly lengthened to cover a span of five grid columns.

(24) Metrical rhythm vs. sung rendition for line 6 of 'Tutocin Shehu'

a. Meter



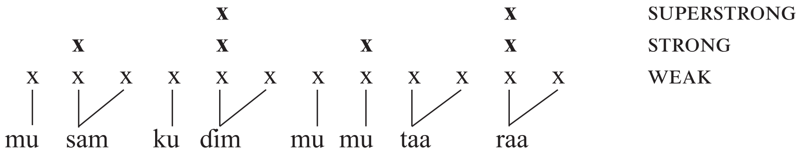
b. Sung rhythm



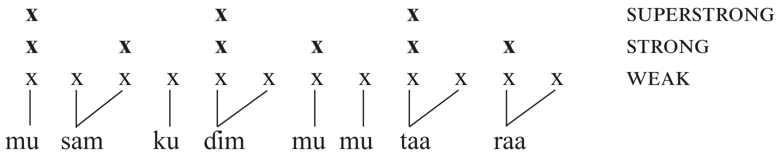
HGU 'Gidan audu baƙo zu'. The singer is the poet, Hawwa Gwaram. In Gwaram's rendition, the twelve terminal positions of the original metrical grid are retained, but the higher levels are drastically altered. The line is rendered not as two iambic metra, but as three initially prominent units with internal binary rhythm.

(25) Metrical rhythm vs. sung rendition for line 3.3 of 'Gidan Audu Baƙo Zu'

a. Meter



b. Sung rhythm

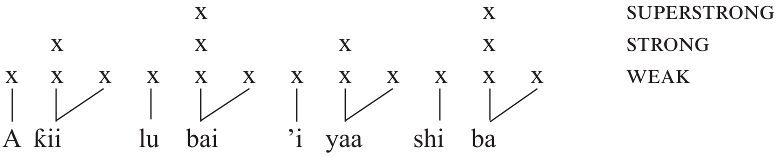


c. Gloss
Mù sam kuɗi-n-mù mù taaràa
let.us get money-of-us let.us collect
‘Let’s get our money and collect it’

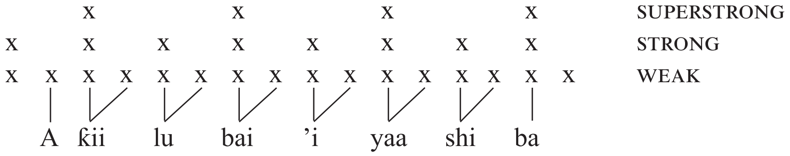
Note that this poem idiosyncratically favors ⏑ ⏑ – – and – – – for the second metron. Using these two metra places a heavy syllable in the penultimate position of the line—precisely where the sung rhythm has a strong beat ([taa] in 25). Thus it seems possible that the data reflect some kind of compromise: the poem/song is faithful to the iambic rajaz verse meter in the first metron, and to the ternary sung rhythm in the second (where rajaz permits poem-to-poem variation). At least for this poem, then, appealing to the sung rendition can explain choices made at the metrical level.

AAA ‘ƘOƘON MABARATA’. The singer is the poet, Alhaji Aƙilu Aliyu. Aliyu’s sung version of the rajaz shows the most striking disparity of metrical and sung grids: he sings his poem in pure binary rhythm, treated here with the sixteen-position grid of 26b.

(26) Metrical rhythm vs. sung rendition for line 44.4 of ‘Ƙoƙon mabarata’
a. Meter



b. Sung rhythm



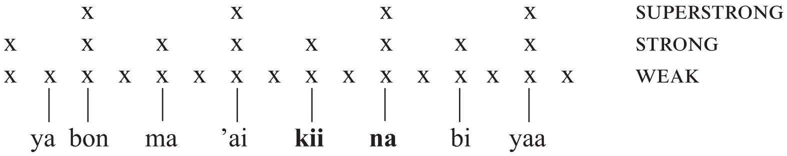
c. Gloss
Aƙiilu bai ’iyaa shi ba
Aƙiilu he.NEG be.able it NEG
‘Aƙilu can’t do it’

Given that heavy and light syllables are mostly given equal numbers of grid slots, one may wonder whether syllable quantity is reflected in recitation at all. We think it is, though only in the first metron. Note that this song favors the default ⏑ – ⏑ – for metron 1. This means that heavy syllables will usually fall in the stronger positions—they are not longer in recitation, but they respect a different sort of prominence alignment, relating syllable weight to metrical strength, not metrical length. Such HEAVY IS STRONG effects have been found in other Hausa singing genres, specifically for the catalectic mutadaarik meter shown above in 1 (Schuh 1995).

However, ‘Ƙoƙon mabarata’ offers little comfort to the conjecture given in §7.1 that the idiosyncratic metron types in line-final position can always be explained on the basis of their sung rendition. Other than in stanza-final lines, the strongly dominant second-metron type for this poem is – ⏑ ⏑ –, which in no way is justified by the sung rhythm. For instance, in 27, a more typical line than 26, the syllables *kii* and *na* are fully mismatched in their weight-to-strength pattern.

(27) An 'unnatural' textsetting for 'Ƙoƙon mabarata' (line 2.3)

a. Sung rhythm



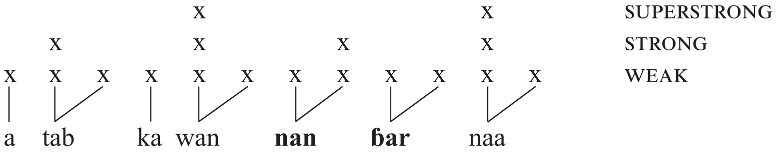
b. Gloss

Yabo-n ma'aikii na biyaa
praising-of the.prophet I.FOC.PERF follow
'Praising of the prophet do I follow'

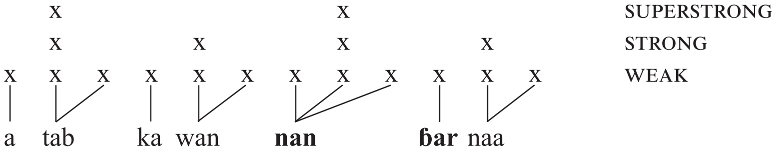
AAA 'Cuta ba mutuwa ba'. The singer is the poet, Alhaji Aƙilu Aliyu. This is the closest realization in singing we have seen to the metrical grid of Fig. 1. We hear the superstrong beat shifted leftward, falling in odd rather than even positions. In addition, in the second metron (which for this poem is predominantly – – –), the first heavy is normally lengthened at the expense of the second, as in 28b.

