

Metrical structure and sung rhythm of the Hausa Rajaz*

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Abstract

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.

* The Supplemental Materials mentioned at various places in the text may be obtained from the *Language* website or from www.linguistics.ucla.edu/people/hayes/hausa/.

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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 and Keyser 1966, 1971, Kiparsky 1975, 1977), augmented for explicitness and precision with the framework of maxent grammar (Goldwater and Johnson 2003, Hayes, Wilson and 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 and 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 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 as well as shared abstract underlying principles. This implies 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 and Keyser 1971:157; Hayes, Wilson and 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 19th century, using Arabic Islamic poetry as a model (Hiskett 1975). During the 20th 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 originals 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 which 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; Hiskett 1975; Galadanci 1975; Muhammad 1979, Schuh 1988a, 1988b, 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 (˘) 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.

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

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

$$\left\{ \begin{array}{c} \cup \cup \\ - \end{array} \right\} - \left\{ \begin{array}{c} \cup \cup \\ - \end{array} \right\} - \left\{ \begin{array}{c} \cup \cup \\ - \end{array} \right\} - \cup -$$

Example:

— — ∪ ∪ — — — — ∪ —
 Nairàa dà kwabòo saabo-n kudfi³
 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. This permits a straightforward computation of the metrical equivalence between ∪ ∪ 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 2476 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*, etc. The stanza-final lines turn out to have not just special rhyming properties, but special metrical properties as well.

In the analysis we will propose, the rajaz line consists of two parallel sister constituents. Following the terminology for Ancient Greek, which has similar units, we will 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 (2) with their corpus counts.

² “Catalectic” designates truncations in the pattern found at or near the end of a line; e.g. catalectic mutadaarik seems like a truncated version of $\left\{ \begin{array}{c} \cup \cup \\ - \end{array} \right\} - \left\{ \begin{array}{c} \cup \cup \\ - \end{array} \right\} - \left\{ \begin{array}{c} \cup \cup \\ - \end{array} \right\} - \left\{ \begin{array}{c} \cup \cup \\ - \end{array} \right\} -$, 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], *k* is [kʰ], *c* is [tʃ], *j* is [dʒ], *sh* is [ʃ], *r* is [r], *ṛ* is [r̄] or [r̃], 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.

(2) *The five primary metron types*

Type	As Metron 1		As Metron 2		All	
	count	fraction	count	fraction	count	fraction
◡ – ◡ –	1146	0.463	521	0.210	1667	0.337
– – – –	173	0.070	864	0.349	1037	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	2368	0.957	2413	0.975	4781	0.965

Excepting – – ◡ –, these metra have exactly six moras (hexamoraic); the remaining metron type – – ◡ – is heptamoraic. The five metron types are all well represented, and the most common type 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 will not attempt to predict their relative frequency; we believe a grammar is sufficient simply if it succeeds in predicting them to be rare.

The 32nd stanza of the poem “Tutocin Shehu” (“The Banners of the Sheikh”) by Mu’azu Hadeja (1955) illustrates all five major metron types.

(3) *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.nii	
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 tenth penny 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 backgrounds

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 e.g. Hayes (1983, 1989b), Prince (1989), Fabb and 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 and Jackendoff 1983), and linguistic stress (Lieberman and Prince 1977, Halle and Vergnaud 1987, Hayes 1995). Such structures are 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**; i.e. 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 as inviolable constraints on metrical structure):

(4) *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*.

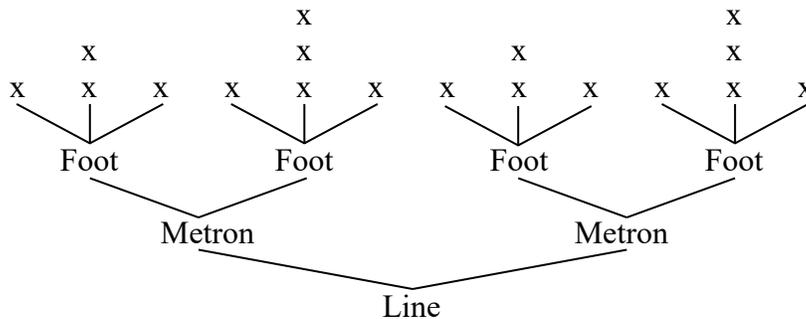
The prominence relations on the grid are defined thus:

(5) *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 will harmlessly omit the relevant structure from our representations.⁵

A bracketed grid structure that obeys the principles of (4) and (5) is as follows:

(6) *The rajaz metrical pattern*

It can be seen that there are two levels of binary branching (the most common type) and one of ternary, yielding a total of $2 \times 2 \times 3$ or 12 grid columns. In terms of the analysis to come, this will be the basis of the factual observation that most lines have 12 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

⁴ Rajaz can also be written in trimeters, 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 reviewer 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 (1984:117-118).

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 (Prince and 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 2000, Goldwater and 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 19th 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, and Shisko 2012). In addition, maxent when scrutinized emerges as a deeply intuitive and rational way to reason from data to predictions.

4.2.1 Intuitive rationale of maxent

The key formula of maxent is as given in (9).

(9) The maxent formula

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

$\Pr(x)$	probability of candidate x
$\exp(y)$	e (about 2.72) to the power of y
\sum_i	summation across constraints
w_i	weight of the i th constraint
$f_i(x)$	number of times x violates the i th constraint

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 and Pater 2016) but it covers only non-stochastic cases.

\sum_j summation across candidates.

In prose, (9) 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 $\sum_i w_i f_i(x)$ in (9), which is often called the **harmony** of a candidate; maxent is indeed one species of the more general approach of Harmonic Grammar (Legendre et al. 1990, Legendre et al. 2006, Pater 2016, Potts et al. 2010).

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 and Rosenbach 2006). In maxent, ganging is a natural consequence 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 is not only well-supported empirically (e.g. Zuraw and Hayes 2017) but also accords with common sense about how evidence is marshaled to arrive at conclusions: ideally, we weigh *all* of the evidence.

The exponentiation operator in (9), $\exp(y)$, also has a common sense basis, as its effect is to require great deal of evidence 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, (9) 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.

4.2.2 Harmonically bounded semi-winners

Formula (9) 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. have incur a proper superset of the

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 and Smolensky (1993:§10.2.2).

constraint violations of some other candidate; Prince and Smolensky 1993:156). This probability never higher than that assigned to the bounding candidate, assuming non-zero 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 and Wilson 2008, Hayes and Moore-Cantwell 2011, Hayes, Wilson, and Shisko 2012), and indeed it will be essential in the analysis to follow.

Summing up, the reasons we adopt maxent are (1) its computational advantages in finding the optimum grammar and statistically testing it; (2) its close correspondence with intuition concerning the role of evidence in arriving at conclusions; (3) its unique behavior in permitting harmonically bounded candidates sometimes to receive substantial probability.

Maxent will here be 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 and Wilson 2008) and in metrics (Hayes and Moore-Cantwell 2011, Hayes, Wilson, and Shisko 2012). Abandoning metrical underlying forms avoids arbitrary and perhaps unfruitful decisions, and 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 /-/; i.e. 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 (10):

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 (13).

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

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

(13)a. *Violation of *STRETCH*



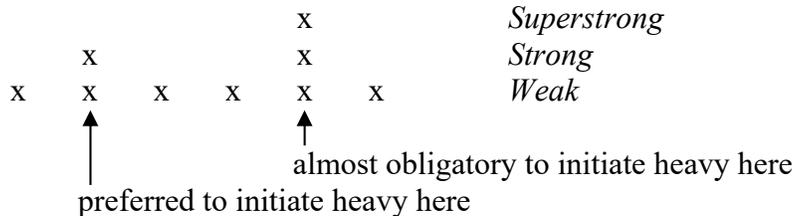
b. *Violation of *SQUEEZE*



We will 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 (6), *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.

(14) *Distribution of heavy syllables in the metron*



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

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 \sim 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.

expected to align even more strictly with heavy syllables than the merely Strong ones. The constraints that are needed for rajaz are given in (15).

(15) 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. The following chart gives the grid alignments of the five basic metron types and their violations of STRONG IS LONG and LONG IS STRONG.

(16) Sample violations of STRONG IS LONG and LONG IS STRONG

x x x x x x x / / ∪ — ∪ —	STRONG IS LONG	LONG IS STRONG
	0	0
x x x x x x x / / — — ∪ —	0	0 1st heavy treated as “as if” light; see below
x x x x x x x / / ∪ ∪ — —	1 from grid column 2	1 from 1st heavy
x x x x x x x / / — ∪ ∪ —	1 from grid column 2	1 from first heavy

Beyond this, it is necessary to account for the asymmetries in the populations of the five types across the two metra, documented above in (2). To review, $\cup \cup - -$ 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 $\cup \cup$, 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 will simply stipulate a ban on line-initial $\cup \cup$, as given in (19):¹⁴

(19) *LINE-INITIAL $\cup \cup$

*[Line $\cup \cup$

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 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 will simply treat it as such.¹⁵

(20) *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 \cup , since the constraints

¹⁴ Violations of *LINE-INITIAL $\cup \cup$ and *TRIPLE LIGHT are modestly underrepresented even in prose (§6.6.3), but the effect is modest and is insufficient to explain the rarity of verse lines that violate them.

¹⁵ We are agnostic concerning the formal implementation of “as if” constraints like (20). 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.

we are employing will prefer the versions where final \cup is treated as $-$. We implemented this in our GEN given above in (10).