(28) Metrical rhythm vs. sung rendition for line 59.1 of 'Cuta ba Mutuwa ba'

a. Meter



b. Sung rhythm



c. Gloss

À tabkà wannàn ɓàrnaa
one.SUBJ do.a.great.amount this harm
'May one be sure about this harm'

7.2. The analysis of 'remapping' in song. The 'remapping' of the Hausa rajaz rhythm into its various sung versions raises theoretical questions—questions that we feel better able to pose than to answer at this phase. What is at issue is how we should construe the singer's task and what are the appropriate components for embodying the singer's knowledge. We consider three possibilities.

Text-based serialism. We are intrigued by the fact that the Hausa poets when they sing manage to adhere to the requirements of the rajaz meter (i.e. the grid of Fig. 1) even when the rhythm of their singing does not match it. One account of how they accomplish this is text-based serialism, which works as follows. (i) The poet composes lines of rajaz using the meter of Fig. 1, yielding a text. (ii) This text is then treated as an input, construed purely as Hausa-language material, and is set in the optimal way to whatever sung grid the poet is employing. The text may not be perfect for setting to the new grid (cf. 26), a fact that we attribute to its origin as poetry.

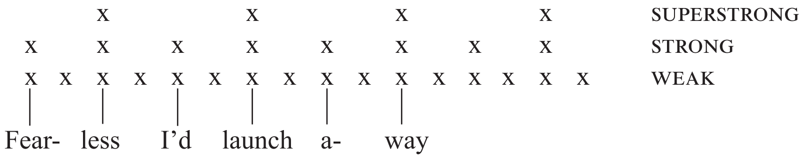
Text-based serialism is almost certainly correct for some types of song. To give an extreme example, Mozart's famous aria for the Queen of the Night, 'Der Hölle Rache', is written in various rhythms that often render quite opaque the iambic pentameter pattern by which Emanuel Schikaneder wrote the text. Text-based serialism is more interesting in the Hausa context, where poetry is often improvised in real time: the serialist view implies that a poet is able simultaneously to form lines that are metrical but also set them in legal correspondence to the sung grid.

A possible objection to text-based serialism could be found in songs where the patterning of syllable quantities seems to be responding to the sung rhythm; we have suggested that this may be true for 'Gidan Audu Baƙo Zu'. Yet this influence is not consistently present in our data; as we saw, 'Ƙoƙon mabarata' is sung to a rhythm that actually goes against its characteristic pattern of syllable quantities.

Full-scale serialism. A stronger theory, full-scale serialism, would propose that the sung version not only is faithful to a text that is licensed by the meter, but also is faithful to the text as it is aligned to the poetic meter. Under this view, it might be possible for the singer to require that syllables placed in strong position in the metrical scansion must likewise be placed in strong in the sung grid. Thus full-scale serialism would involve 'correspondence to a correspondence': the linking of syllables to grid slots in the meter, itself a kind of correspondence, serves as the base for a different linking in the song.

Evidence for full-scale serialism is hard to find. One possibility to consider is English hymnody, where weak syllables are sometimes sung in strong position, matching their metrical scansion. An example is given in 29; it is the sung setting of a line written by Samuel Stennett in iambic trimeter, with the typical line-initial stress inversion found in English iambic poetry.

(29) A hymn line inheriting its setting from the verse source?[22]



One might argue that the stressless syllable *-less* is placed in strong position because it is so placed in the original metrical scansion—a 'correspondence-to-a-correspondence' effect. The argument for full-blown serialism is not watertight here, however, because the genre of hymnody generally imposes strict requirements of syllable count and consistent syllable placement; these factors might force the textsetting of 29 in any event.[23]

We have been alert to the possibility of Hausa songs that necessitate full-scale serialism but have not found any.

Unique reliance on the sung grid. A third possibility is that singing is not serialist at all. It is often possible to compose lines directly to the sung grid by adopting slightly different principles of composition. For instance, we might imagine that the sung version of 'Tutocin Shehu' given in 24 is based on the sung musical grid given, but instead of Superstrong is Long, the poet uses Superstrong is Extremely Long, formalized appropriately. Using such altered constraints, the singer might be able to avoid reference to the metrical grid entirely.

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[22] The sung setting is from *The sacred harp, 1991 edition* (Sacred Harp Publishing Company), p. 128.

[23] The concept of 'melic template', developed in Dell 2015, may also be applicable here.

This approach would not deny that the original meter has some sort of effect on the textsetting, but this effect is essentially diachronic—the original meter gives rise to syllable patterns that are roughly compatible with the sung grid, but when novel composition takes place, it is only the sung grid that is mentally present for the singer. Thus, there is no supposition that a singer-poet can simultaneously satisfy the requirements of two grids at once.

Unique reliance on the sung grid is the theoretical approach taken by Hayes and MacEachern (1998) in a study of English folk song—they assume that folk poets use only the sung grid (this is most often the grid of 29). This ignores, perhaps incorrectly (Kiparsky 2006), the fact that much of their material scans fairly well in an orthodox spoken-verse meter, namely iambic tetrameter. The approach nevertheless is not obviously false as a means of analyzing our Hausa data. Dell (2015) also argues for unique reliance on the sung grid for French traditional song.

If correct, the theory of unique reliance on the sung grid forces us to assume, at least in some cases, 'unnatural' principles of rhythmic alignment. For example, in 25 above, the preference for iambic metra in the first half of the line goes against the sung grid that is assumed, and a metrical grammar that achieves a fit to the data will need to use unnatural constraints. Unnaturalness in this area is somewhat similar to unnaturalness in phonology, which likewise often has a diachronic explanation.

The theory of unique reliance on the sung grid raises, in principle, the question of whether there even exists such a thing as 'rajaz meter' as a general concept. In fact, we think the concept of 'rajaz meter' is well supported. A Hausa rajaz must be sung to a rajaz-appropriate tune, just as a poem (say) in catalectic mutadaarik must be sung to a mutadaarik-appropriate tune; the two cannot be mixed and matched. The rajaz meter exists as an abstraction underlying all of its various sung realizations.[24]

8. The phonetic realization of sung rhythm. Our final topic relates the analysis to measurable data, the durations of the sung syllables. This is a challenging topic for analysis, as these durations are not a direct reflection of the grid column counts; they respond to various factors: some musical, some phonological, and some expressive (Sundberg 1991). We seek here only to understand the interaction of musical and phonological influences, leaving the problem of musical expression for future work.