We will invoke a distinct “as if” principle as the basis of our treatment of the aberrant heptamoraic $--\cup-$ metron. Recall from (2) 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 initial heavy to be treated as light. From this and other principles emerges the prediction that initial $--\cup-$ should be the only legal heptamoraic metron — all others are ruled out by independently needed constraints. Thus, for example, we might expect heptamoraic $-\cup--$ to occur line-initially, but this would count as a version of $\cup\cup--$, which is impossible line-initially because of *LINE-INITIAL $\cup\cup$. 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 $\cup\cup-/\cup\cup-/\cup\cup-/\cup-$ but the first foot may alternatively be rendered $-\cup-$ (Schuh 1995). Persian works like Hausa mutadaarik, in that heavy may replace light in the initial position of any meter that begins $\cup\cup$ (Elwell-Sutton 1976:86). Greek iambic trimeter is like Hausa rajaz, but more general: $--\cup-$ metra may be substituted for basic $\cup-\cup-$ 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.

(21) 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 (21) a constraint, as some Hausa poets actually *prefer* to invoke the substitution. In the analysis to follow, we will 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 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 will first demonstrate how highly-weighted constraints pick out the five basic metron types from GEN as the most common. We then turn to

¹⁶ As a reviewer 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.

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 non-canonical metron types.

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

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

<i>Constraint</i>	<i>Weight</i>
(11) *STRETCH	100
(12) *SQUEEZE	100
(15b) SUPERSTRONG IS LONG	100
(19) *LINE-INITIAL ◡ ◡	100
(18) *TRIPLE LIGHT	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 will record such values as zero.

The tableaux given in (23) are abbreviated versions of computationally-implemented tableaux (available in the Supplemental Materials) that evaluate all the candidates in the GEN of (10). 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.

(23) 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
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 the 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 to derive not just the five basic metron types, but to offer a nuanced, frequency-matching analysis of all the data in our corpus. The 2476 lines of our corpus come from 11 different poems, no two of which show exactly the same pattern (even

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

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 than the first four lines.

Below, we give a fuller presentation of our data, giving the percentage frequency of each of the five primary metron types for each of the 11 poems, which are identified by title and author initials (for full details see Appendix A).

(24) *Data for Eleven Rajaz poems: Metron 1*

<i>Position in stanza</i>	<i>Poem</i>	<i>Total lines</i>	∪ - ∪ - (percent)	- - ∪ -	- ∪ ∪ -	- - -	∪ ∪ - -
<i>Nonfinal</i>	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 Kokon Mabarata	208	97.6	0.0	0.0	0.0	0.0
	ADS Tabarkoƙo	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
<i>Final</i>	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 Kokon Mabarata	52	88.5	7.7	1.9	0.0	0.0
	ADS Tabarkoƙo	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	2.5

(25) Data for Eleven Rajaz poems: Metron 2

Position in stanza	Poem	Total lines	◡ – ◡ –	– ◡ –	– ◡ ◡ –	– – –	◡ ◡ – –
Nonfinal	AAA Cuta ba Mutuwa ba	268	0.4	0.0	0	86.6	10.4
	AAA Jihar Kano	60	1.7	5.0	93.3	0.0	0.0
	AAA Kokon Mabarata	208	1.0	1.4	97.1	0.0	0.0
	ADS Tabarkoƙo	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 Rokon 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 Kokon Mabarata	52	65.4	0.0	28.8	0.0	0.0
	ADS Tabarkoƙo	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 Rokon 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

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 $5 \times 11 \times 2 \times 2 = 220$ 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 67 stanzas, hence $4 \times 67 = 268$ non-stanza-final lines; of these 181 have ◡ – ◡ – as their first metron, i.e. 67.5% of the total; this is the first value given in table (24). Data do not sum to 1 across rows because we do not include any of the non-canonical 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 one single line.

To visualize the data, the reader may find it useful at this point to turn ahead to the graphs of (36) on p. 30, 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, ◡ – ◡ – 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%.

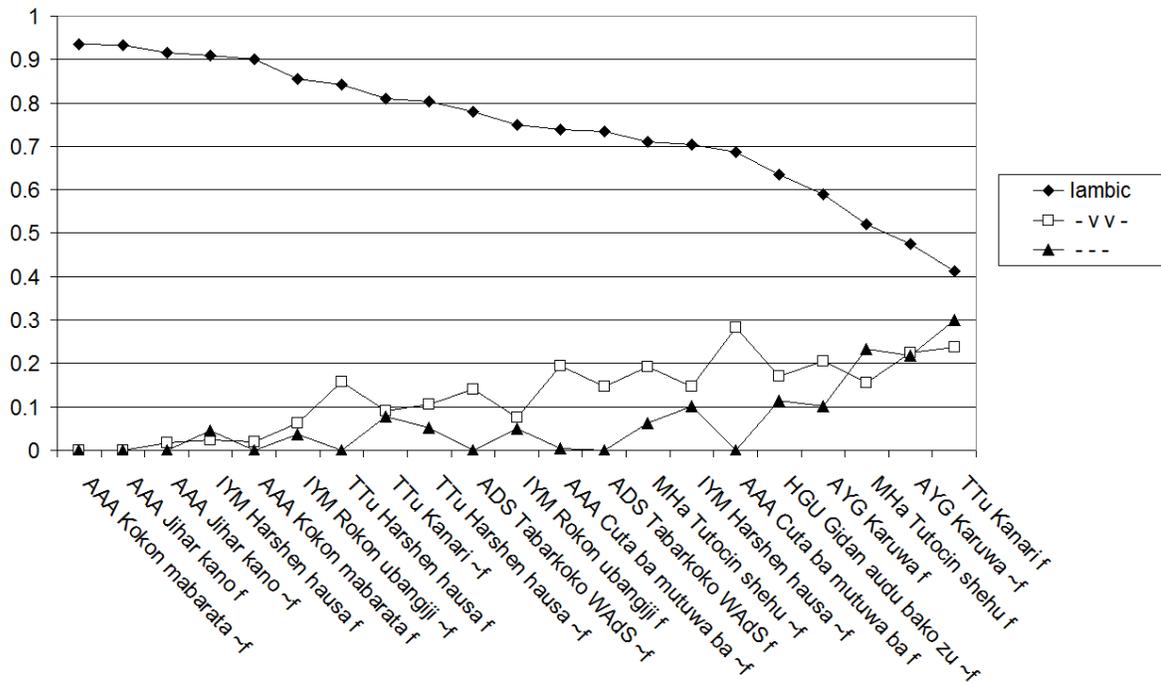
The analysis to follow covers first Metron 1, then Metron 2.

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 will refer to the two metron types $\cup - \cup -$ and $-- \cup -$ as **iambic** since, as (16) showed, they are the only ones that (making use of (21), INITIAL HEAVY-FOR-LIGHT) perfectly realize the iambic structure of the metron.

In the data of (24) and (25) we find that the iambic category is always the most common. Then, with few exceptions, $\cup - \cup -$ is always more frequent than $-- -$. The relative preferences for all the data are shown in (26); in the data labels, “f” means “stanza-final” and “~f” means “non-stanza-final.”

(26) Relative preference for iambic, $\cup - \cup -$, 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 hence of metrical style. In (27) we give the violations of the three relevant metron types (iambic, $\cup - \cup -$, and $- - -$) for these two constraints:

(27)

	STRONG IS LONG	LONG IS STRONG
Iambic ($\cup - \cup - / - - \cup -$)		
$- \cup \cup -$	*	*
$- - -$	*	**

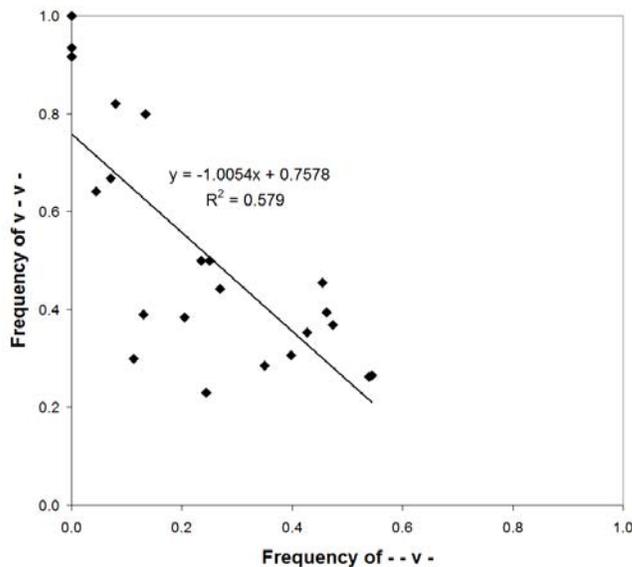
Chart (27) displays a pattern known to be important in Optimality Theory, harmonic bounding. The metron $- - -$ has every violation that $- \cup \cup -$ has, plus an additional violation of LONG IS STRONG; and if we abstract away from INITIAL HEAVY-FOR-LIGHT (irrelevant, for reasons to be explained), then $- \cup \cup -$ has every violation that $\cup - \cup -$ and $- - \cup -$ 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 and Smolensky 1993:156). As noted in §4.2.2, 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 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 (26), 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 the poets work the same in Metron 1; (26) 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.

(28) *Weights of STRONG IS LONG and LONG IS STRONG for 11 poems*

	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 Kokoƙon Mabarata	0.2	3.9
ADS Tabarkoƙo	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 Rokon 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

Turning now to the two iambic metra, $\cup - \cup - / - - \cup -$, the picture is rather different: these trade off, such that using one more means using the other less. The following scattergram illustrates this.

(29) Trade-off for $\cup - \cup -$ and $-- \cup -$ in the first metron

The slope of the regression line is very close to -1 , indicating tradeoff. We suggest that within the rajaz system as a whole, $\cup - \cup -$ and $-- \cup -$ 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 (21) INITIAL HEAVY-FOR-LIGHT, 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, $\cup - \cup -$ and $-- \cup -$ 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.