In our study, we rely on a recent body of work that uses grammars with weighted constraints to model phonetic realization. Some studies from which we have adopted our methods are Flemming 2001, Katz 2010, Ryan 2011, Braver 2013, Windmann et al. 2015, and Flemming & Cho 2017. Following Lefkowitz 2017, we deviate slightly from these proposals by generating not single values but probability distributions, which are matched against the variable distributions seen in the data.

For data we focus here on a single song, the version of 'Tutocin Shehu' described in §7.1. We measured the duration of 562 syllables, taken from the first twenty stanzas of Abubakar Ladan's sung rendition. Durations were measured by hand in Praat (Boersma & Weenink 2015); we assigned syllable boundaries visually, assisted by occasional auditory checking of the segmented syllables.[25] Our descriptive goal was to predict as accurately as possible the duration of each measured syllable, based on its weight and the

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[24] The concept of a meter realizable with a variety of sung rhythms is standard, indeed publicly promulgated, in English hymnody, where tunes are printed with formulae to indicate their meters to facilitate tune/text substitutions.

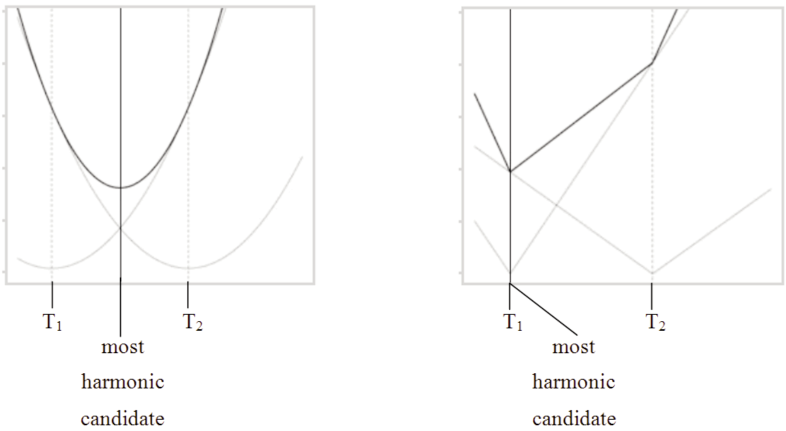
[25] For geminate segments, there is no syllable boundary evident in the phonetic record and we simply divided the geminate's duration in half.

type of metron in which it occurs. The recordings and measured data are posted in the supplemental materials.

8.1. Framework. A fundamental principle of phonetic realization is that the phonetic system seeks a quantitative compromise between conflicting targets. For instance, the second formant value for stop consonants at their release point is known to be a compromise between the steady-state F2 value of the following vowel and an abstract target associated with the consonant, the so-called ‘locus’ (Sussman et al. 1993). In the domain of duration, compromises often involve the phonological hierarchy: a higher-level domain like the syllable has a target duration, which is compromised against the target durations of the segments that comprise it (Lehiste 1972, Fujimura 1979, Flemming 2001). Katz (2010:91), who models the durations of segments within syllables, aptly describes this compromise as ‘fitting partially-malleable objects into a partially-malleable container’—syllables that contain *n* + 1 segments tend to be longer than comparable syllables with *n* segments, but not by as much as the average segment duration, because segments of the longer syllable get compressed.

In Flemming 2001, the principle of compromise is formalized in constraint-based grammars. The key idea is to assign to every phonological entity and phonetic parameter a target value, along with a weighted, gradient constraint that penalizes the degree of deviation from the target for each candidate. In selecting an output, penalties of every constraint are summed—in effect, forming a harmony score—and the phonetic configuration selected by the grammar is the one that has the lowest harmony penalty.

Importantly, for Flemming the penalties exacted by the constraints are calculated by squaring the deviation of the candidate from the target. This is needed because compromise will occur only with a penalty function that has a gentler slope near its target value. If we use absolute deviations, the resulting V-shaped functions can result in an optimum candidate that would wrongly reflect solely the preferences of a single constraint. This can be seen in Figure 16, adapted from Flemming & Cho 2017. The darker line represents overall harmony, summed from the harmony contributions of the two constraints whose harmony profiles are plotted in gray.



a. Harmony = squared deviation from target b. Harmony = simple deviation from target

Figure 16. Squaring the deviations from target creates compromise.

A finding that emerges clearly from Katz’s (2010) work (as well as the earlier model of Klatt 1979) is that deviations involving compression sometimes ought to be penalized differently from deviations involving extension. This is true, in fact, of our own data, which are not fit very well by the classical parabolic model that Flemming proposed (see §8.3 below). To remedy this, we follow Lefkowitz 2017 in replacing the penalty parabolas seen in Fig. 16 with two hemiparabolas, which share their minimum point but can have different slopes. Formally, this is done by assigning two constraints to each phonetic target. Constraints of the *STRETCH family are assumed to involve a phonetic dimension, a target, and a weight; violations are defined as [candidate value – target value]^2 if the candidate value is greater than the target value, otherwise zero. For constraints of the *SQUEEZE family, violations are defined as [target value − candidate value]^2 if the candidate value is less than the target, otherwise zero. The graph in Figure 17 relates the penalty for deviation from target in the case of an idealized constraint pair in which the weight of *SQUEEZE is 0.03 and the weight of *STRETCH is 0.015. Since the harmonic penalty is based on squared distance, we see two joined hemiparabolas, of which the one for *SQUEEZE is steeper.

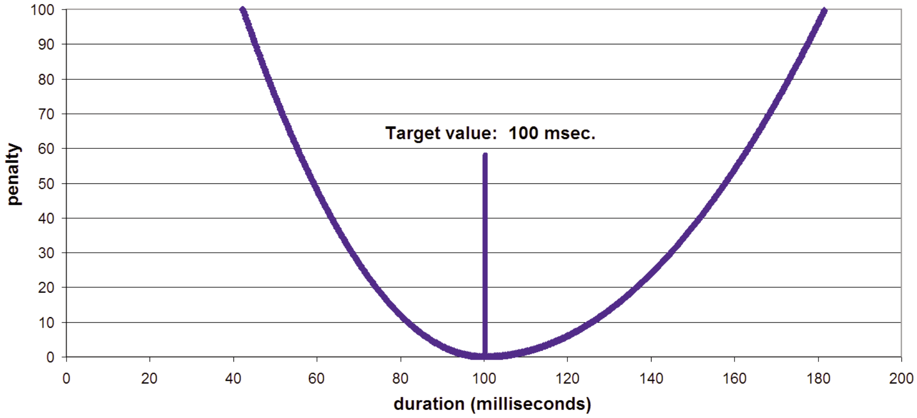


FIGURE 17. Harmonic penalty in the dual hemiparabola system.