6.4 Analysis of Metron 2

Metron 2 stands out for its greater degree of poem-to-poem idiosyncrasy; a graph analogous to (26) for Metron 2 (see Supplemental Materials) forms a tangle of lines, not the clean pattern seen in (26). 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 metra 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 (36) below.) Often the stanza-final metron adheres to a particular type with very high frequency; see the rightmost figures in (36).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.

6.4.1 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 $\cup \cup - -$ 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 only affect stanza-final position.

6.4.2 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.

6.4.3 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 10 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).

¹⁸ Our reviewers queried how the rajaz data relate to the commonly-suggested principle of **closure** in metrics, sometimes expressed “beginnings are free, endings strict” (Kiparsky 1968; Hayes 1983; Ryan, ms.). Our checking of this point (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 and 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.

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):

(30) *A Persian meter* (Elwell-Sutton 1976:102)

$$\cup - \cup - / \left\{ \begin{array}{c} \cup \cup \\ - \end{array} \right\} - - / \cup - \cup - / \left\{ \begin{array}{c} \cup \cup \\ - \end{array} \right\} -$$

This is the simplest statement of the pattern, but it neglects the fact that the first $\left\{ \begin{array}{c} \cup \cup \\ - \end{array} \right\}$ position is realized as – only 3% of the time, whereas the second $\left\{ \begin{array}{c} \cup \cup \\ - \end{array} \right\}$ position is realized as – 35% of the time (Elwell-Sutton 1976, 128-129). We suggest that among the other constraints of the system (for which see Elwell-Sutton 1976, Hayes 1979, Deo and Kiparsky 2012) Persian includes a quantitative clausula constraint, – – CLAUSULA. If the data gathered by Elwell-Sutton (pp. 127-134) are representative, this constraint plays a major role in the Persian metrical system:

realization of $\left\{ \begin{array}{c} \cup \cup \\ - \end{array} \right\}$ 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 (2011:42) suggests this meter strongly respects $\cup \cup - -$ CLAUSULA. In sum, it appears that quantitative — or even fundamentally non-quantitative — 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.

(31) *Quantitative clausula constraints for rajaz*

- a. – – CLAUSULA
- b. – – – CLAUSULA
- c. $\cup \cup -$ CLAUSULA
- d. – – – CLAUSULA, STANZA-FINAL

We also employ a fifth constraint, which is a just a contextualized version of (15a) STRONG IS LONG, affiliated to the last metron of the stanza:

(32) STRONG IS LONG — 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 ($-\cup-$), but we prefer to express this in authentic structural terms, paralleling the general STRONG IS LONG constraint.

The constraint (31a), – – CLAUSULA, is a more general version of (31a) – – – 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

lines ending in $\cup \cup - -$. Inspection of the graphs in (36) indicates that in general, when a poet favors $\cup \cup - -$ line-finally (s)he also favors $- - -$. It is to capture this tendency that we adopt $- -$ CLAUSULA rather than the more specific $\cup \cup - -$ CLAUSULA.

6.5 Full model

Adding the five constraints of (31)-(32) to the eight already presented, we now have the tools to produce a complete model of the data for each poem. The 11 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 (10), along the violations for each constraint. We also included the frequencies of each metron type in every position; these appear in table (24)-(25) 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 plug-in 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 and 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 $- - \cup -$ to $\cup - \cup -$. 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 $- -$.

6.5.1 Weights obtained

We first give the weights that our procedure yielded for each poem.

(33) *Results of maxent modeling: weights*

	*STRETCH	*SQUEEZE	INITIAL HEAVY-FOR-LIGHT	*LINE-INITIAL ∪ ∪	*TRIPLE LIGHT	LONG IS STRONG	SUPERSTRONG IS LONG	STRONG IS LONG	SIL - LAST METRON OF STANZA	--- CLAUSELA	--- CLAUSELA, STANZA FINAL	∪ ∪ - CLAUSELA	-- CLAUSELA	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 Kokon 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 Tabarkoko	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 Rokon 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	

In digesting these numbers it is useful to sort the constraints by median weight, as follows:

(34) *Constraints sorted by median weight*

<i>Constraint</i>	<i>Median weight</i>
*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
--- CLAUSELA, STANZA FINAL	1.2
-- CLAUSELA	0.8
∪ ∪ - CLAUSELA	0.5
STRONG IS LONG	0.4
--- CLAUSELA	0.4
LONG IS STRONG	0.3
INITIAL HEAVY-FOR-LIGHT	0.25

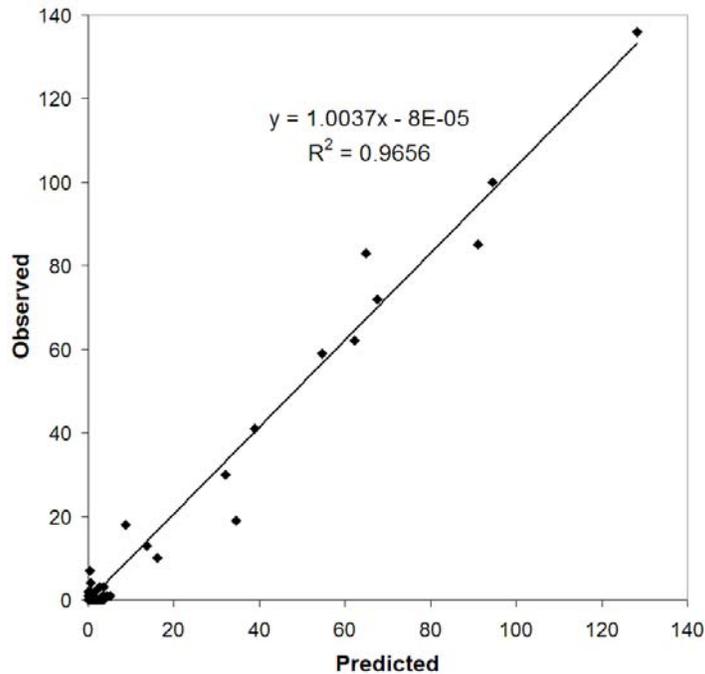
The top six constraints include the five principal constraints of the analysis that served as the sole constraints in the sketch of §6.1 (i.e. *STRETCH, *SQUEEZE, SUPERSTRONG IS LONG, *LINE-INITIAL ∪ ∪, *TRIPLE LIGHT). These constraints generally have substantial weights — these are hardly at 100, as we set them in the sketch analysis, but on the other hand 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.

6.5.2 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 (35):

(35) Scattergram for Tutocin Shehu: predicted vs. observed metron counts



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 probability close to zero (undergeneration). Essentially similar scatterplots are obtained for the other poems.

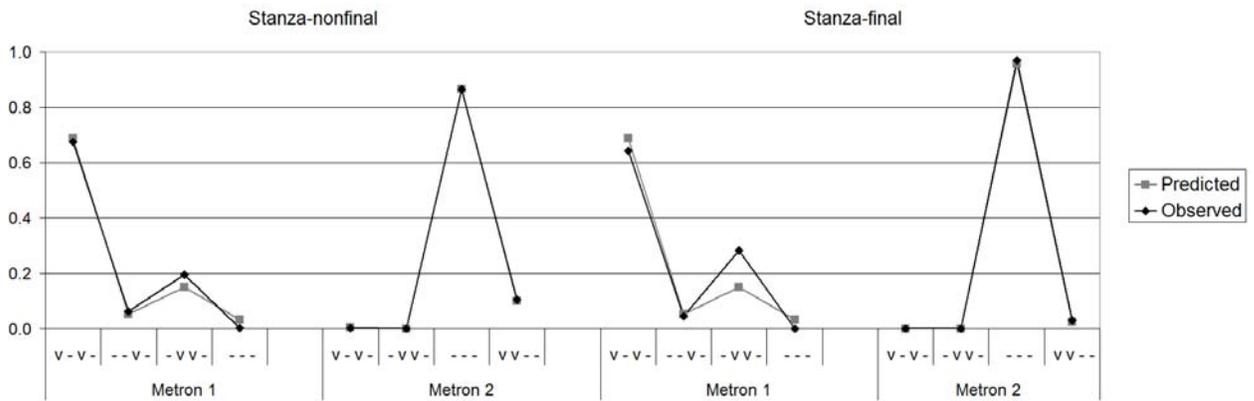
The plots can be inspected for outliers (points far from the diagonal), which sometimes suggest possible improvements to the grammar. For instance, for Tutocin Shehu there are data points at (35 predicted, 19 observed) and at (9 predicted, 18 observed), both fairly far off the diagonal. Both represent --- as Metron 1; (35, 19) is for stanza-nonfinal position, (9, 18) for

stanza-final lines. Nothing in our constraint set distinguishes Metron 1's 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.

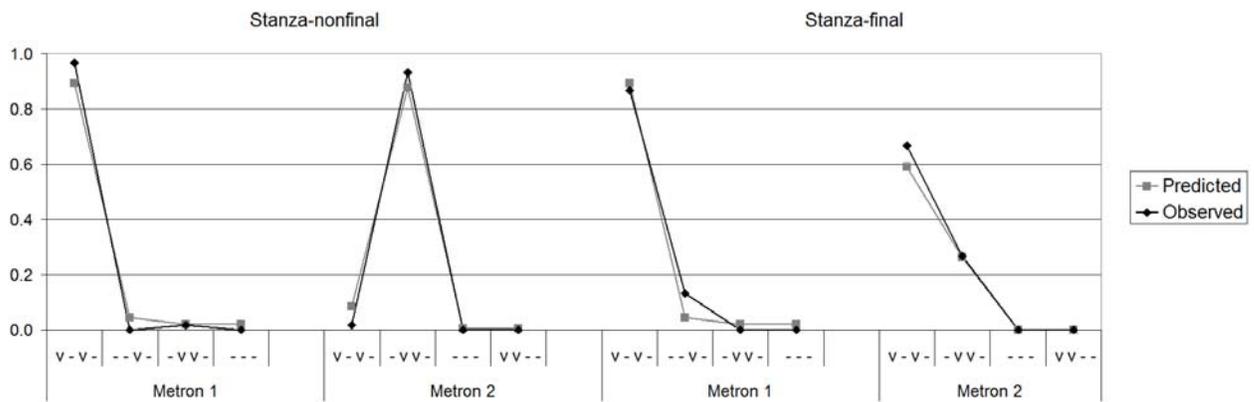
Lastly, we can assess how the system is describing variation across poets by looking at line graphs comparing predicted (gray) vs. observed (black) values for the four principal metron types of both first and second metra. A series of 11 graphs doing this for each poem are provided below in (36).

(36) Graphs of predicted vs. observed values for all 11 poems (major metron types)

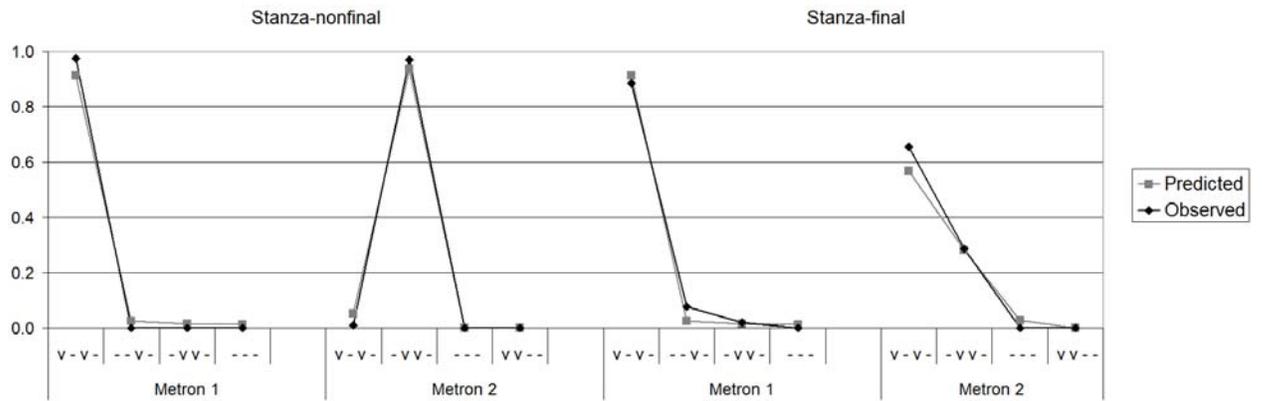
a. AAA Cuta ba Mutuwa ba



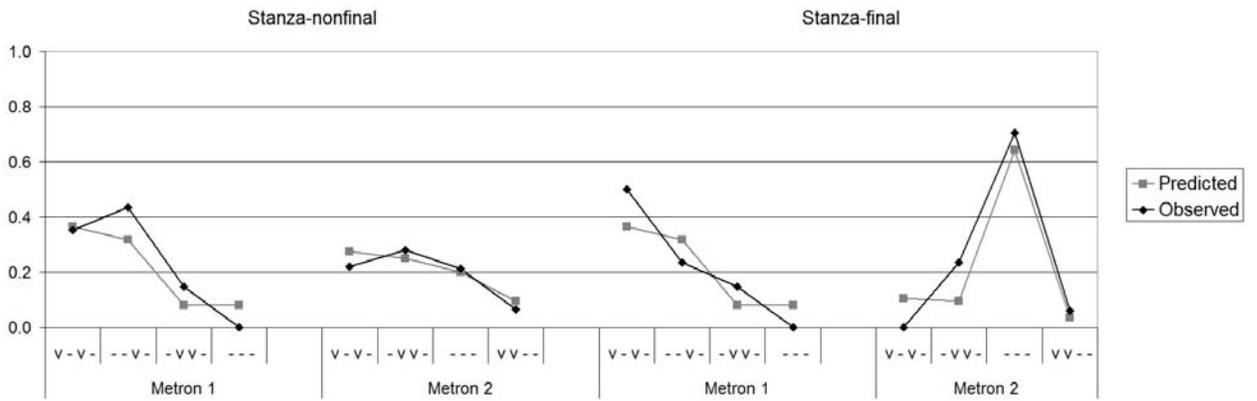
b. AAA Jihar Kano



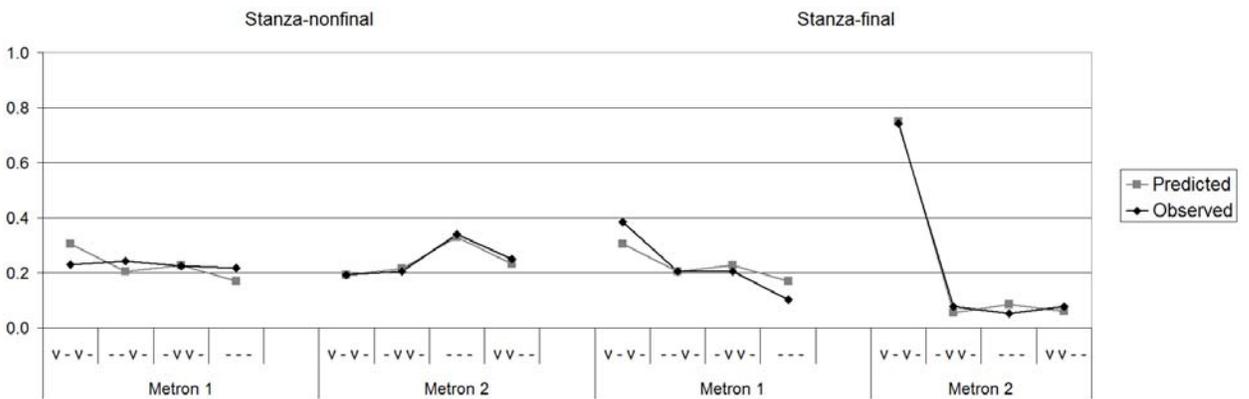
c. AAA Kokon Mabarata



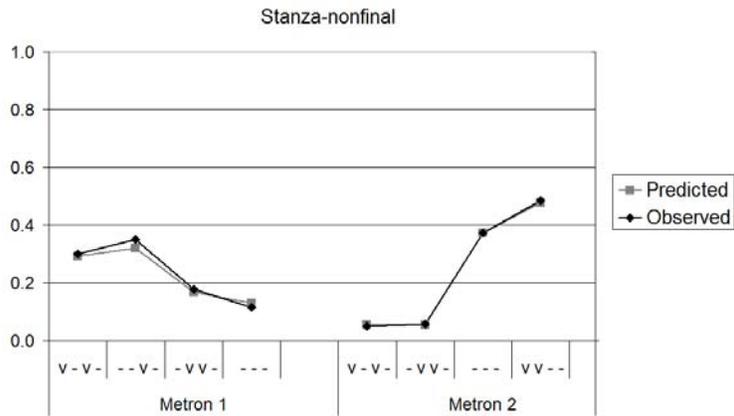
d. ADS Tabarkoko



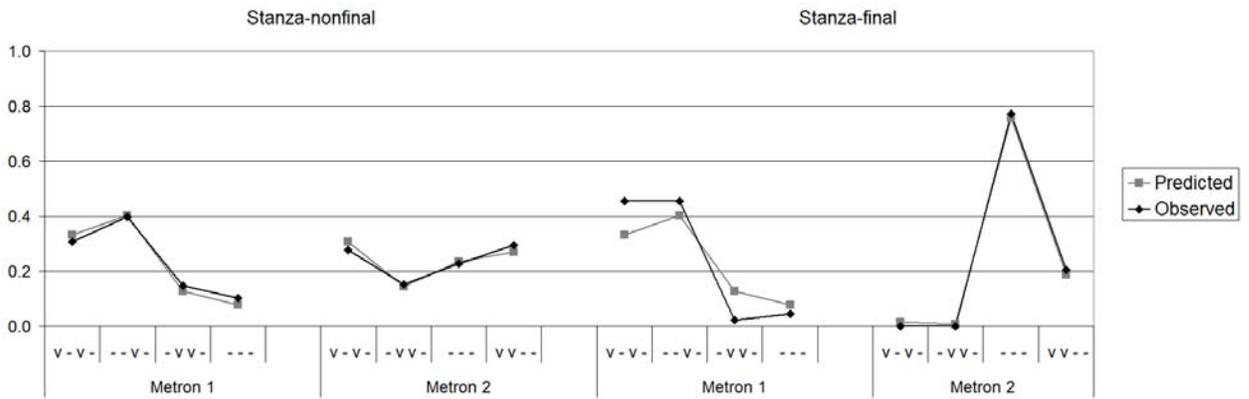
e. AYG Karuwa



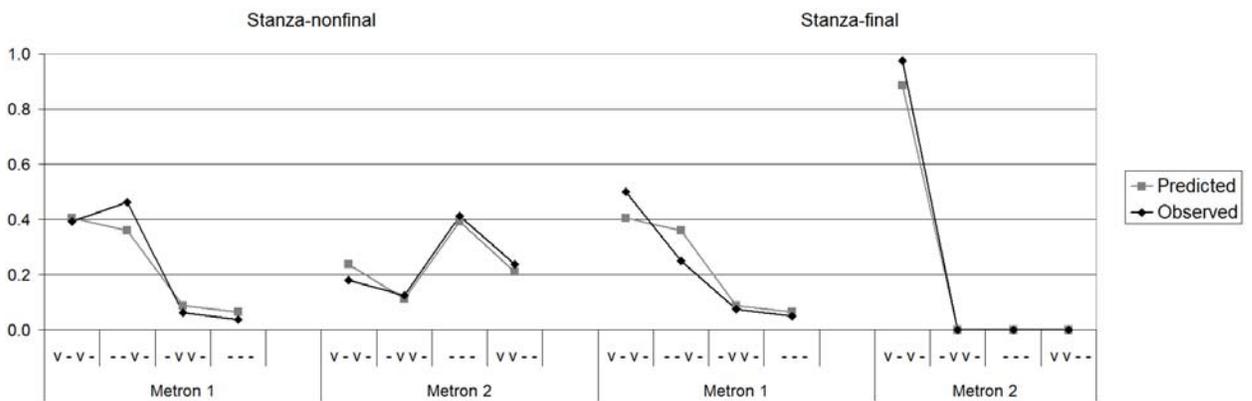
f. HGU Gidan Audu Bako Zu (last line is always refrain)