8.2. TOWARD A PHONETIC ANALYSIS OF THE RAJAZ. Under this framework, we can set up duration targets for four categories, which will ultimately be paired with *STRETCH and *SQUEEZE constraints as we model the sung-verse data.

Two of the targets are phonological: the syllable and the mora. We believe that syllable targets crosslinguistically typically have somewhat less than double the value of mora targets; in the resulting compromises heavy syllables are pronounced longer than light syllables, but not twice as long—they stretch their syllable target, but compress their mora target. This empirical pattern evidently holds good for Hausa. We examined recordings of two native speakers producing spontaneous narratives,[26] and in the speech of the female speaker, heavy syllables averaged 227 ms and light 138 ms, a ratio of 1.64. For the male speaker, heavy syllables averaged 223 ms and light 134 ms, a ratio of 1.51.

The other targets are musical: the grid column and a higher-level unit to be described later. These targets are superimposed on the normal phonological targets, altering—but not obliterating—the normal duration patterns. A model of this sort has been proposed by Katz (2010:127–33) to model rhythmic speech in English.

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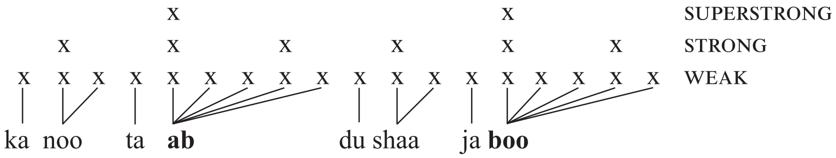
[26] We used materials prepared by Richard Randall of Stanford University for the purposes of Hausa language instruction. Both recordings narrate the procedure for applying decorative henna.

We suggest that musical duration targets, like phonological ones, should be multilevel. To produce music in an even rhythm, it is necessary for the musician not only to produce equivalent musical notes at roughly equal intervals, but also to maintain an even beat at higher levels; indeed, the most rhythmically salient level is usually not the lowest (cf. Lerdahl & Jackendoff 1983:21 on the 'tactus' level).

Recall that the material we are analyzing phonetically is the syllable durations in the first twenty stanzas of 'Tutocin Shehu'. The sung grid we proposed for this song, which was given in 24 above, is repeated in 30.

(30) The sung grid for 'Tutocin Shehu'

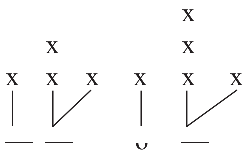


Since we will be assuming that one of the phonetic targets for musical rhythm is the grid column, our analysis is claiming that at some level the singer is attempting to give roughly equal durations to every grid position: thus, musically speaking, [ka] in 30 should have the same duration as [ta], [du], and [ya]; [noo] and [shaa] should have twice that duration, and [ab] and [boo] five times as much. For purposes of calculation, if two or more grid columns share the same syllable, we divide the measured duration equally between them.

For the higher-level musical target, we might in principle pick domains defined by grid marks at the strong or superstrong levels of the grid. Practical considerations, however, led us instead to use an ad hoc target, which we call the HEMIMETRON. The hemimetra in our sung grid consist of columns 1–4 and 10–13; these are occupied in the case of 30 by the syllables [ka noo ta] and [dù shaa yà]. We do this for the practical reason that measurement of the very long syllables of the song (like [ab] and [boo]) proved to be unreliable—their right boundaries often fade into a pause, leading segmentation to be quite uncertain. Our hemimetron has no theoretical significance, but serves as an accurately measurable proxy for structurally authentic higher-level units.

Given that we are limiting our attention to hemimetra, the effects of the (phonological) mora target and the (musical) grid column target will be quite similar, since in most cases each grid column of the hemimetron is filled by precisely one mora. The crucial case that distinguishes the two targets is the heptamoraic metron, in which the initial bimoraic syllable is compressed into a single grid slot, as in 31.

(31) Structure posited for the heptamoraic metron



As we will see, such syllables do indeed have special durational properties in song.

DEFINING THE SPECIFIC GOALS OF THE MODEL. We now have four targets (mora, syllable, grid column, and hemimetron), with *STRETCH and *SQUEEZE constraints for each. Using these targets and constraints (i.e. twelve model parameters), our model attempts to predict the phonetic durations of all 562 syllables in the data. Since these durations actually vary quite a bit, even for syllables in similar phonological and metrical circumstances, we actually seek to derive probability distributions over durations, hoping to match the distributions seen empirically.[27]

The maxent framework we have adopted for metrics can also be used to match these probabilities. In order to do this, however, we must solve a preliminary problem. In metrics, we are dealing with a manageable number of candidates, formed from the discrete categories ⏑ and –. But in phonetics, there are an infinite number of candidates even for very short intervals, since time and other phonetic parameters are continuous. To make computation feasible, we adopt the idealization of treating time as a set of slices, each 20 ms long. Specifically, we round each observed syllable duration to the nearest 20 ms, and our grammar selects from a discrete set of candidates spaced 20 ms apart. This procedure could be made more refined by using shorter time slices, but we think that for our purposes the 20 ms time grid suffices.

Restricting the search space. Experimentation with our model proved that with twelve parameters, it is insufficiently constrained, in the sense that large numbers of possible parameter settings yield similar results, and search algorithms that seek optimum values do not converge consistently on the same outcome.[28] Seeking a more principled account, we therefore adopted additional assumptions in order to obtain a more constrained model.

Our first such assumption is that Hausa singers know how to sing in tempo. This means that, other than random fluctuations, the targets for grid column and hemimetron are achieved, and thus that we can set these targets as the mean values observed for these categories, which happen to be 145 ms and 579 ms, respectively. Naturally, the target for grid column is one fourth the value of that for hemimetron, since our hemimetra contain four grid columns.