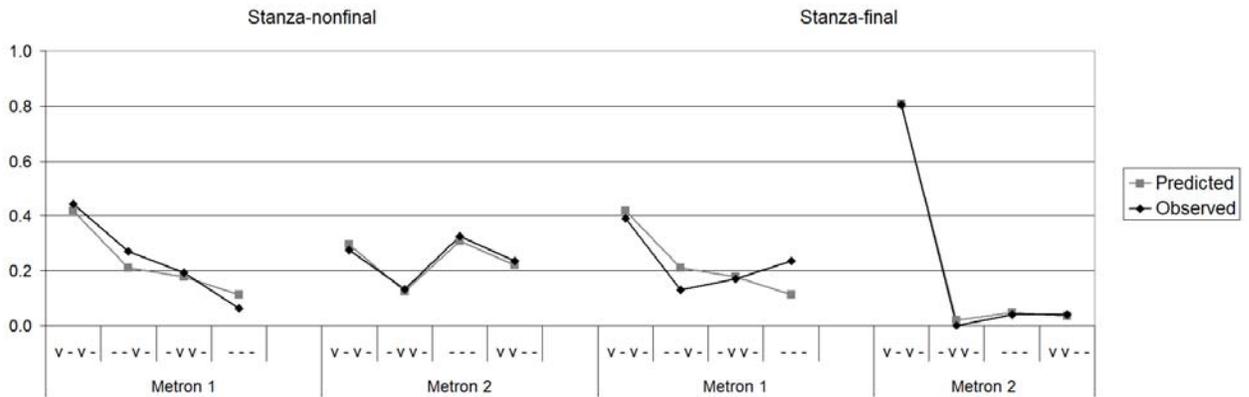
g. IYM Harshen Hausa



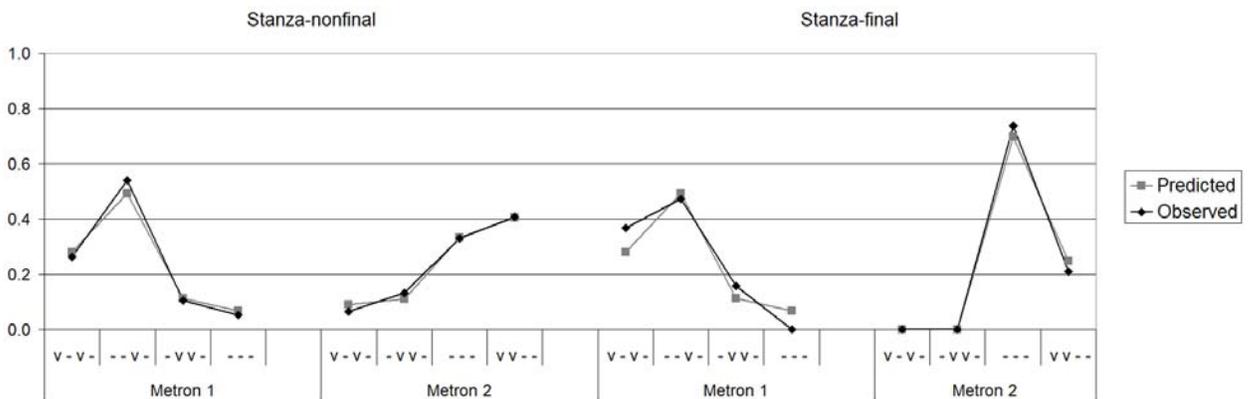
h. IYM Roƙon Ubangiji



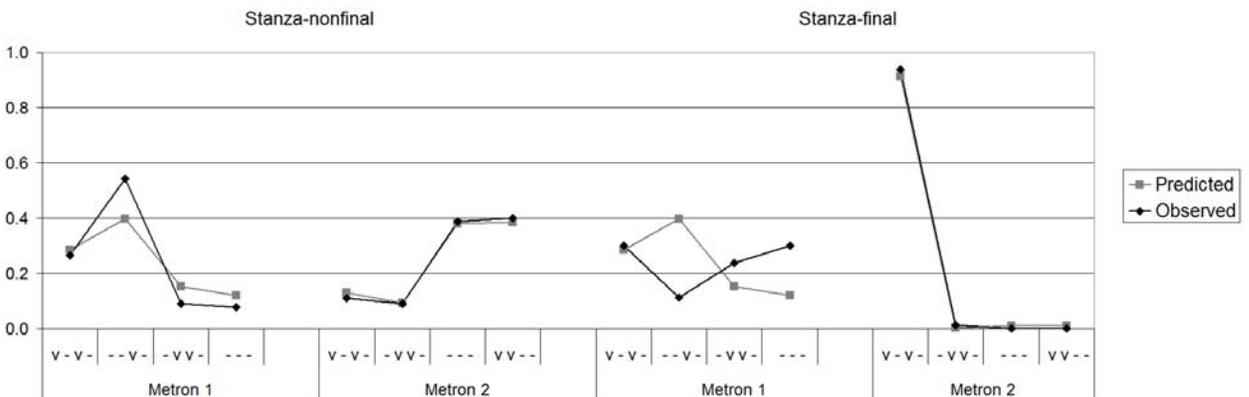
i. MHa Tutocin Shehu:



j. TTu Harshen Hausa



k. TTu Kanari



The fit is in general rather good, with the worst case being TTu Kanari. 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 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

6.6.1 Statistical significance

For all 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 be 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 ($p \ll 0.001$) for all 11 poems. The other constraints fall somewhere between these two extremes; for full details, see Supplemental Materials.

6.6.2 Restrictiveness

Our reviewers 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 .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 (27) shows, ∪-∪- also beats -∪∪- at this constraint, meaning 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

¹⁹ In Metron 2, high-weighted --- CLAUSULA, not surprisingly, did indeed give --- the probability of 1.

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

6.6.3 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 (Tarlinskaja 1976, Gasparov 1980, Bailey 1975; 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 (materials and analyses all in 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 $\cup - - - \dots$ we can either take $\cup - -$ as our Metron 1 or $\cup - - -$, but neither of these is hexamoraic. Real rajaz verse is not like this; all but a few irregular lines permit of 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.

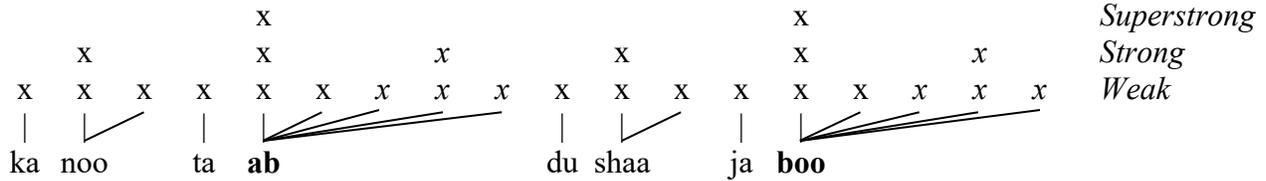
7. Performing the rajaz in song

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. However, as already mentioned, the standard way to render a Hausa poem audible is to

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 $\{\cup - \cup -, \cup \cup - -, - \cup \cup -, - - -\}$ can dominate under some weighting (see (25)). However, even here, the situation is not “anything goes.” For instance, $- - \cup -$, legal as Metron 1, cannot be derived as Metron 2 without allowing in a whole raft of other outcomes. Further, certain Metron 2 patterns are incompatible with particular Metron 1 patterns: $\cup \cup - -$ cannot dominate in Metron 2 if $- \cup \cup -$ dominates in Metron 1; and if Metron 1 is exclusively $\cup - \cup -$ 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.

b. *Sung rhythm*

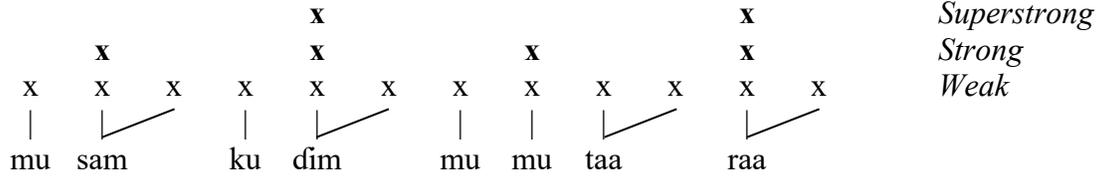


7.1.2 *HGU Gidan Audu Bako Zu*

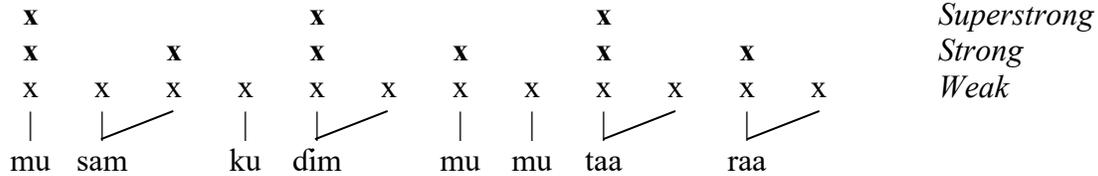
The singer is the poet, Hawwa Gwaram. In Gwaram’s rendition, the 12 terminal positions of the original metrical grid are retained, but the higher levels are drastically altered. The line is rendered not as two iambic metra, but as three initially-prominent units with internal binary rhythm.