Our second assumption, borrowed from Katz 2010:127–33, is that singing is a sort of overlay on speech; the normal durational patterns are altered—in a compromising way—in the direction needed for musical form. We will suppose that the syllable target is 1.5 times the mora target. This value is compatible with our prose sample, though many other values are as well; the prose data do not suffice to set a precise value. We choose 1.5 for its plausibility and concreteness. We adopt a ratio, rather than an absolute value, because this lets us reserve one parameter (the mora target) as the means of encoding speech or singing tempo.

With these assumptions in place, we have simplified the model by eliminating three of its twelve parameters. The remaining parameters are the eight constraint weights (four *Squeeze, four *Stretch) and the target for mora duration.

To complete the grammar, we compute the best-fit weights. This was done by entering all of the duration data into a spreadsheet (see the supplemental materials), expressing the model and maxent math with appropriate spreadsheet entries, then using the Solver utility in Excel to find the weights. The solution appears to be stable, as the software converges on it from a wide variety of initial settings of the nine parameters.[29]

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[27] For extensive discussion of the probability distributions generated with hemiparabolas, see Lefkowitz 2017.

[28] In classical maxent modeling, as noted above, the search space is convex, meaning an optimum set of weights is guaranteed to be found. But when we add in the target values, convexity no longer holds. This is just one case of the 'hidden structure' problem in language learning (Tesar & Smolensky 2000).

[29] If we start with an unrealistically high setting for mora duration, like 300 ms, the search gets stuck in a an inferior local optimum.

8.3. Modeling results. The optimized parameter values are given in 32.

(32) Parameters for the best-fit maxent duration grammar

Mora target	113 ms
Weight of *Squeeze Mora	1.68
Weight of *Stretch Mora	6.19
Weight of *Squeeze Syllable	0.24
Weight of *Stretch Syllable	2.35
Weight of *Squeeze Grid Column	0.90
Weight of *Stretch Grid Column	2.06
Weight of *Squeeze Hemimetron	0 (vacuous)
Weight of *Stretch Hemimetron	0.77

The zero weight assigned to *Squeeze Hemimetron means that an optimized grammar is better off without such a constraint.

Grammar 32 can be used to compute the predicted probability for the possible durations of the syllables in each type of hemimetron (– – ⏑, – ⏑ ⏑, ⏑ – ⏑, ⏑ ⏑ –, and – –). The predicted distributions are multidimensional and hard to visualize, but from them we can calculate the predicted distribution of durations for individual syllables in each of the five types. In Figures 18–22 these are plotted against a smoothed version of the empirical distributions.[30] The different colors and datapoint shapes stand for the different syllables of the hemimetron. The probability distributions predicted by the theory are shown with bold lines, and the observed relative frequencies with thin lines. In a perfect model, the bold lines would obscure their thin counterparts.

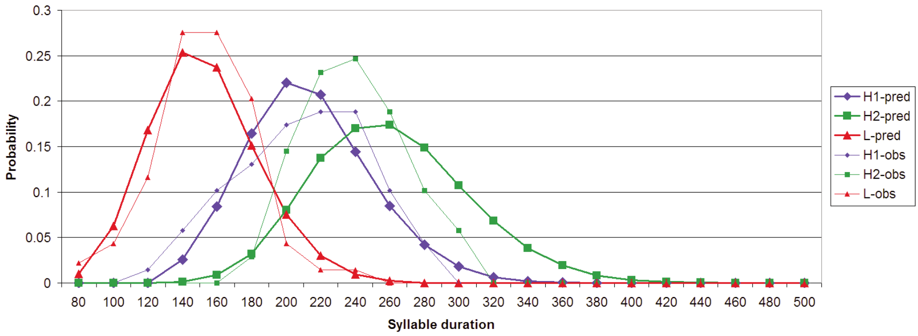

Figure 18. Model fit: HHLH metra (H_1H_2L hemimetron) syllable weight distributions.

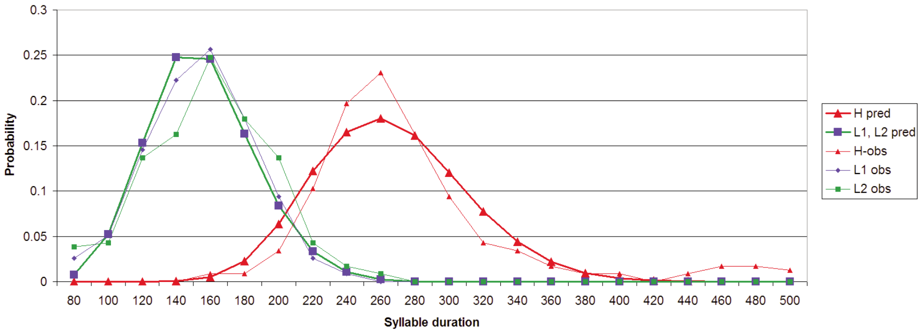

Figure 19. Model fit: HLLH metra (HL_1L_2 hemimetron) syllable weight distributions.

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[30] Each value displayed is the mean of itself and the two adjacent values; this is done to make visually more interpretable curves. Full data are available in the supplemental materials.

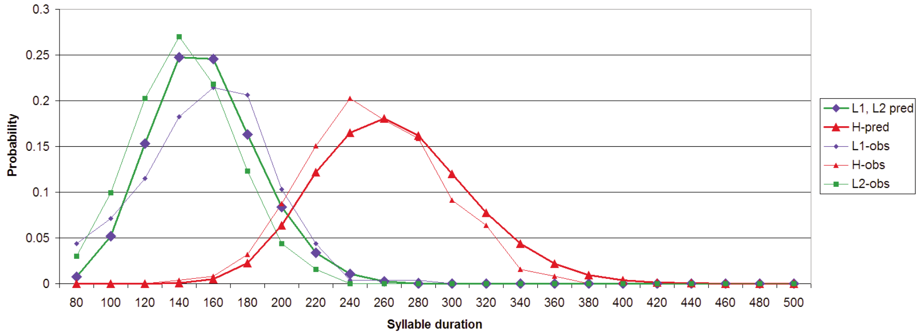

FIGURE 20. Model fit: LHLH metra (L_1HL_2 hemimetron) syllable weight distributions.

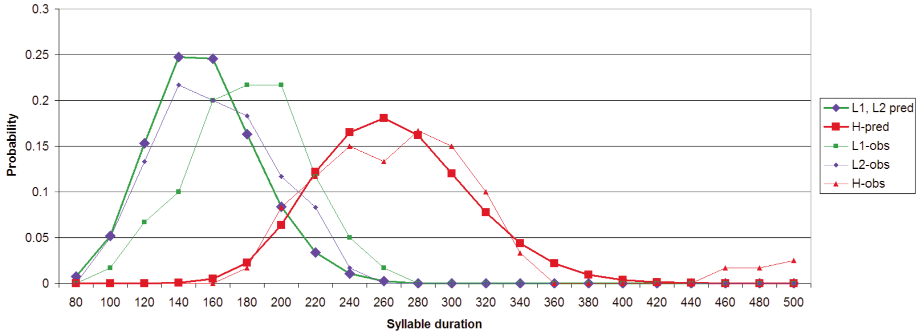

FIGURE 21. Model fit: LLHH metra (L_1L_2H hemimetron) syllable weight distributions.

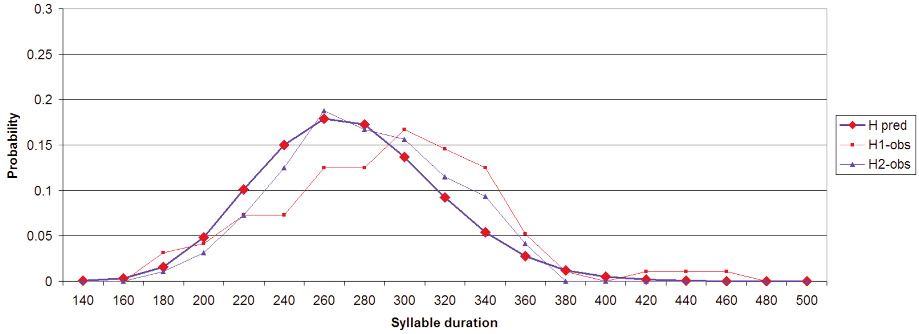

FIGURE 22. Model fit: HHH metra (H_1H_2 hemimetron) syllable weight distributions.

8.4. QUALITATIVE PREDICTIONS. While the generally good match is reassuring, a closer understanding of the model can be achieved by establishing and assessing its QUALITATIVE predictions—predictions that emerge from the fundamental principle of compromise, as generated by the model's equations. We examine four such compromises.

First, as noted above, heavy syllables are not twice as long as one light. This follows from the compromise between syllable and mora targets described earlier. Our model predicts this pattern quite accurately, as the graph in Figure 23 shows.

There is a further nuance: in song, the ratio of syllable to mora is slightly closer to the ideal of 2 : 1 than it is in prose (values: 1.69 for song vs. 1.64, 1.51 for the prose samples). The reason, we suggest, is that the targets imposed by sung rhythm are stretching out the ratio a bit closer to its ideal 2 : 1 value. In effect, we are seeing a triple compro-

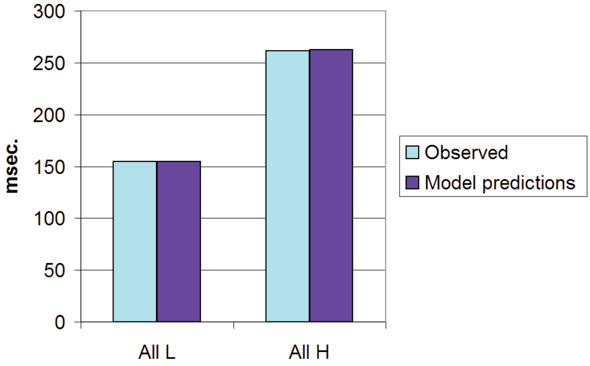

FIGURE 23. Durations of heavy vs. light syllables: observed vs. predicted.

mise, with the basic conflict between syllable and mora targets being also influenced by the grid column targets in sung rendition.

Next, the model predicts that heavy syllables in – – – metra should be longer than heavy syllables in ᴗ ᴗ – –, ᴗ – ᴗ –, or – ᴗ ᴗ – metra. The moras of light syllables are, as it were, ‘fat’ moras, being longer than the moras that pair up to form a heavy syllable, for the reason just given. The syllables of – – – metra do not have to share the metron with fat moras and thus have more room. The maxent model predicts the difference, though not a big enough difference to model the data with full accuracy; see Figure 24.

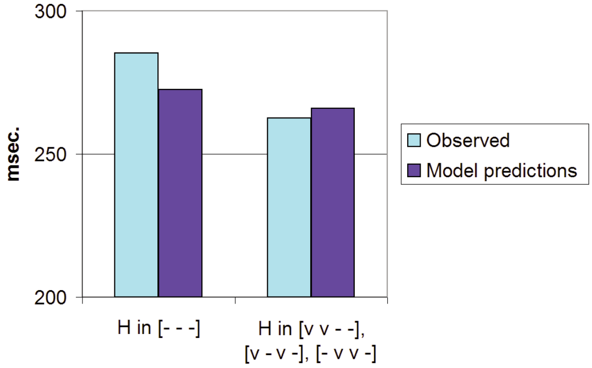

FIGURE 24. Durations of heavy in – – – vs. other heavy.

Consider next the status of heavy syllables in heptamoraic (– – ᴗ –) metra. These are subject to a crowding effect, as there is an extra mora in the hemimetron that must share room with the others. For this reason, the heavy syllables of heptamoraic metra are predicted to be slightly shorter than those of comparable metra: namely ᴗ ᴗ – –, ᴗ – ᴗ –, and – ᴗ ᴗ –. The specific predictions of the model go in the right direction, though the effect is not strong enough to match the data exactly; see Figure 25. For a reason to be made clear shortly, Fig. 25 gives only the second heavy syllable of a heptamoraic metron; still further shortening will be found in the first.

Perhaps the most interesting case is the first heavy syllable of heptamoraic metra. This is the shortest type of heavy syllable in our data.[31] In our model, we treat this fact

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[31] Indeed, we embarked on the study of phonetic duration precisely because, relying on ear judgment alone, we disagreed on whether to classify these syllables as musically long or short.