(38) *Metrical rhythm vs. sung rendition of line 3.3, “HGU Gidan Audu Bako Zu”*

a. *Meter*



b. *Sung rhythm*



c. *Gloss*

Mù sam kudi-n-mù mù taaràa (line 3c)
 let-us get money-of-us let-us collect
 ‘Let’s get our money and collect it’

As noted above (see (36f)), 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 (38)). 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.

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.

7.2.1 *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. grid (6)) 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. (a) The poet composes lines of rajaz using the meter of (6), yielding a text. (b) 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. (39)), 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 "HGU Gidan Audu Baƙo Zu" (§7.1.2). Yet this influence is not consistently present in our data; as we saw, "Kokon mabarata" (§7.1.3) is sung to a rhythm that actually goes against its characteristic pattern of syllable quantities.

7.2.2 *Full-scale serialism*

A stronger theory, full-scale serialism, would propose that the sung version is faithful not just to a text that is licensed by the meter, but 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 (42); 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.

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. (2014), and Flemming and 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 §7.1.1. We measured the duration of 562 syllables, taken from the first 20 stanzas of Abubakar Ladan’s sung rendition. Durations were measured by hand in Praat (Boersma and 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 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

²⁴ The concept of a meter realizable with a variety of sung rhythms is standard, indeed publically 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.

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 effectively models the durations of segments within syllables, aptly describes this as a 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.

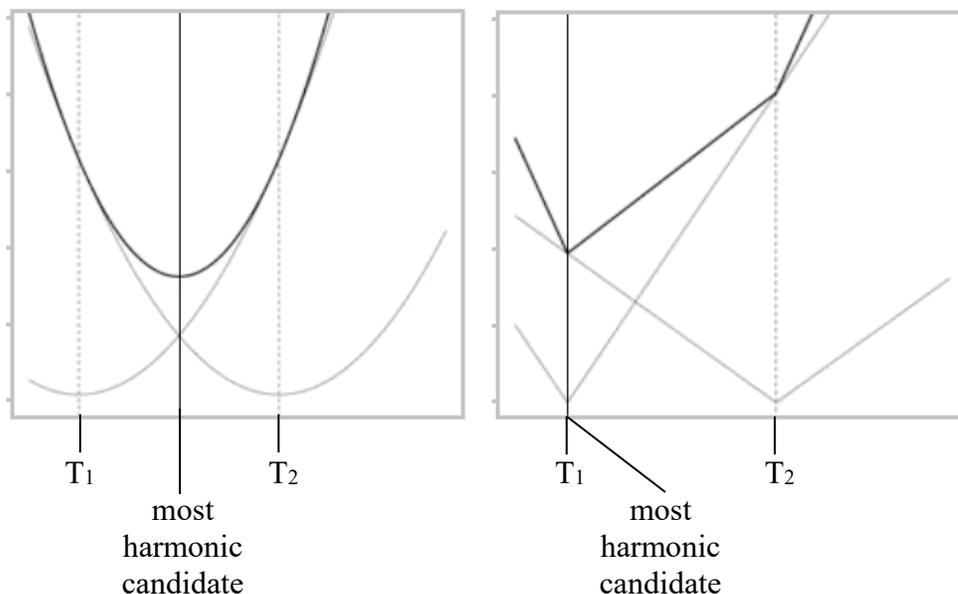
In Flemming (2001), the principle of compromise is formalized in constraint-based grammars. The key idea is to assign to every phonological entity and phonetic parameter a **target** value, along with a weighted, gradient constraint that penalizes the degree of deviation from the target for each candidate. 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 one single constraint. This can be seen in the following figure, adapted from Flemming and Cho (2017). The darker line represents overall harmony, summed from the harmony contributions of the two constraints whose harmony profiles are plotted in gray.

(43) *Squaring the deviations from target creates compromise*

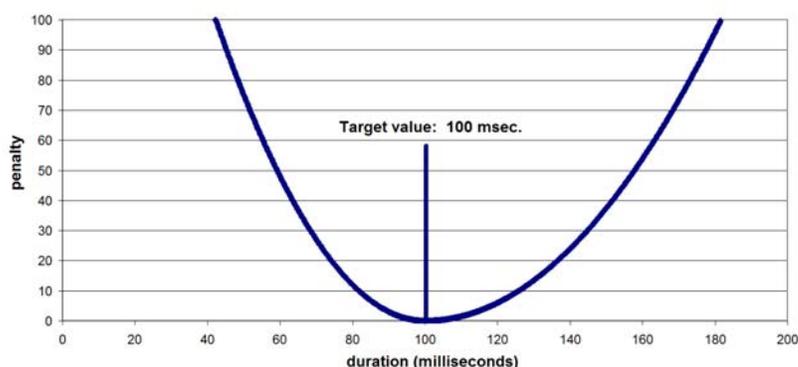
a. Harmony = squared deviation from targets

b. Harmony = simple deviation from target



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 (43a) 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 (44) 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.

(44) *Harmonic penalty in the dual hemiparabola system*

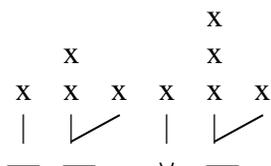


8.2 Toward a phonetic analysis of the rajaz

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 will be phonological: the syllable and the mora. We believe that syllable targets cross-linguistically typically have *somewhat less than double* the value of mora targets; in the resulting compromises heavy syllables will be 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 msec., light 138 msec., a ratio of 1.64. For the male speaker, heavy syllables average 223 msec., light 134 msec., a ratio of 1.51.

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

(46) *Structure posited for the heptamoraic metron*

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

8.2.1 *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. 12 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 \smile and $-$. But in phonetics, there is 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 msec. long. Specifically, we round each observed syllable duration to the nearest 20 msec., and our grammar selects from a discrete set of candidates spaced 20 msec. apart. This procedure could be made more refined by using shorter time slices, but we think that for our purposes the 20 msec. time grid suffices.

8.2.2 *Restricting the search space*

Experimentation with our model proved that with 12 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 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

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 and Smolensky 2000).

to be 145 msec. and 579 msec. respectively. Naturally, the target for grid column is 1/4 the value of that for hemimetron, since our hemimetra contain four grid columns.

Our second assumption, borrowed from Katz (2010:127-133), 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 the duration data into a spreadsheet (see 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

8.3 Modeling results

The optimized parameter values are given in (47).

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

Mora target:	113 msec.
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.

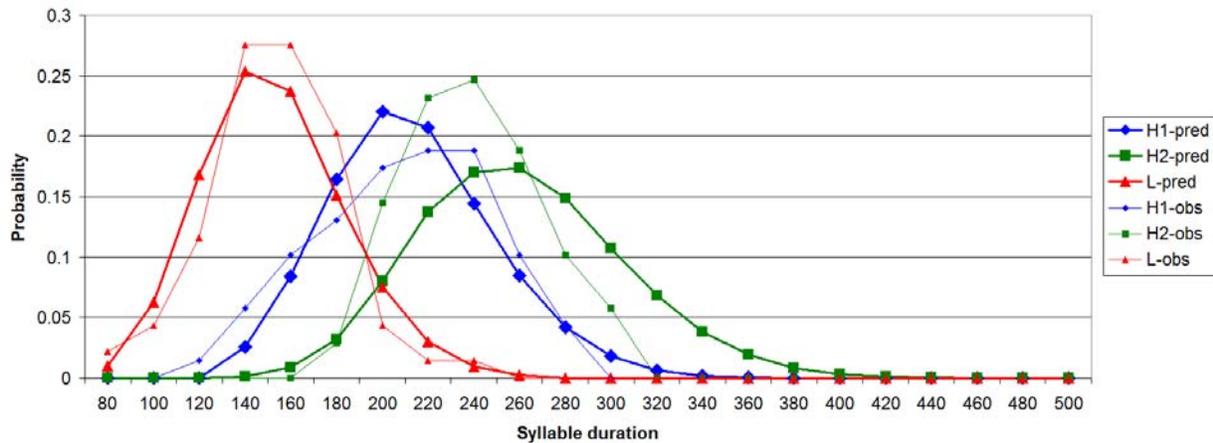
Grammar (47) can be used to compute the predicted probability for the possible durations of the syllables in each type of hemimetron (— ∪, — ∪ ∪, ∪ — ∪, ∪ ∪ —, and — —). The predicted distributions are multidimensional and hard to visualize; but from them we can calculate the