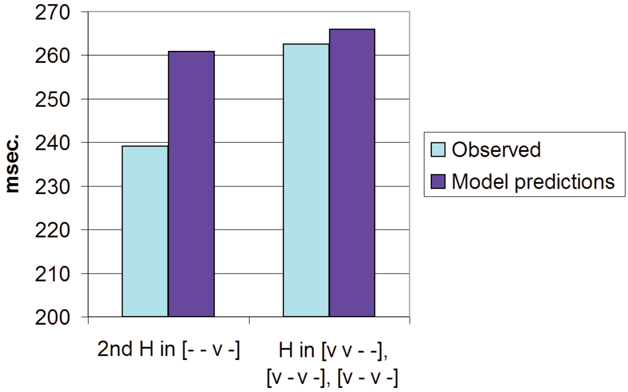

Figure 25. Second heavy syllable of heptamoraic metra vs. all heavy syllables in comparable metra.

as follows. These syllables are unique in being heavy, yet occupying a single grid column, a configuration we attribute to the purely metrical convention (§5.3) that line-initial heavy syllables may be counted metrically as light. The alignment was shown explicitly in 31 above. We assume further that the associations seen in 31 are carried over into the sung grid, which was given in 24b. This seems natural, since the sung grid closely resembles its metrical original, differing only in the extra grid marks shown in italics in 24b.

Thus, initial heavy syllables in heptamoraic metra are subject, uniquely, to the strongly compressive effects of the powerful constraint *Stretch Grid Column, which leads the model to predict short durations for them. This prediction is qualitatively correct, although too large in magnitude to be fully accurate. In Figure 26, we compare the special first heavy of – – ⏑ – with the second heavy; the latter is the closest comparable case since both are subject to the squeezing of heptamoraic metra in general.

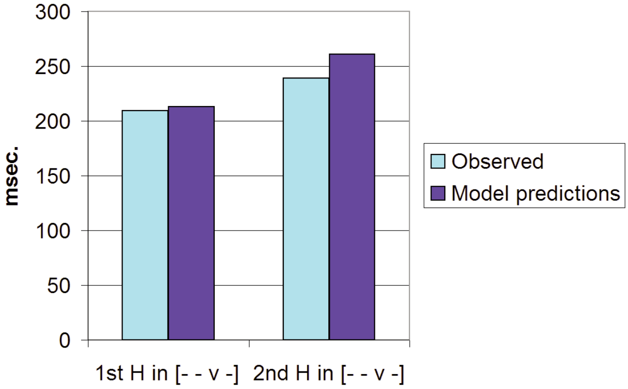

Figure 26. First heavy vs. second heavy of heptamoraic metra.

8.5. Overall model accuracy. The model distinguishes fourteen different syllable types in total, which differ according to weight, the number of moras in the metron, the number of ‘fat’ moras as defined above, and the compressive effect of assignment to a single grid column, just discussed. When we plot predicted vs. observed average duration as a scattergram, we find a reasonably good model fit.

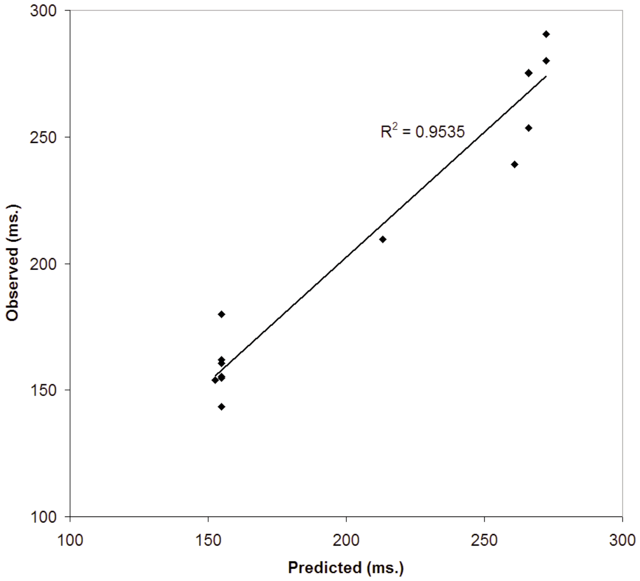

FIGURE 27. Scattergram of predicted vs. observed duration for all fourteen syllable types.

Our model outperforms a comparable single-parabola model of the type proposed by Flemming, with just four constraints each doing the work of a pair of hemiparabolic *STRETCH/*SQUEEZE constraints; in particular our model emerged as more accurate as assessed both by the likelihood ratio test used earlier ($\chi^2(4) = 28.9$, $p < 0.00001$) and in terms of its ability to capture the qualitative generalizations just given.

8.6. MODEL SUMMARY. We have shown: (i) that a simple maxent model, cast in a variant of the framework of Flemming (2001), can capture the distributions of durations seen in our sung data; (ii) that the compromise effects characteristic of phonetic grammar in general are well attested in our data; and (iii) that these effects emerge from the model in the expected way. Following Katz, we have shown that the phonetic system is adaptable: the phonetic targets of sung rhythm are superimposed on the phonological targets, adjusting the duration ratio of heavy to light syllables closer to the 2 : 1 ideal.

9. SUMMARY. We have attempted a fairly complete account of the Hausa rajaz, with treatments of metrics, sung rhythm, and phonetic realization. The second of these areas was limited solely to systematic observation, but for the first and third areas we offered formalized analyses that make explicit quantitative predictions. This is something that we think the maxent framework greatly facilitates: we can start with an intuitive understanding of a phenomenon, then express this understanding precisely with representations and constraints, and finally use maxent modeling to show that our original conception can serve as the basis for an accurate, quantitative characterization of the data.

APPENDIX A: LIST OF SONGS AND SOURCES

AAA ‘Cuta ba Mutuwa ba’

- Alhaji Aƙilu Aliyu, ‘Cuta ba Mutuwa ba’ [Injury is not death], in *Fasaha Aƙiliyya*, pp. 38–44, Zaria, Nigeria: Northern Nigerian Publishing Company, 1976.
- sixty-seven stanzas
- Recording: By the poet, recorded in the early 1970s; recording supplied by Graham Furniss. Only the last nine stanzas available.

AAA 'Jihar Kano Muka Fi So a Ba Mu Ba Kaduna Ba'

- Text: Alhaji Aƙilu Aliyu, 'Jihar Kano Muka Fi So a Ba Mu Ba Kaduna Ba' [Kano State is what we prefer to be given, not Kaduna], in *Jiya da Yau*, ed. by Abdullahi Umar Kafin-Hausa, 44–51. Ibadan: Longman Nigeria Ltd., 1983.
- fifty-three stanzas; only fifteen stanzas scanned
- No recording

AAA 'Ƙoƙon mabarata'

- Text: Alhaji Aƙilu Aliyu, 'Ƙoƙon mabarata' [Alms seekers' bowl], in *Ciza Ka Busa*, ed. by Isma'ilu Jinaidu, 91–102, Ibadan: Longman Nigeria Ltd., 1981.
- 124 stanzas, of which fifty-two were scanned.
- Recording: By the poet, recorded about 1973; recording in the archive of the Centre for the Study of Nigerian Languages, Bayero University, Kano

ADS 'Tabarƙoƙo'

- Text (scanned version): Aliyu Ɗan Sidi, 'Tabarƙoƙo' [A male buff-backed heron], in *Waƙoƙin Aliyu Ɗan Sidi Sarkin Zazzau*, pp. 4–6, Zaria, Nigeria: Northern Nigerian Publishing Company, 1980.
- thirty-four stanzas
- Text (recorded version): Aliyu Ɗan Sidi, 'Tabarƙoƙo', in *Zaɓaɓɓun Waƙoƙin Da da na Yanzu*, ed. by Ɗandatti Abdulƙadir, 67–72, Lagos: Thomas Nelson (Nigeria) Ltd., 1979.
- Recorded version has thirty-six stanzas.
- Recording: Adamu Malumfashi, recorded by RGS in Zaria, 8/5/1983. We have not been able to arrive at a consistent grid transcription of the sung version of this poem and have not attempted to analyze it here.

AYG 'Karuwa'

- Text: Ahmadu Yaro Gabari, 'Karuwa mai kama da bushiya' [Prostitute, who is like a hedgehog], in *Waƙoƙin Hikima*, ed. by Ibrahim Yaro Yahaya, 32–37, Ibadan & Zaria: Oxford University Press, 1975.
- thirty-nine stanzas
- No recording

HGU 'Gidan Audu Baƙo Zu'

- Text: Hawwa Gwaram, 'Waƙar Gidan Audu Baƙo Zu' [Song of the Audu Bako Zoo], in *Alƙalami a Hannun Mata*, ed. by Beverly Mack, 21–23, Zaria, Nigeria: Northern Nigerian Publishing Company, 1976.
- thirty-five stanzas
- Recording: By the poet; recording obtained 1979 from the Indiana Archive of Recorded Music

IYM 'Harshen Hausa'

- Text: Ibrahim Yaro Muhammad, 'Waƙar Harshen Hausa' [Song of the Hausa language], in *Waƙoƙin Hikimomin Hausa*, pp. 75–81, Zaria, Nigeria: Northern Nigerian Publishing Company, 1974.
- forty-four stanzas
- No recording

IYM 'Roƙon Ubangiji'

- Text: Ibrahim Yaro Muhammad, 'Roƙon Ubangiji' [Beseeching the Lord], in *Waƙoƙin Hikimomin Hausa*, pp. 42–48, Zaria, Nigeria: Northern Nigerian Publishing Company, 1974.
- forty stanzas
- No recording

MHa 'Tutocin Shehu'

- Text: Mu'azu Haɗeja, 'Tutocin Shaihu da Waninsu' [Banners of the Sheikh and others], in *Waƙoƙin Mu'azu Haɗeja*, pp. 5–10, Zaria, Nigeria: Northern Nigerian Publishing Company, 1970 [originally published 1955].
- seventy-seven stanzas
- Recording: Abubakar Ladan, recorded in the early 1970s; recording in the archive of the Centre for the Study of Nigerian Languages, Bayero University, Kano

TTu 'Harshen Hausa'

- Text: Tijjani Tukur, 'Waƙar Harshen Hausa' [Song of the Hausa language], in *Zaɓaɓɓun Waƙoƙin Da da na Yanzu*, ed. by Ɗandatti Abdulƙadir, 187–89, Lagos: Thomas Nelson (Nigeria) Ltd., 1979.
- nineteen stanzas
- No recording

TTu 'Kanari'

- Text: Tijjani Tukur, 'Kanari' [Canary], in *Waƙa a Bakin Mai Ita, Littafi na Biyu*, ed. by Centre for the Study of Nigerian Languages, Kano, 4–13, Zaria, Nigeria: Northern Nigerian Publishing Company, 1979.
- eighty stanzas
- Recording: A recording by the poet is available, but the recitation style lacks a rhythm that could be consistently aligned to a grid.

Appendix B: Irregular metra

In Table A1 we list all observed noncanonical metron types. Note that in the second metron, all types ending in ⏑ have a frequency of zero; this is because under the assumption of *brevis in longo* (§5.3) there are no line-final light syllables.

TYPE	AS METRON 1		AS METRON 2		ALL	
	COUNT	FRACTION	COUNT	FRACTION	COUNT	FRACTION
– – – –	1	0.0004	1	0.0004	2	0.0004
– – ⏑	1	0.0004	0	0.0000	1	0.0002
– – ⏑ ⏑	9	0.0036	0	0.0000	9	0.0018
– ⏑ –	5	0.0020	7	0.0028	12	0.0024
– ⏑ – –	1	0.0004	4	0.0016	5	0.0010
– ⏑ – ⏑ –	0	0.0000	1	0.0004	1	0.0002
– ⏑ ⏑ – –	1	0.0004	0	0.0000	1	0.0002
– ⏑ ⏑ ⏑	6	0.0024	0	0.0000	6	0.0012
– ⏑ ⏑ ⏑ ⏑	1	0.0004	0	0.0000	1	0.0002
⏑ – –	4	0.0016	17	0.0069	21	0.0042
⏑ – – –	4	0.0016	13	0.0053	17	0.0034
⏑ – ⏑ ⏑	38	0.0153	0	0.0000	38	0.0077
⏑ – ⏑ ⏑ –	0	0.0000	1	0.0004	1	0.0002
⏑ ⏑ –	0	0.0000	1	0.0004	1	0.0002
⏑ ⏑ – ⏑	3	0.0012	0	0.0000	3	0.0006
⏑ ⏑ – ⏑ –	3	0.0012	2	0.0008	5	0.0010
⏑ ⏑ ⏑ –	17	0.0069	6	0.0024	23	0.0046
⏑ ⏑ ⏑ – –	0	0.0000	2	0.0008	2	0.0004
⏑ ⏑ ⏑ ⏑ –	13	0.0053	8	0.0032	21	0.0042
⏑ ⏑ ⏑ ⏑ ⏑	1	0.0004	0	0.0000	1	0.0002
TOTAL	*108*	*0.0435*	*63*	*0.0254*	*171*	*0.0343*

Table A1. Marginal metron types.

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