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

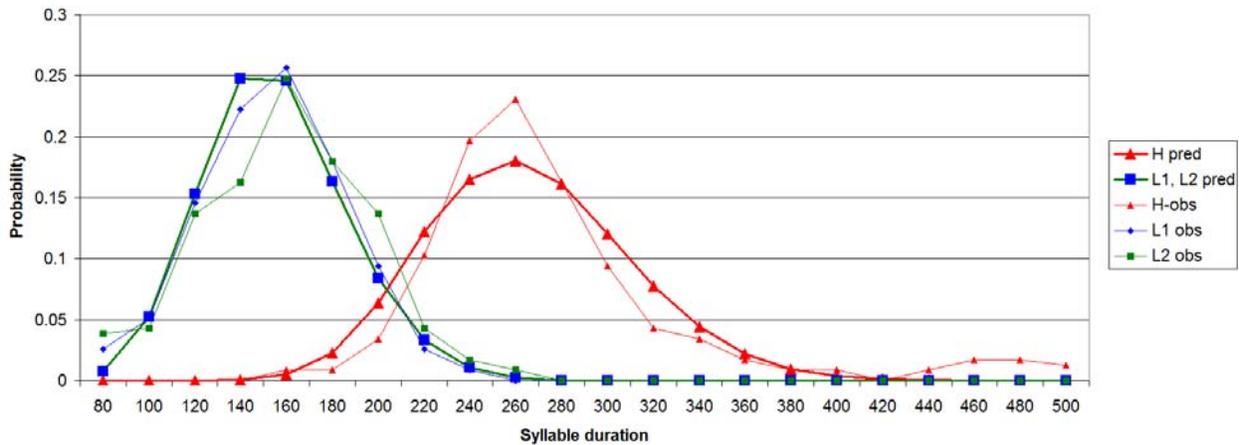
predicted distribution of durations for individual syllables in each of the five types. These are plotted against a smoothed version of the empirical distributions in (48).³⁰ The different colors and datapoint shapes stand for the different syllables of the hemimetron. The probability distributions predicted 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.

(48) Model fit: distributions of syllable weights in each major metron type

a. HLLH metra (H₁H₂L hemimetron)

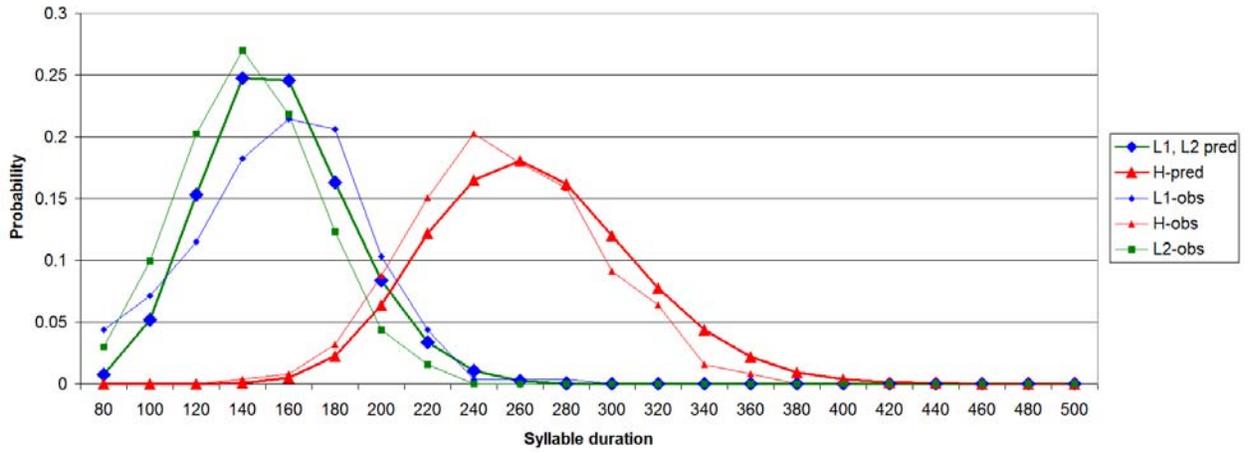


b. HLLH metra (HL₁L₂ hemimetron)

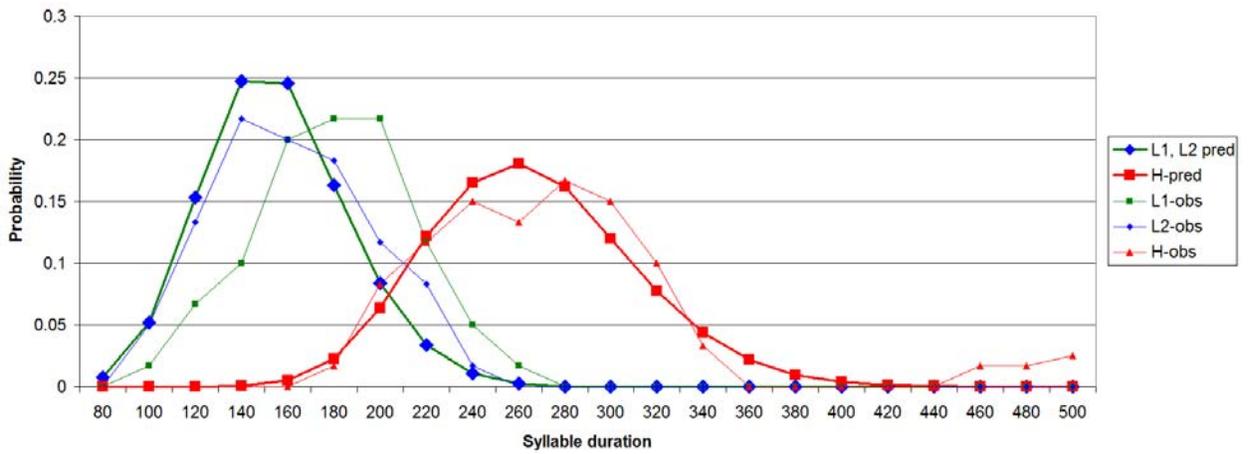


³⁰ Each value displayed is the mean of itself and the two adjacent values; this is done to make visually more interpretable curves; full data are available in the Supplemental Materials.

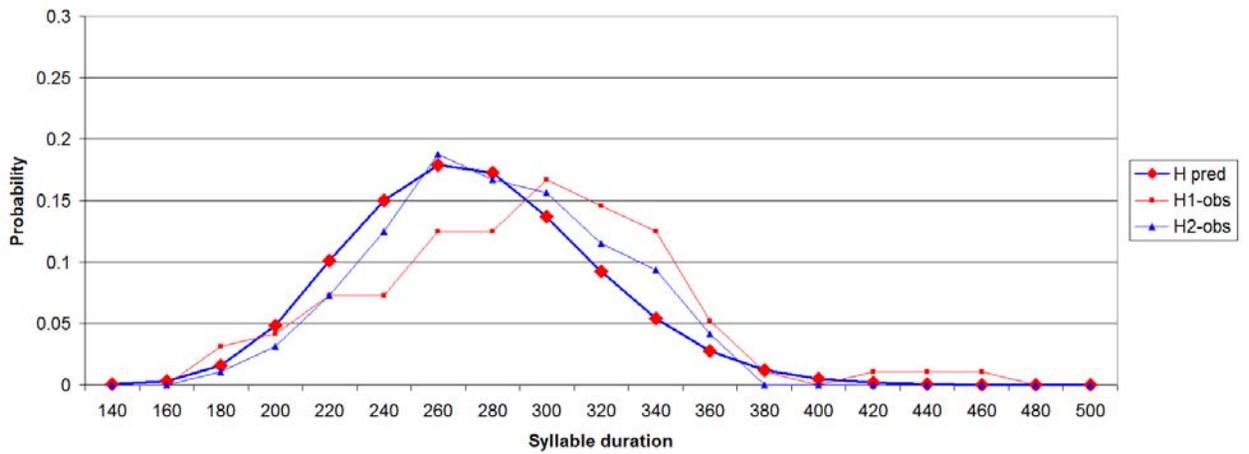
c. LHLH metra (L_1HL_2 hemimetron)



d. LLHH metra (L_1L_2H hemimetron)



e. HHH metra (H_1H_2 hemimetron)

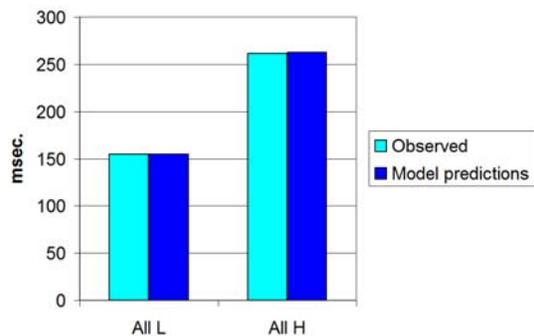


8.4 Qualitative predictions

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 will examine four such compromises.

First, as noted above, heavy syllables are not twice as long as two lights. This follows from the compromise between syllable and mora targets described earlier. Our model predicts this pattern quite accurately, as graph (49) shows.

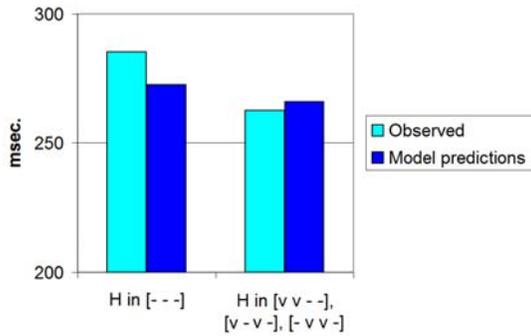
(49) *Durations of heavy vs. light syllables: observed vs. predicted*



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

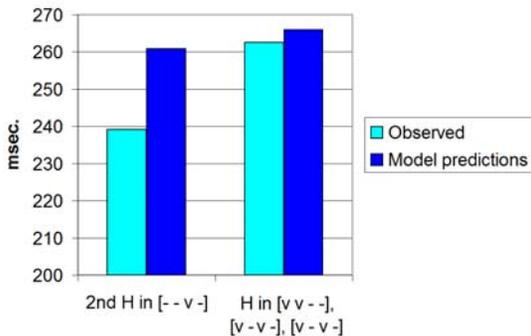
Next, the model predicts that heavy syllables in — — — metra should be longer than heavy syllables in ∪ ∪ — —, ∪ — ∪ —, or — ∪ ∪ — metra. The moras of light syllables are, as it were, “fat” moras, being longer than the moras that pair up to form a heavy syllable, for the reason just given. The syllables 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.

(50) Durations of heavy in --- vs. other heavy



Consider next the status of heavy syllables in heptamoraic (— ∪ —) 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 ∪ ∪ —, ∪ — ∪, and — ∪ ∪. The specific predictions of the model go in the right direction, though the effect is not strong enough to match the data exactly; see (51). For a reason to be made clear shortly, (51) gives only the second heavy syllable of a heptamoraic metron; still further shortening will be found in the first.

(51) 2nd heavy syllabic of heptamoraic metra vs. all heavy syllables in comparable metra



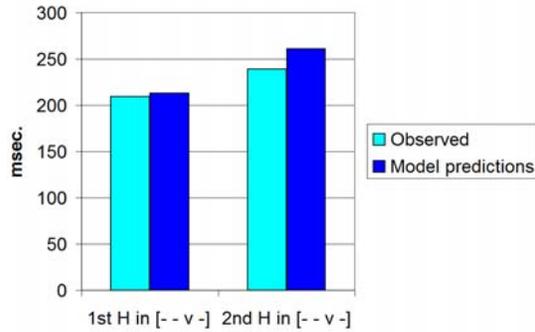
Perhaps the most interesting case is the first heavy syllable of heptamoraic metra. This is the shortest type of heavy syllable in our data.³¹ In our model, we treat this fact as follows. These syllables are unique in being heavy, yet occupying one single grid column, a configuration that we attribute to the purely metrical convention (§5.3) that line-initial heavy syllables may be counted metrically as light. The alignment was shown explicitly in (46). We assume further that the associations seen in (46) are carried over into the sung grid, which was given above in (37b). This seems natural, since the sung grid closely resembles its metrical original, differing only in the extra grid marks shown in italics in (37b).

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

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

to predict short durations for them. This prediction is qualitatively correct, although too large in magnitude to be fully accurate. In (52) below, 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.

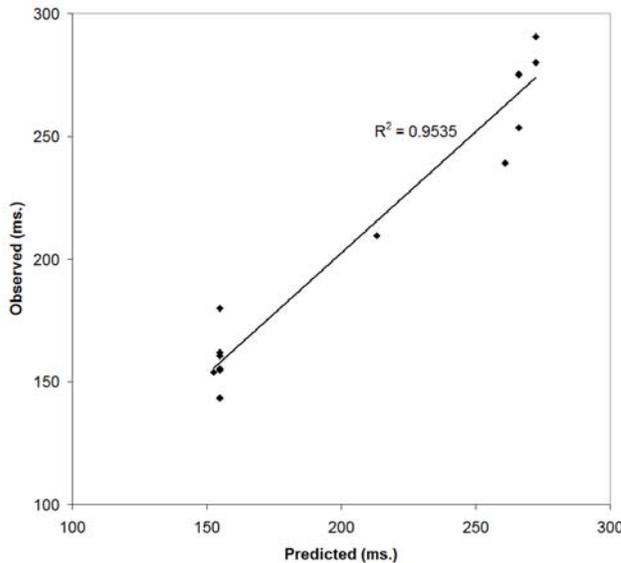
(52) *1st heavy vs. 2nd heavy of heptamoraic metra*



8.5 Overall model accuracy

The model distinguishes in total 14 different syllable types, 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.

(53) *Scattergram of predicted vs. observed duration for all 14 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 ($\chi^2(4)=28.9$, $p < .00001$) and in terms of its ability to capture the qualitative generalizations just given.

8.6 Model summary

We have shown: (a) 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; (b) that the compromise effects characteristic of phonetic grammar in general are well attested in our data; (c) 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 Akilu Aliyu, “Cuta Ba Mutuwa Ba” [Injury is not Death], in *Fasaha Akiliyya*, pp. 38-44, Zaria, Nigeria: Northern Nigerian Publishing Company, 1976.

67 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 Akilu Aliyu, “Jihar Kano Muka Fi So a Ba Mu Ba Kaduna Ba” [Kano State is What We Prefer to be Given, not Kaduna], in Abdullahi Umar Kafin-Hausa (ed.), *Jiya da Yau*, pp. 44-51, Ibadan: Longman Nigeria Ltd., 1983.

53 stanzas; only 15 stanzas scanned

No recording

AAA Kokon Mabarata

Text: Alhaji Akilu Aliyu, “Kokon Mabarata” [Alms Seekers’ Bowl], in Isma’ilu Jinaidu (ed.), *Ciza Ka Busa*, pp. 91-102, Ibadan: Longman Nigeria Ltd., 1981.

124 stanzas, of which 52 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 Tabarkoko

Text (scanned version): Aliyu Dan Sidi, "Tabarkoko" [A male buff-backed heron], in *Wakokin Aliyu Dan Sidi Sarkin Zazzau*, pp. 4-6, Zaria, Nigeria: Northern Nigerian Publishing Company, 1980.

34 stanzas

Text (recorded version): Aliyu Dan Sidi, "Tabarkoko," in Dandatti Abdulkadir (ed.), *Zababbun Wakokin Da da na Yanzu*, pp. 67-72, Lagos: Thomas Nelson (Nigeria) Ltd., 1979.

Recorded version has 36 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 Ibrahim Yaro Yahaya (ed.), *Wakokin Hikima*, pp. 32-37, Ibadan & Zaria: Oxford University Press, 1975.

39 stanzas

No recording

HGU Gidan Audu Bako Zu

Text: Hawwa Gwaram, "Wakar Gidan Audu Bako Zu" [Song of the Audu Bako Zoo], in Beverly Mack (ed.), *Alkalami a Hannun Mata*, pp. 21-23, Zaria, Nigeria: Northern Nigerian Publishing Company, 1976.

35 stanzas

Recording: By the poet, recording obtained 1979 from the Indiana Archive of Recorded Music

IYM Harshen Hausa

Text: Ibrahim Yaro Muhammad, "Wakar Harshen Hausa" [Song of the Hausa Language], in *Wakokin Hikimomin Hausa*, pp. 75-81, Zaria, Nigeria: Northern Nigerian Publishing Company, 1974.

44 stanzas

No recording

IYM Rokon Ubangiji

Text: Ibrahim Yaro Muhammad, "Rokon Ubangiji" [Beseeching the Lord], in *Wakokin Hikimomin Hausa*, pp. 42-48, Zaria, Nigeria: Northern Nigerian Publishing Company, 1974.

40 stanzas

No recording

MHa Tutocin Shehu

Text: Mu'azu Hadeja, "Tutocin Shaihu da Waninsu" [Banners of the Sheikh and Others], in *Wakokin Mu'azu Hadeja*, pp. 5-10, Zaria, Nigeria: Northern Nigerian Publishing Company, 1970 [originally published 1955].

77 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, "Wakar Harshen Hausa" [Song of the Hausa Language], in Dandatti Abdulkadir (ed.), *Zababun Wakokin Da da na Yanzu*, pp. 187-189, Lagos: Thomas Nelson (Nigeria) Ltd., 1979.

19 stanzas

No recording

TTu Kanari

Text: Tijjani Tukur, "Kanari" [Canary], in Centre for the Study of Nigerian Languages, Kano (ed.), *Waka a Bakin Mai Ita, Littafi na Biyu*, pp. 4-13, Zaria, Nigeria: Northern Nigerian Publishing Company, 1979.

80 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 (54) we list all observed non-canonical metron types. Note that in the second metron, all types ending in \cup have frequency zero; this is because under the assumption of *brevis in longo* (§5.3) there are no line-final light syllables.

(54) *Marginal metron types*

Type	As Metron 1		As Metron 2		All	
	count	fraction	count	fraction	count	fraction
----	1	0.0004	1	0.0004	2	0.0004
-- \cup	1	0.0004	0	0.0000	1	0.0002
-- $\cup\cup$	9	0.0036	0	0.0000	9	0.0018
- \cup --	5	0.0020	7	0.0028	12	0.0024
- \cup ---	1	0.0004	4	0.0016	5	0.0010
- \cup - \cup --	0	0.0000	1	0.0004	1	0.0002
- \cup - \cup ---	1	0.0004	0	0.0000	1	0.0002
- \cup - \cup - \cup	6	0.0024	0	0.0000	6	0.0012
- \cup - \cup - \cup - \cup	1	0.0004	0	0.0000	1	0.0002
\cup ---	4	0.0016	17	0.0069	21	0.0042
\cup ----	4	0.0016	13	0.0053	17	0.0034
\cup - \cup - \cup	38	0.0153	0	0.0000	38	0.0077
\cup - \cup - \cup --	0	0.0000	1	0.0004	1	0.0002

υ υ –	0	0.0000	1	0.0004	1	0.0002
υ υ – υ	3	0.0012	0	0.0000	3	0.0006
υ υ – υ –	3	0.0012	2	0.0008	5	0.0010
υ υ υ –	17	0.0069	6	0.0024	23	0.0046
υ υ υ – –	0	0.0000	2	0.0008	2	0.0004
υ υ υ υ –	13	0.0053	8	0.0032	21	0.0042
υ υ υ υ υ	1	0.0004	0	0.0000	1	0.0002
total	108	0.0435	63	0.0254	171	0.0343

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